Mediacite, Liege: Design to Fabrication

Abstract:

This paper documents the steps followed to design and construct the roof of Media City in Liege. It explains the concepts of design and investigates further into the communication techniques used by the designers and their methods of translating and interchanging information between them. Further more, this study introduces new means of collaboration between disciplines by establishing advanced interoperability tools which enhance and speed up the design process managing to achieve complex design tasks.

1. Introduction

This case study describes the process followed from design to fabrication of the complex-shaped roof structure of Mediacite in Liege. It focuses on the collaboration between the members of the design team (Architect-Engineer-Contractor) and the data-exchange methods that were used to realise the project. The content of this paper is derived from the author's personal investigation and through conducted interviews to members of the contributing design teams.

The 400m long roof, designed by Ron Arad Architects, Buro Happold Engineers and constructed by IEMANTS, covers an area of 42,000 square meters and spans between two existing buildings that make up a 6.5 hectare retail, leisure and office development in the centre of Liege, Belgium. The adjacent buildings were designed by Jasper Eyers Architects and TPF Ingenier. The fact that the development of the buildings to support the roof was still in progress when RAA was commissioned to design it created an early challenge for the members of the design team and initiated the idea for a parametric definition of the scheme. Two significant aspects characterise this project: the tight deadline of 9 months, during which the roof had to be designed and tendered, and the fact that the structural engineers had only been involved half-way through, therefore not permitting them to have an impact on the early design stages. The project was completed in 2009.

2. Architectural design development

Ron Arad Architects is a distinctive architectural practice which primarily designed furniture and sculptures, keen on creating unusual, complex shapes while remaining relatively persistent on the initial design concepts. Ron Arad's idea for this project was to create "compression" and "tension"

zones, in a visual manner, by varying the dips and rises of beam elements that flow longitudinally towards the exit of the mall where they expand, relieving the flows energy(Figures 1a and 1b).
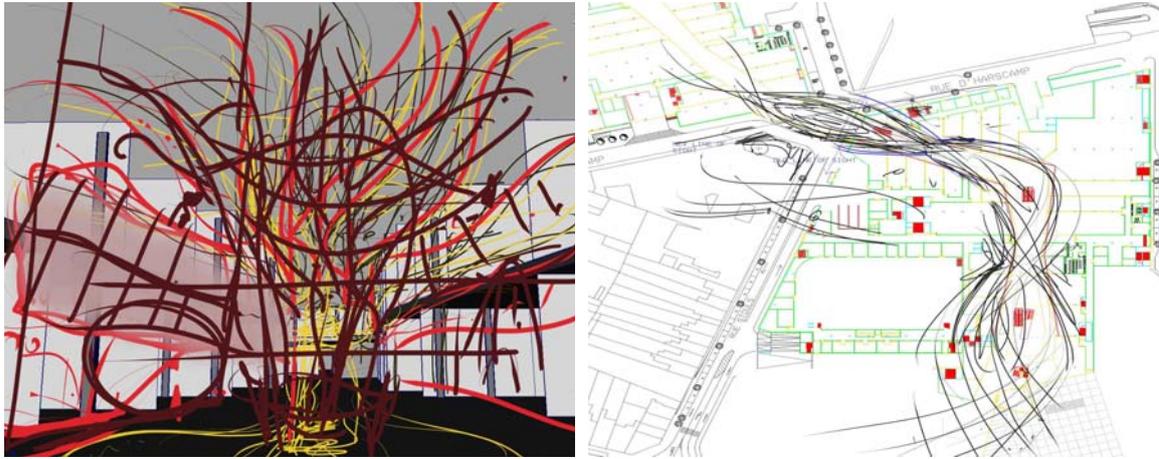

Figure 1 (a) and 1 (b): Architects' concept expressed through sketches.

The architects' team began rationalising Ron's idea by drawing a set of surfaces defining the shape boundaries, modelled in Autodesk's MAYA [1]. These surfaces were described parametrically using MAYA Construction History, since changes were anticipated in the adjacent structure and consequently to the roof's boundaries. The initial grid was agreed and drawn in plan, reproducing the initial sketch as shown in the picture below (Figure 2).
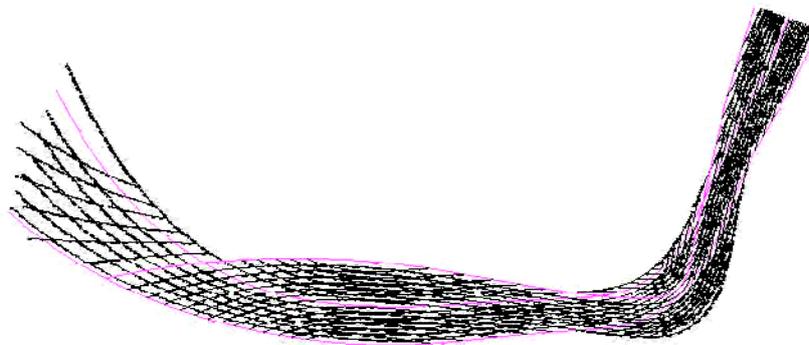

Figure 2: Planar grid

In order to produce the ribs, the 2D grid was projected onto the set of surfaces, producing a respective network of curves. 2D surfaces were formed by the network of curves which were then extruded to form the 3 dimensional ribs. The ribs' depth was controlled parametrically by changing the curvature of the top and bottom offset surfaces (Figures 3a and 3b).
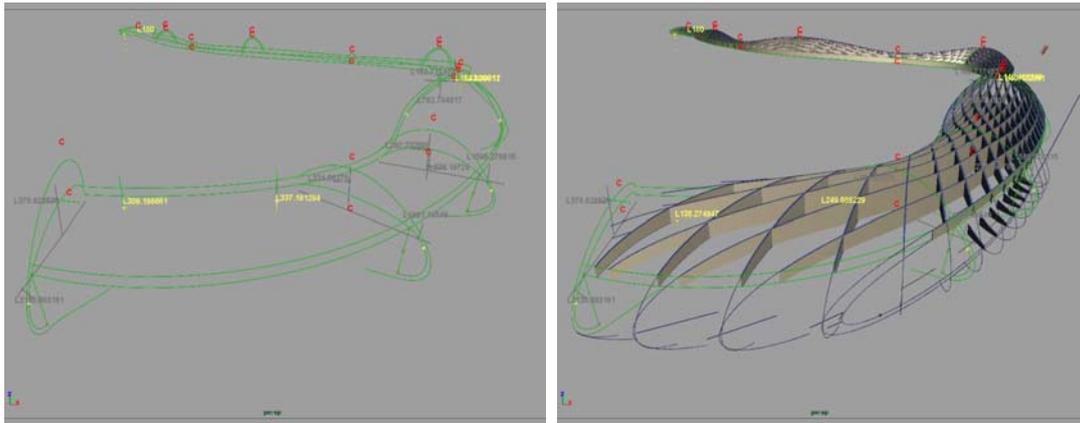
Figures 3 (a) and 3 (b): Parametric definition of the architectural model.

At this point the changes made to the parametric model were only for visual purposes to satisfy the initial concept and were limited due to the possibilities of the software package used at that stage. The architect's team soon realised therefore that in order to take the design further they had to move to a more consistent model which would also allow for more input parameters to be controlled.

The geometry was then reconstructed entirely using Autodesk Alias Design [2] which enabled the shape to be manipulated easily and allowed for control of a large number of parameters, as the design moved to a more detailed stage. For example parameters were set to control the pitch of the ribs to fit the drainage demands and to design the faceted cladding panels (Figure 4).
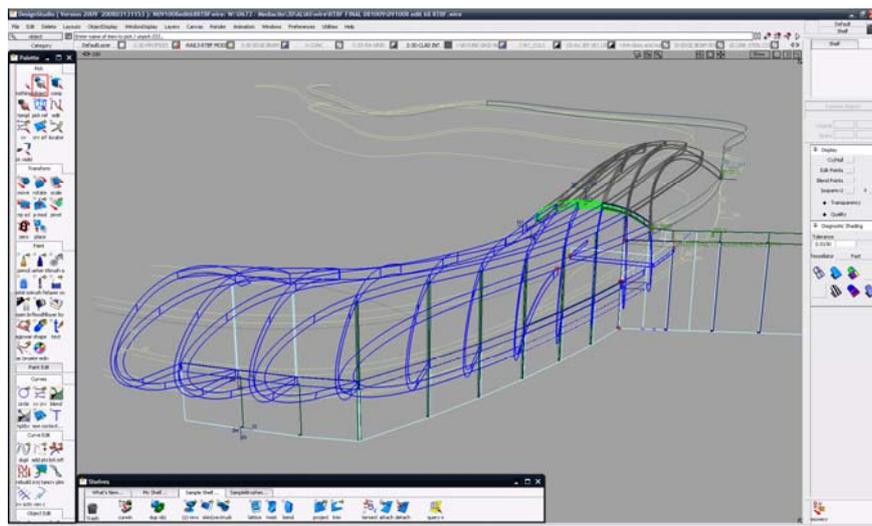

Figure 4: Architects model in Autodesk Alias Design.

The improved model was used to export un-extruded surfaces through IGES [3] format to Rhino to be used later by the Structural engineers in creating their analytical model for structural design.

3. Translating the architectural model for structural analysis

At an early stage, the structural engineers were given the 3D geometry that was produced in MAYA and had to generate the analytical model (that consists of linear elements). As mentioned above, the initial geometry created in MAYA was very coarse and contained inconsistencies with large tolerances in the intersections between the surfaces. To confront that, Buro Happold's Geometry Group had to repeat the procedure that was primarily followed by the architects but in different software environments, to achieve the desired interoperability with structural analysis software packages.
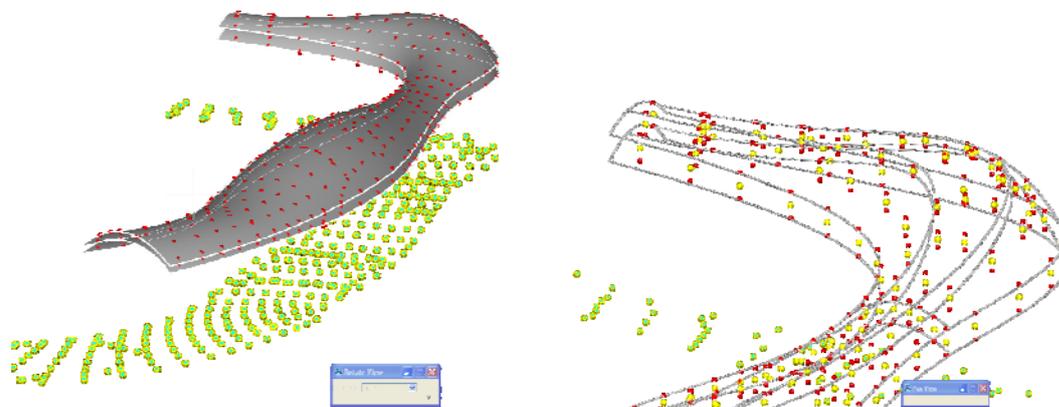
Figures 5(a) and 5(b): Generating rib intersection points in Generative Components

The planar grid was imported into ANSYS [4], a finite element analysis software which automatically intersected all members in the imported model, created nodes connected by linear segments (consequently creating Finite Elements [5]) which were then stored in text files. The nodal data was then imported into Bentley's Generative Components [6] as planar points and projected onto the set of surfaces that were provided (Figures 5a and 5b).

The set of surface indexed points were connected together with vertical lines (parallel to Z –axis) and were divided in half, generating midpoints that when connected formed the analytical centre line. Generative Components has an in-built function that exports point coordinates in Excel spreadsheets. The coordinates inside the spreadsheets were sorted and imported into an FEM package for an initial analysis.

The analytical model generated was inaccurate since division points were only created at the ribs'
intersections and long segments were created neglecting the real ribs' curvature. The above lengthy
procedure was soon abandoned as the architects had switched design software and started using Alias
Design which enabled the geometry to be exported directly into Rhino 3D as surfaces [7]. The
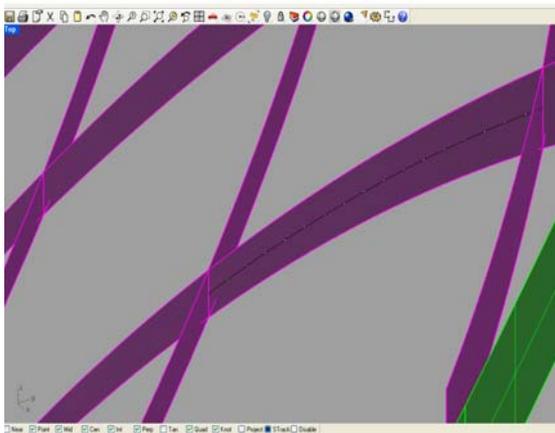translation process from Rhino 3D to the analytical model was automated with applications written by
the Geometry Group.

Figure 6: Finding the mean curve of the surface.   Figure 7: Slicing the surface, generating point
divisions.
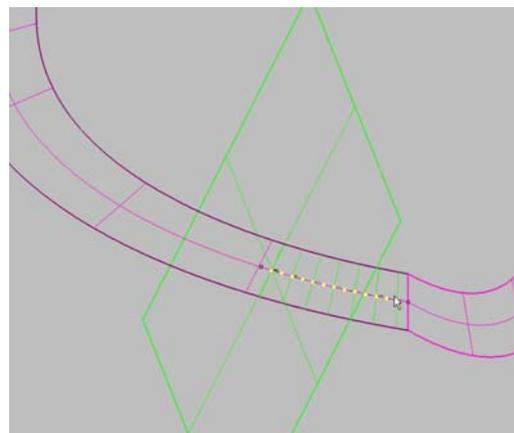
The first application to automate this process was written in RhinoScript [8], a scripting language based
on Visual Basic that adds functionality to Rhino. Using the model imported from Alias Design, the
script isolated the top and bottom edges from each rib, found the mean curve between them and then
divided it into equally spaced points that were named accordingly (Figure 6). The division was done by
slicing both the mean curve and the rib surface with a plane perpendicular to the mean curve (Figure 7).
Each different rib surface was given a dedicated name according to its distance from a dummy point, so
that each division point created by the slice would be referenced to the specific rib. For example the
first point created on the surface "3501" would be "3501001", the second "3501002" and so on. Every
consequent point was connected with a straight line forming the beam segments that were also named
according to their creation points. The slice also produced a line perpendicular to the mean curve
passing through each point, denoting the depth of the rib at each division. An important parameter that
was controlled by the script was the distance between the points which was modified accordingly to fit

the desired detail of the exported model (smoother or coarser) and to avoid clashes when the rib curvature became tight. For the structural analysis, links with length of 500mm reasonably simulated the roof geometry while producing a lighter analytical model.

Another script was then created to export point coordinates, line segments and their section depths to text files. The script generated two sheets, one containing the name, coordinates and section depth of each point while the second one specified the name of each link along with its corresponding end points. This data was then translated into Excel spreadsheet format and was sorted using simple spreadsheet functions. Each different section was named according to the mean value of the end point depths of each segment, rounded up to 50mm.

The spreadsheet shown below contained everything that was needed to form the analytical model for the structural analysis (Figure 8).

Figure 8: Excel data to be export in analysis software

Autodesk Robot Structural Analysis can import this spreadsheet data by reading nodes, interconnecting links (beams) and section types, resulting in the model shown below (Figure 9).
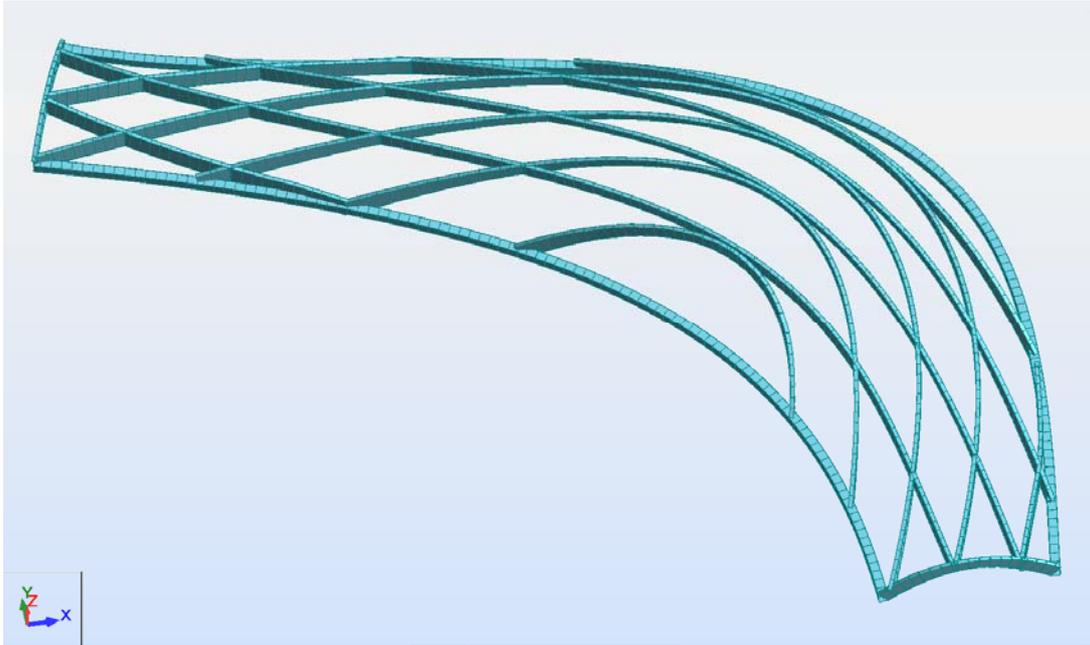
Figure: Analytical model inside Robot Structural Analysis

4. Structural engineering input to architectural shape

After the architectural shape had been translated into an analytical model, the roof had to be engineered

to withstand gravity and lateral loads. The roof was divided in 8 different segments, each

approximately 60 meters long, separated by movement joints to minimize thermal expansion. The ribs

were formed by varying-depth, steel hollow sections of constant width (200mm) that were curved in

plan. Additional web stiffeners were added to control buckling failure of slender sections. The roof was

clad by ETFE cushions, lighter than other types of proposed cladding, which could fit the complex

shape without being heavily engineered (Figure 10).
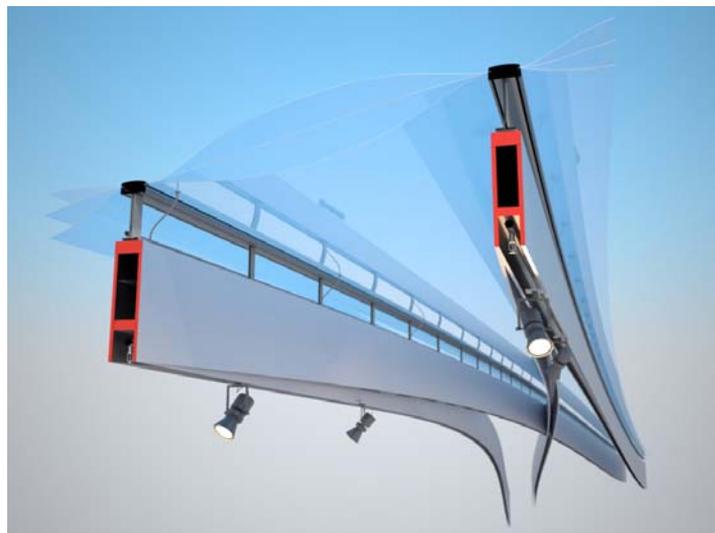
Figure 10: Fabricated box sections supporting the ETFE cushions.

In an initial analysis attempt, it was realised that the ribs of the roof were too dense and were adding a lot of weight to the structure and thus had to be reduced. This caused some trouble to the architects' design team since the grid was not defined parametrically and it would demand a large effort in order to be redesigned. A number of iterations of the grid were carried out until the desired result was found, stalling the project progress.

A manual process of form optimisation, contradicting the automation of the modelling process, took place in a latter stage, by controlling the rib curvatures in order to minimize deflections. The architects' parametric model was used to check the visual impact of these changes, whereas on the engineers' side all changes were made manually, demanding a large amount of time and thus preventing an optimum result of structural integrity of the roof. A more logical approach to improving the roof's structural form would be that the engineers controlled the parametric model according to the structural analysis results, since the interoperability between the models was achieved. Instead of that, traditional ways of exchanging data (section drawings) were used as the architect wanted to maintain total control of their model and consequently the roof's shape.

The structure was designed using Robot's post processor but since changes in shape were limited due to architectural constraints, any structurally insufficient section could only be strengthened by increasing its plate thickness. This resulted in a variation of section plate thicknesses between 8 and 25 mm.

5. Fabrication data exchange

Taking the complexity of the roof into consideration, any traditional way of producing fabrication drawings would comprise a difficult and lengthy process. Consequently, and not having the luxury of time, the engineers had to feed the contractor with construction information while producing a minimum amount of drawings.

IEMANTS STAALCONSTRUCTIES, who were commissioned to fabricate the roof, were using a CAD/CAM [9] software named BOCAD [10], a powerful software package but still incapable of reproducing the roof's complex geometry. Since data could not be exchanged directly between Robot and BOCAD, the need to develop a common platform for this purpose was identified. This was done

in conjunction with BOCAD's software developers and Buro Happolds' Geometry Group. For this, the scripts initially written in Rhino were re-parameterized to produce points in smaller increments of 100 mm, which produced a finer model for construction purposes, and were exported again as Excel spreadsheets following a similar sequence as described above.

BOCAD's programmers on the other hand, had to then extend the capabilities of their software in order to be able to import spreadsheet data and translate it into "constructible" geometry. That means that the faceted sections, (that only made sense in an analytical FEM model) had to be transformed to beam entities that included all the information needed by a CNC machine to fabricate them (Figure 11).
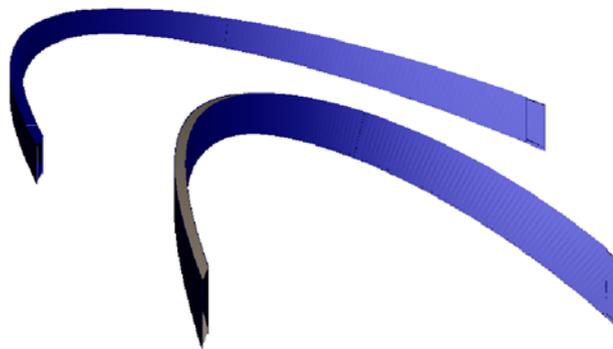

Figure 11: Single beam entities created in BOCAD

This enabled the fabricator to perform any further operations that are regularly available in a CAD/CAM package, for example finding proper intersections between elements, designing connections, adding stiffeners etc.

The fabricator had the ability to change the parameters of the model inside the spreadsheets, resend the data to BOCAD and let the model regenerate automatically. This added an important interoperability feature between Rhino and BOCAD allowing changes to be facilitated in either software. Each model of one segment of the roof would normally need one to two hours to be regenerated in BOCAD.

A similar approach was adopted for incorporating cladding information from the ETFE contractor in to the model in order to fabricate the cladding joints.

A three-dimensional mesh was then exported from BOCAD to be checked against the architects' and engineers' models. The checking process was done manually by superimposing each single piece of the design teams' models, carefully scanning for clashes or large tolerances and checking the rib curvatures and plate thicknesses (Figure 12).
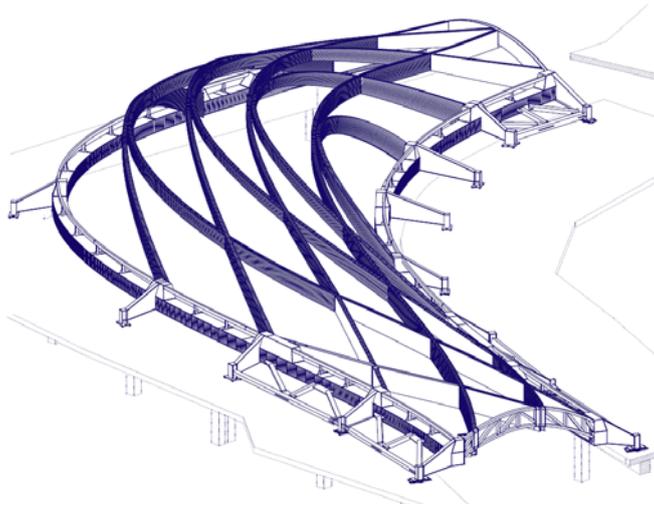
Figure 12: Three dimensional mesh output from BOCAD.

The communication between the design teams had been accomplished only by exchanging spreadsheets and a few sets of set-out drawings. Despite the fact that information flow was automated to a large extend, approximately 130 technical queries were made from the contractor to each of the two design teams, revealing some data loss within the automation process.

6. Fabrication process

By this stage, the project had undergone a value engineering process where the cost of having straight, singly curved and doubly curved beams was estimated. It was then decided to redesign the roof by taking into account these costs and by manually checking the visual impact that these changes would have. After the fabrication model had been checked, each beam entity was decomposed to plated elements. Every plate was unrolled in plan and sent to the CNC machine to be cut. Up to this point the fabrication process was fully automated following the CAD/CAM procedures. The fabrication drawings, which contained all the flattened plates and their final bent geometry, were also automatically produced. For the ribs to be curved in both directions the cut plates were bent out of plane using jigs, which were also cut according to the bent curvature, and were welded in place. Additional plates were welded on the flanges every 100mm to guide the bending process (Figure 13).

Figure 13: Beam bent in out of plane curvature

Each approximately 60m long roof segment was prefabricated and preassembled in the contractors facilities and was transported to site. Assembling the pieces on site was not possible since all the pieces are welded to each other and site-welding is not permitted. The fabrication process and the erection of the steelwork had lasted 13 months and the project was completed 8 months later (Figure 14).

Figure 14: A whole segment of the roof is preassembled in the workshop

7. Conclusions:

The roof of Mediacite reflects a major challenge in designing and fabricating modern complex structures. This example incorporates the collaboration of the major contributors of the design team and reveals a successful result, a project completed on time regardless of its shape complexity and the difficulties that were faced during design. It seems remarkable that such a high degree of

interoperability was achieved at the end, even though each contributor was working on a different software platform, producing what seemed like un-exchanged data at first (Figure 15).
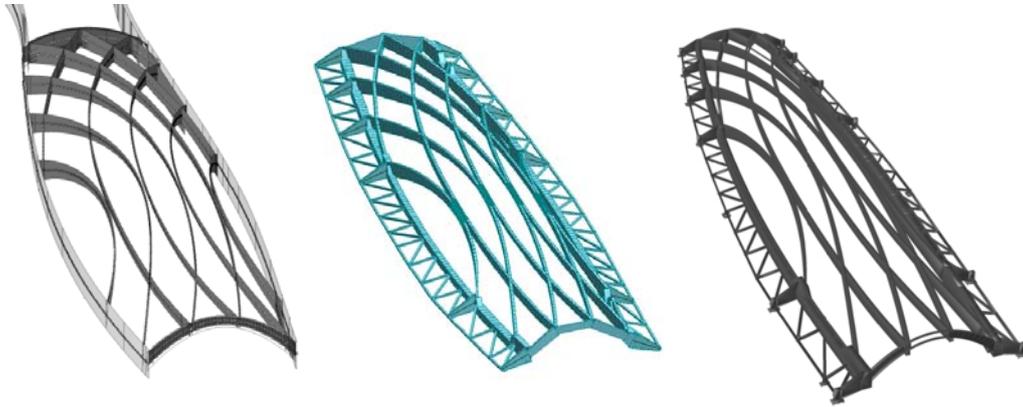

Figure 15: The three different platforms used by the design team : Alias Design, Robot Structural Analysis and BOCAD.

A large effort was spent in order for each of the models to be translated for use in the next level of the design process (Figure 16). Despite that, the translation was not always very precise and an amount of data was lost during the process, which can be proved by the large number of technical queries that were created. It is acknowledged therefore, as discussed with the project contributors, that mistakes were made in choosing the right software at each stage and that in future projects the collaboration would be better managed [11]. The fact though, that construction information was passed from the engineers to the contractors with the minimum amount of drawings issued demonstrates that it is possible, even now, for design methods to be automated to a large extent.

The example of Mediacite also suggests the need for the existence of a common platform to be used by all the members of the design team. It is evident that a large amount of time could be saved and data loss would be minimised if a sound communicating platform was established in the very start of the design process or even if the roof was visualised, analyzed and designed with the same software .
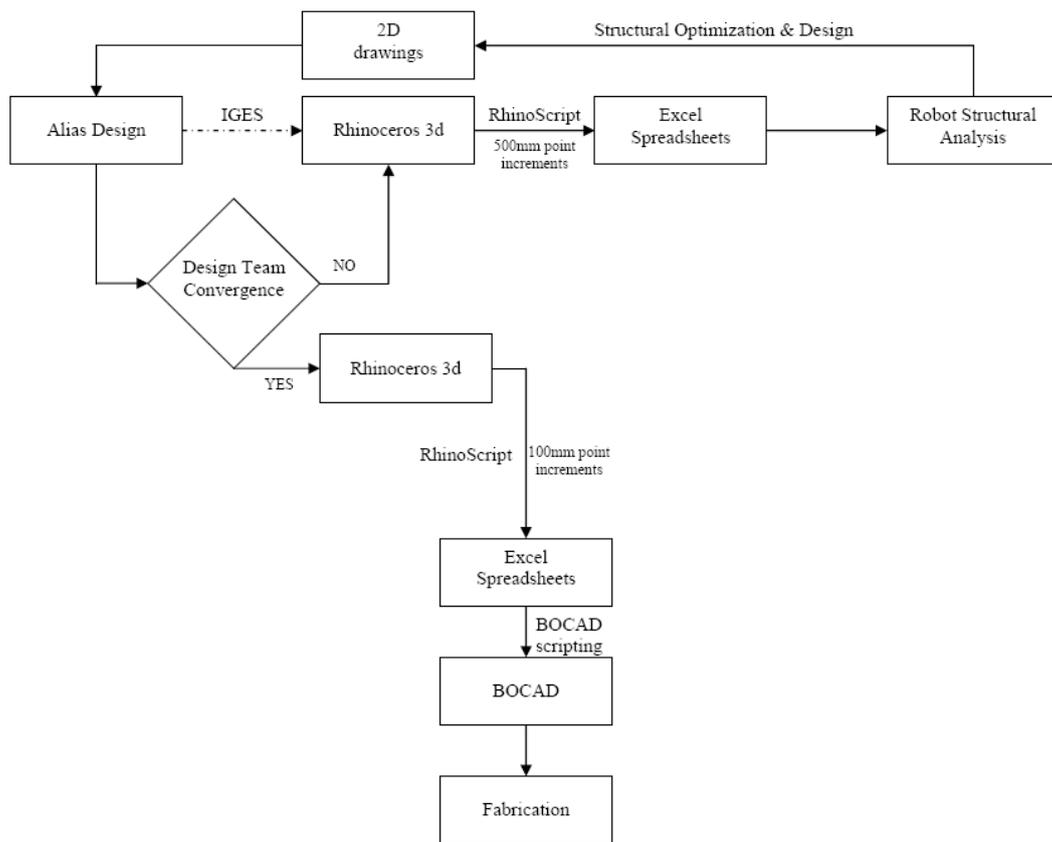
Figure 16: Software work flow diagram.

Acknowledgements

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