New Vodafone building in Oporto – A white concrete jagged shell

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ABSTRACT: The new Vodafone building in Oporto is a five storey high, with three basement levels, openspace office building. It will certainly become an architectural landmark for the city. The 7336 m² slab building is defined by its highly irregular white concrete façade. The purpose of this irregularity is to convey a “sensation” of “motion”, as this is the brand image of the Client (Vodafone). The development of the geometry and the structural design was made by Afaconsult (Portugal).

1 INTRODUCTION

1.1 Building description
The designed building will be the new office headquarters of the communications enterprise “Vodafone” for the northern region of Portugal. It will have three basement levels for parking, technical rooms and training rooms. The ground floor will be used for a mega-store and the upper floors will be for “open-space” type work areas.

The Building’s main characteristic is its white concrete façade. It is made up of planar irregular polygons that create a jagged shell of concrete and glass.

The façade will also act as one of the main load carriers of the building so that no additional slab supports will be required along the periphery of the building. This design required a great articulation between the architect and the structural engineering team and allowed for the structure to be “hidden in plain sight”.

To maintain coherence between the outer geometry and the interior spaces, one of the cores and several columns will also have an irregular geometry and almost no vertical alignments will exist.

1.2 Structural design
The building’s 0.30 m thick concrete flat slabs will be supported in the basement levels by the soil retaining walls, by the building’s two stair cores and by an array of columns of approximately 8 × 8 m².

In the upper floors the building’s plan area is decreased and the main load carrier becomes the 0.40 m thick façade, the cores and 3 main columns.

The façade carries the load from the slabs and its own self-weight, working as an arch and passing the forces from one level to the other through point supports on the vertexes of the arches.

The transference of loads between the façade and basement levels is done through concrete walls in the first basement level (−1) that act as deep beams.

These deep beams are supported by the columns in the parking floors (−2 and −3).
1.3 Design challenges

Although this building isn’t particularly large or high its design brought about several challenges, some of which were already expected and others appeared unexpectedly throughout the process.

The original and most important challenge was the analysis and design of the outer shell in order to validate the architect’s geometry.

However, as the geometry became consolidated another challenge came up, as the loads to carry from one level of the façade to the other were very high that making these supports compact enough became almost impossible.

Even with the shell’s geometry carefully calculated and analyzed, it was still necessary to devise a process in which this complex and irregular geometry could be built without compromising the work’s speed and economy.

And lastly from a purely designers’ point of view it was also necessary to figure out a way of putting this project to paper accurately so that the work on the site could be as facilitated as possible.

2 FAÇADE DESIGN

2.1 Structural analysis and design

The structural analysis of the façade was carried out in three-dimensional finite element method software.

This analysis started with some simple models including only the façade. As the results of these simpler models were promising, several minor changes to the geometry were suggested to the architect to improve the façade’s behavior.

As the geometry became more stable during the design, the created models increased their complexity, included the whole building’s structure and were used to perform the analysis of all structural elements including walls, cores, columns, slabs, etc.

2.2 Façade behavior

The structure model revealed that the behavior of the façade was quite good, as the arch mechanisms proved to be quite stiff.
The horizontal forces that are generated on the slabs are then absorbed by the building’s cores.

This stiff behavior has, however, one big drawback, which is the huge horizontal forces that are generated at the contact points between the different levels of panels (Figures 7 and 8).

The vertical loads are a result of the loads on the slabs that are supported by the façade, as well as the façades self-weight. The horizontal forces are, however, caused by the difference of spans between the different arches. As these arches are much abutted, the horizontal forces are very large and the different spans generate a force differential at the contact points. This differential generates a horizontal force at the contact point. The design of these contact points is described in detail in the next chapter.

2.3 Façade detailing

The irregularity of the façade, with both concave and convex edges creates an additional difficulty which is the reinforcement detailing. The longitudinal reinforcement cannot be continuous between panels in the concave edges and therefore must be anchored (Figure 9). The vertical reinforcement will be made up of stirrups which will have individual heights. No two rebar will be alike in this façade.

The typical panel cross section reinforced with 5Ø25 ant the top and bottom edges, Ø16/0.125 along the side edges and stirrups Ø16/0.125 (Figure 10). This reinforcement is mostly to control cracking width.

As this is a plain sight concrete structure, cracking was limited to 0.20 mm width.

In the side façades of the building, which don’t have any windows and the stresses are much lower, in order to facilitate the construction process, continuity of rebar along concave edges will be allowed. However, the vertexes of the rebar will be anchored to the other face of the panel with Ø6 hooks (Figure 11).

2.4 Panel connection design

As was already shown, the forces that the connection between panels must support are very large and the designers were especially surprised by the magnitude of the horizontal forces parallel to the façade. At first the design was to be of a hinged connection, as the
bending moments were negligible. This would be a Freyssinet type hinge. These hinges work quite well with only vertical loads or relatively small shear (less than 25% of vertical load). As this is clearly not the case this idea was abandoned.

With the magnitude of forces at play it was clear that a concrete (even with reinforcement) would not be enough to guarantee the safety of these connections and a composite solution would have to be found. Several ideas were discussed but the final design was to make the connection with S355 steel plates up to 80 mm thick that would be embedded in the concrete panels and welded to each other by full penetration welds. This connection is extremely compact and virtually unnoticeable. The embedded plates will be anchored to the concrete with shear connectors welded to the plates and with rebar also welded to the plates. These rebar “sow” the tension stress between the panels.

Although this connection is not hinged, the low inertia of the cross section when compared to the rest of the structure does not transmit significant bending moments.

### 3 CONSTRUCTION PROCESS

One of the demands of the client for this building was that its construction should not last longer than 18 months (including finishes). The complexity of the geometry of this building is not very appropriate for fast construction times and is very prone to geometry errors.

The construction process has to be one that allows a fast execution time and minimizes errors. The basement levels will be built using traditional methods but the upper floors will require special methods and equipments.

A steel temporary support structure will be erected alongside the building to support the formwork for the façade. The construction of each floor and respective level of façade will be comprised of 4 basic steps:

- Setting up of the formwork for the façade along the periphery of the previously poured slab.
- Pour of the façade.
- Setting up of scaffolding and formwork for the next slab.
- Slab concrete pour.
Each cycle, corresponding to one floor should take approximately 4 weeks.

4 3D DESIGN AND MODELING

4.1 Building information modeling
The complex geometry and lack of vertical alignment increases the amount of information that the designers must convey to the contractor. No matter how good the design of the structure, it would still be impossible to build it if a quick and simple way to provide the necessary information for the work site. With this level of geometrical complexity it was clear from the beginning that traditional two-dimensional CAD tools would not be enough to produce the design.

It was decided that the structure’s geometry would be generated using a three-dimensional Building Information Model (BIM). The BIM contains all the information regarding the geometry of the building’s structure from its foundations to the roof.

Since it is a parametric model changes are automatically updated in the whole project. Since all plans, sections and elevation were created through it, once any change in design was inputted in the model, all the drawings were automatically updated. This model also allowed several problems to be anticipated and solved in proper time.

4.2 Façade geometrical definition
The particular geometry of the façade panels, with no alignments whatsoever meant that its representation could not be performed by simple plans and elevations as in usual buildings. Even with the BIM design, the amount of cross-sections needed to properly represent all of the panels would be very unpractical, especially on the work site.

The solution was to create elevation drawings of the different façades, based on 3D designs with Portuguese geodesic coordinates. All panels are numbered and every vertex is located with coordinates.
In addition to these elevations, all panels were flattened so that their real dimensions could be seen and so that on site the formwork can be properly prepared.

With these drawings, the contractor can prepare each panel’s formwork and then place it properly with the help of a topographic surveyor, and the desired geometry can be built with minimal deviations.

5 CLOSING NOTE

Modern Architecture challenges designers and builders to create structures that defy not only physics but pushes the state of the art of design and construction. The process of creating this building were sculpture meets structure has forced everyone involved in it to excel and develop new tools and skills.

This building, when finished, will certainly become a landmark of Oporto city and a symbol of the client company. The additional cost of the shell structure, when compared to a traditional solution reduces the cost of finishing the façade and gives the building its identity.

The excavation stage has finished in January 2008 and the construction of the superstructure begins in February. The structure should be finished before 2009 and the building should be completely ready during the first months of 2009.