Taman Wawasan Aviary Enclosure, Putrajaya, Malaysia

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It is always a challenge to design large structures to enclose vast spaces, but even more so to define the shape and aesthetic of a light, transparent and functional structure within a free-form natural landscape.

The Malaysian government is building a new city to house its government and ministries. This includes all the facilities and services required to help build the local economy. Whole townships are being constructed to house the workforce of the city, along with the facilities, conveniences and entertainment required for a new social centre and to promote tourism in the region. To this end a major new aviary is to be constructed, which will be on a par with the greatest aviaries across the world. The aviary is to house an array of species from across the world, as well as native birds, in a natural landscape with freedom of flight. It is to be constructed in a greenfield steep sided valley, formerly a rubber plantation with terraced slopes.

The design has addressed the need to fit an enclosure into a free-form landscape which at the early stages of the design was without a defined shape. In addition its form and extent were subject to the advancement of the brief and the natural development of the landscape architecture of the forest floor below. The adaptability of the structural design made these issues feasible.

This paper describes the derivation of the aviary enclosure, the early design options explored and the final scheme of a 120m long by 80m wide by 45m high cable net structure draped over steel struts. It discusses the influences of the operation of the aviary, including the choice of mesh in which to clad the aviary, and the final form finding methods, analysis techniques and detailing approaches.

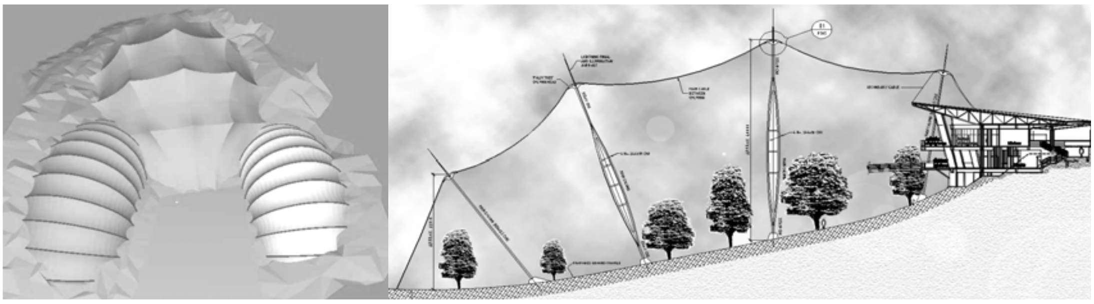

Figure 1 General Views of Aviary

INTRODUCTION

The Malaysian government is building a new city, Putrajaya, 25km south of Kuala Lumpur (Figure 2). The new city is to become the centre of government for Malaysia and will include the Prime Minister's residence, Parliament and Ministries. The aim is to ease congestion in Kuala Lumpur and promote development in the region at a time when Malaysia is suffering a downturn in its economy.

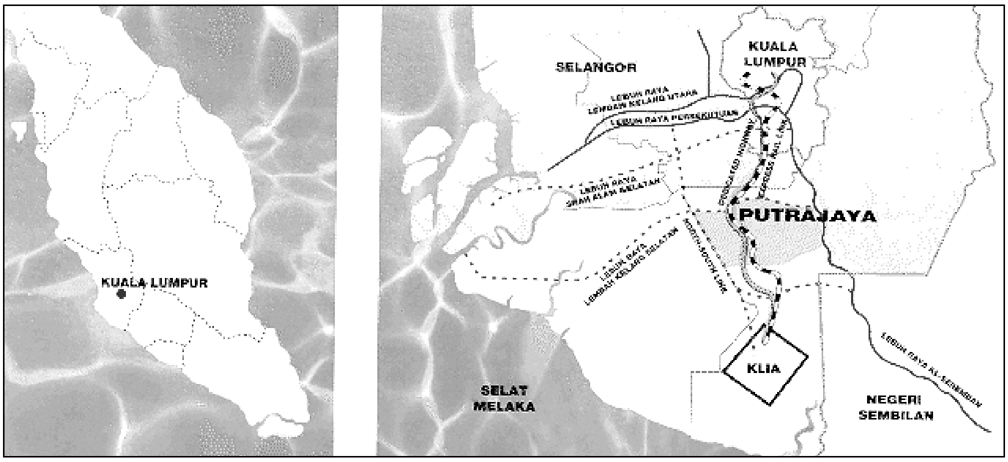

Figure 2 Location Map of Putrajaya, Malaysia

The new development is immense and will initially accommodate a population of a third of a million. It will include all the supporting industries, workforce, accommodation, transportation, open spaces and leisure amenities required for such a new urban centre. A major attraction is to be constructed to promote tourism and provide leisure facilities for the residents – the Taman Wawasan Aviary.

The Client, Kuala Lumpur City Centre Berhad, has put together a team to design the new aviary. Sinclair Knight Merz in Malaysia has been appointed as structural engineers on the project and the London office is providing advice on the design of the enclosure to the aviary space.

EXISTING SITE

Figure 3 The Existing Site

The aviary is to be located close to the new Ministry of Finance, in a valley surrounded on three sides by steep slopes (Figure 3). The whole of this area was originally a rubber tree plantation and much of this remains with terraced slopes to the valley. The geology is residual soil underlain by sedimentary shale formation. Whilst the existing site has been surveyed, it has been difficult to determine how the shape of the site will be changed when the vegetation is removed.

CLIENT REQUIREMENTS

Facilities - The aviary is to be a facility for enjoyment and education - its name, Taman Wawasan, means ‘Garden of Vision’ – and a range of complementary facilities will be constructed alongside the main aviary enclosure. The development is broadly split into two parts: the entrance area which will include general facilities for exhibitions, bird-flight shows (an amphitheatre is included), retail and catering; and the aviary itself. At the top end of the site, set into the side of the aviary will be the Mata Helang (Eagle’s Eye) restaurant which will provide dramatic views across the massive internal volume of the enclosure. Visitors will generally spend half their time in the entrance area being introduced to bird-life and the rest in the aviary to see the wildlife itself. The aviary will take up approximately half the site and is to be a vast enclosed space, about 120m long x 80m wide x 45m high.

Aviary Function - Some groups of birds must be kept separated in order to provide the correct environment for each and to create themed zones such as a specific zone for Malaysian birds. Hence three zones are to be created in three separate aviaries – one main enclosure and two side enclosures. However the aviaries will abut each other in order that the visitors may walk seamlessly from one aviary to another.

All three aviaries provide for the free flight of birds. The aim is that the birds will be seen in as natural an environment as possible. The main aviary is to be of large volume and high, with free views across the space.

Aesthetics - The enclosing structure is to be lightweight, translucent and minimalistic with a minimal impact on the floor of the aviary and the space the structure encloses. The enclosure is to be of considerable height to give a sense that this is an external space. The attention should be on the birds, not the enclosure. Since the structure and the enclosing fabric are so tightly interdependent, Sinclair Knight Merz’s role extends to the entire system.

Design Team - The team put together for this project includes Sabit ACLA as landscape and aviary function designer (and hence the lead designer), Sinclair Knight Merz as structural engineer and Hijjas Kasturi Architects as the architect for the various buildings around the site.

INITIAL DESIGN DEVELOPMENT

Aesthetics - Sinclair Knight Merz carried out a study into precedents and drivers for the design of such an aviary. Many aviaries have been constructed around the world, with obvious examples including the Munich aviary (Frei Otto and Ted Happold) and the Snowdon Aviary at London Zoo (Lord Snowdon, Cedric Price and Frank Newby) (Figure 4). There is also an existing aviary in Kuala Lumpur.

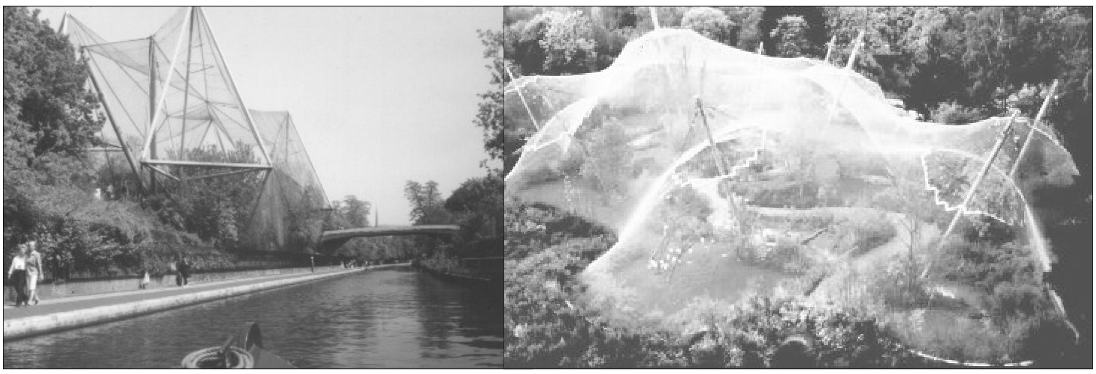

Figure 4 Snowdon Aviary at London Zoo and Munich Aviary

A number of options were considered for enclosing such a large volume. It was desirable to span the entire space without columns, but the team considered that the cost of such a structure and the increased size of the supporting structural members which would detract from the desired lightness of structure. Hence such solutions were discarded. It was felt that to provide as light and translucent structure as possible steel bending or compression members (such as those in the structure of the London Aviary) should be avoided and a tension structure was therefore felt to be the appropriate way forward.

Whilst the architects wanted to create a dramatic structure from the outside, they were keen to detract attention from the enclosure from within, and a natural shape was desired to blend in with the surrounding enclosed landscape. Precedents from nature were explored and used to drive the aesthetic design, as can be seen in Figure 5. The structures of the three aviaries were explored together to ensure that the final shape was unified and coherent, as well as natural and organic in form. The eventual plan shape was considered to be akin to a bird in flight.

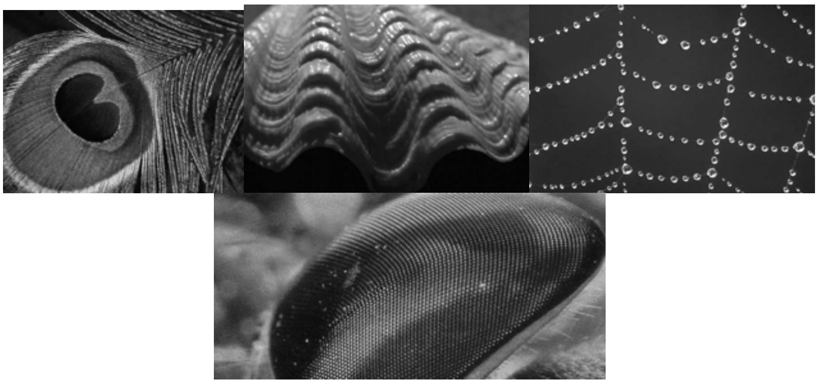

Figure 5 Precedents From Nature

A draped tension structure was felt to satisfy the many aesthetic considerations and hence a doubly curved anti-clastic shape was adopted as the solution.

Structural Form - Two options were considered as the structure for this. The first was a cable net structure with a non-structural mesh cladding and the second was a structural mesh acting as a membrane (such as the Munich Aviary). The choice was driven by the following factors:

- We were considering significant spans between support points in order to reduce the structural clutter within the enclosure.
- Ease of erection was important due to the size and height of the enclosure and the restricted space in the valley location.
- Cost was to be minimised.

For these reasons a structural mesh was felt to be impractical. The long spans would result in local high stresses in the mesh, the layout space and welding requirements would make erection difficult and the cost would be high. A cable net structure was a more ‘known’ structure that would be relatively easy to construct and could be clad in a variety of mesh-type materials.

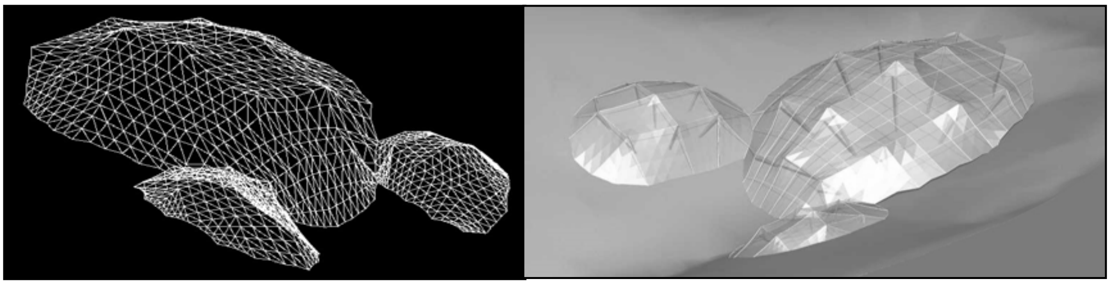

Figure 6 Preliminary Structural Concept

Eventually a preliminary structure (Figure 6) was derived which took the form of a cable net structure supported on masts, anchored to the ground at the boundary and clad in a non-structural mesh. The supporting masts were designed as open frames to improve their ‘permeability’ from an aesthetic point of view.

The side aviaries called for a different solution. The original concept was for a cable net structure much the same as the main aviary. However the architect was keen for a different visual impact. Also, the cable net scheme tended to restrict the height of the enclosure at the perimeter, and allowed less space for free flight of the birds.

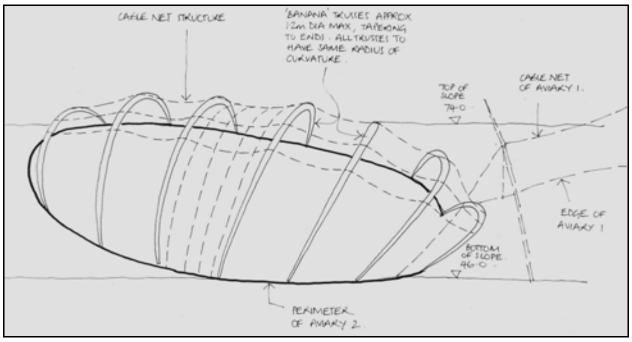

Figure 7 Side Aviary Structural Scheme

Therefore a solution was developed (Figure 7) which incorporates ‘banana’ trusses, devised to span over the short direction of the aviaries, over which a cable net is draped. This formes a ‘wild west wagon’ type of canopy, as used in many fabric canopy schemes. A finer grid of smaller cables than those on the main aviary is used due to the smaller scale of this enclosure and to ensure that the curvature of the net is smooth.

To derive such a structure physical models were built to explore natural shapes and 3D CAD models developed to define a preliminary shape. Following this a form finding computer analysis was carried out using Birdair’s MCM/MCAP software which refined the shape and confirmed its suitability and the size of the structural members.

DETAILED DESIGN DEVELOPMENT

Once the general shape and form of the aviary had been defined, the functional aspects of the aviary could be planned. This included the high level walkways, stairs, escalators, lifts, ramps and paths for the visitors around the valley within the enclosure, the arrangement of pools and vegetation, the position of the entrances and the incorporation of the Mata Helang restaurant.

Openings - Originally it was intended that openings into the cable net would be formed at the anchorage points for the cable net i.e. structural portals would be created which the cable net could be fixed to. However much of the planning of the aviary space and the detailed design of the entrance-ways was subject to design development at a time when the detailed design of the cable net needed to be commenced. It was also difficult to engineer the support of the net off the new Meta Helang building, which was still in its initial design phases.

Therefore, an alternative method of forming openings was required which allowed openings to be incorporated at a later stage. The solution adopted was to create cut-outs in the cable net and mesh using cable annuluses or canteneries to transfer the forces. These openings were incorporated allowing the penetrating elements to be developed independently or added at a later date without significantly altering the behaviour of the cable net. This also allowed openings to be formed at levels higher up in the enclosure where high level walkways penetrated the net.

Anchorages - The cable net requires anchorages at regular intervals along its perimeter. A continuous reinforced concrete wall will be formed, anchored to foundations. The level of this wall will generally be maintained at a level of 1m above ground level. However to cope with the future developments in the ground levels it is designed with deep footings to allow an increase in this height.

The height of the wall will help with maintenance issues for the cable net and mesh by inhibiting the build up of vegetation and leaf litter against the mesh. The wall will curve on plan to follow the cusped profile of the perimeter of the cable net. The cables are fixed to the wall with standard adjustable anchorages to allow tensioning.

Mesh - The choice of mesh to clad the cable net was driven by a number of issues:

- Maximum aperture size to prevent birds of all sizes escaping, or birds heads becoming trapped.
- Minimum aperture size to avoid birds claws becoming caught in the mesh.
- Transluscency
- Durability, security and ease of maintenance
- Ability to deform and flex to take up required patterns on the doubly curved surface of the cable net.
- Strength, ability to be prestressed and to support live loads.

Connectivity to the cable net and between panels.We were keen to ensure that the detailing of the mesh is of high aesthetic quality. Figure 8 shows the kind of effect we were keen to avoid! Since the cable of the main net are at reasonably large centres, up to 5m, the mesh also needs to span in catenary between the cables without significant deformation. Hence it is necessary to prestress the mesh. Therefore the choice of mesh, its detailing and the method of erection was critical to achieve these aims.

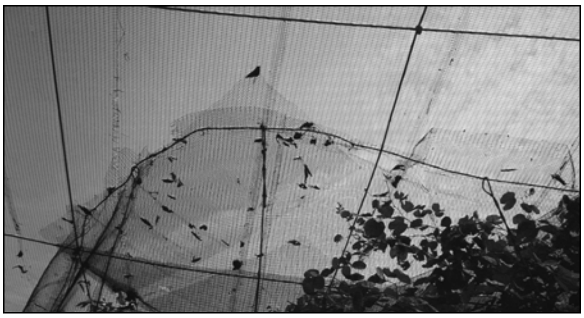

Figure 8 Poor Mesh Detailing

Welded meshes, including zoo meshes, are available but they were deemed to be too rigid and not suitable for such a free-form shape. A crimped mesh which does not have any mechanical fixing between the wires was found to be much more suitable and satisfied all of the above criteria. It has the useful property of being able to rack in-plane which allows it to adopt the surface patterns on the cable net more readily. It is also available in stainless steel. The final mesh type chosen was a Potter and Soar Windermere mesh with 1.6mm diameter wires and 7mm aperture (Figure 9).

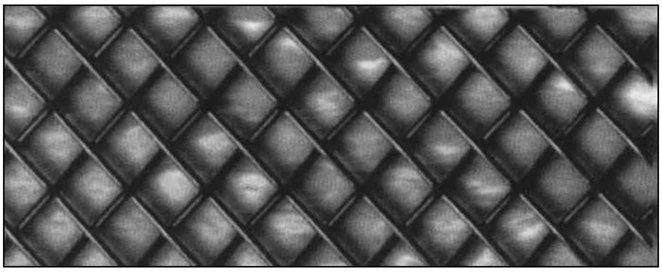

Figure 9 Chosen Mesh Type

The mesh is available in 2m wide strips. Connection details are required between strips along the sides at and the ends of a roll. Various mesh strip configurations were considered to suit the anticlastic shape of the net. However the most successful was to lay the panels at a 45° angle to the cable net grid (Figure 10). This ensured an even distribution of panels across the cable net and allowed the panels to be of constant width. It also disassociated the grids of the cable net from the mesh strips, which otherwise may have been at odds with each other aesthetically.

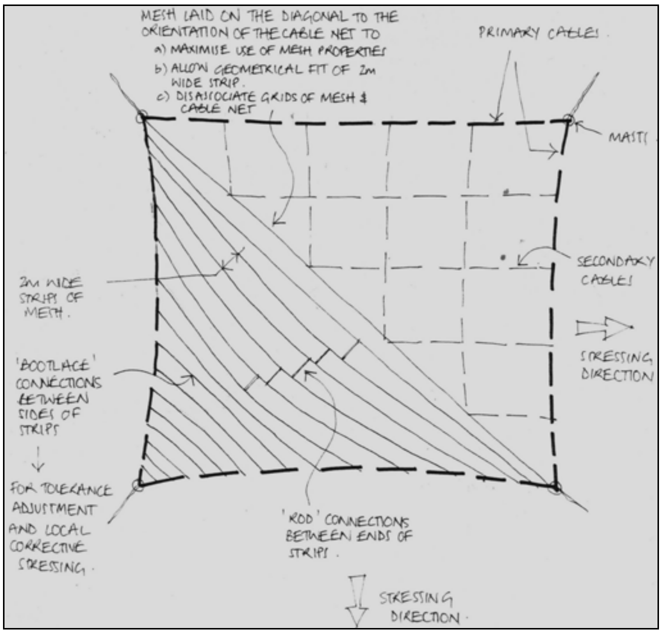

Figure 10 Mesh Configuration

The end connections are such that the strips can be continuous and adjustment is not critical. A loop and rod connection was devised for this. The side connections are capable of providing adjustment of the gap between the mesh strips to allow them to fit on this irregular three dimensional surface, and of evenly transmitting prestress forces. A ‘bootlace’ stitching of the strips has been developed for this.

The mesh is to lie in a plane above that of the cable net, avoiding complex cable to mesh connections. The mesh will be fixed to ‘stools’ clamped to the cable, which have a domed head to allow the mesh to be pulled over the cable net, prestressed and adjusted during construction without snagging.

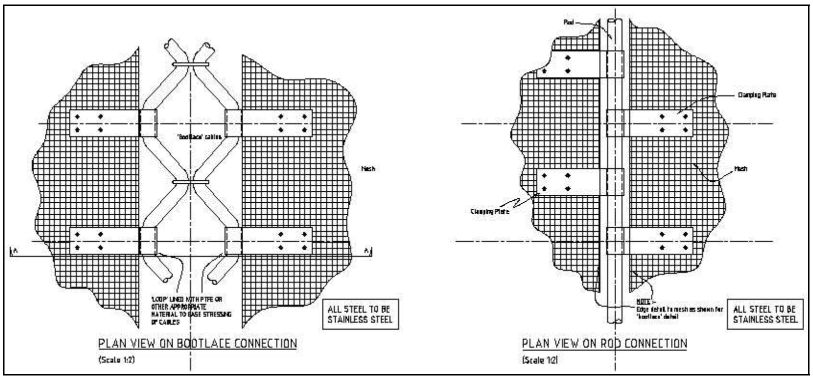

Figure 11 Mesh Details

The mesh is fixed to the wall at the perimeter with continuous clamping bars attached to a threaded rod which is in turn fixed to a continuous steel channel bolted to the wall. This allows a pretension to be induced in the mesh as the threaded rod is tightened. The final pretensioning scheme for the mesh is to be devised by the successful contractor.

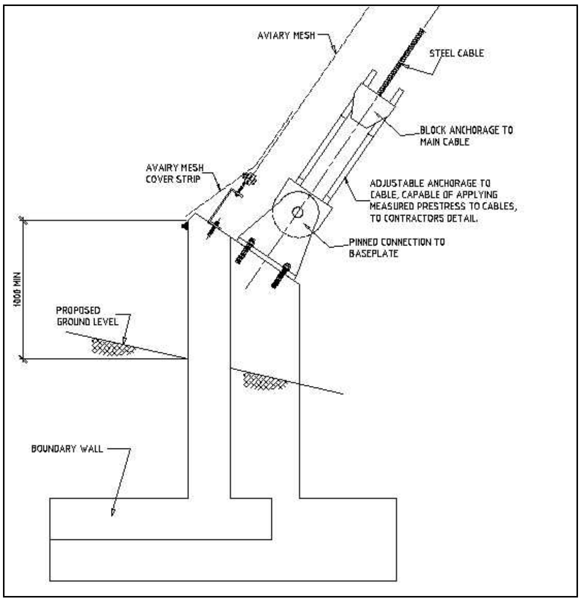

Figure 12

Masts and Trusses - The masts and banana trusses are formed from steel tubular sections in tapering three dimensional vierendeel configurations. For the design of the banana trusses stiffness was a driving factor in order to avoid deflections affecting the stresses in the cable net.

SETTING OUT

The strategy for the definition of the setting out of cable to net was to ensure an efficient and ‘regular’ structure with a relatively simple setting out system. This would also result in an efficient distribution of forces in cables, minimise forces in connections, produce regular cable spacings, regular spans for mesh and a regularised setting out for mesh.

Initially a physical model of the cable net (Figure 13) was constructed to explore the three dimensional aspects of the geometry. This highlighted the critical setting out criteria and showed how sensitive the geometry is to the positioning and drape of the cables.

Hence the entire structure is based on a set of toroidal surfaces intersecting at tangent points (Figure 13). This was initially developed on a trial and error basis using the three dimensional capabilities of AutoCad. The main aviary was firstly defined with a single torus with axis dimensions to suit the desired perimeter. However it was found that the enclosure dipped too low towards the Mata Helang and therefore an additional torus was added for this back section which intersected tangentially with the first towards the top of the enclosure.

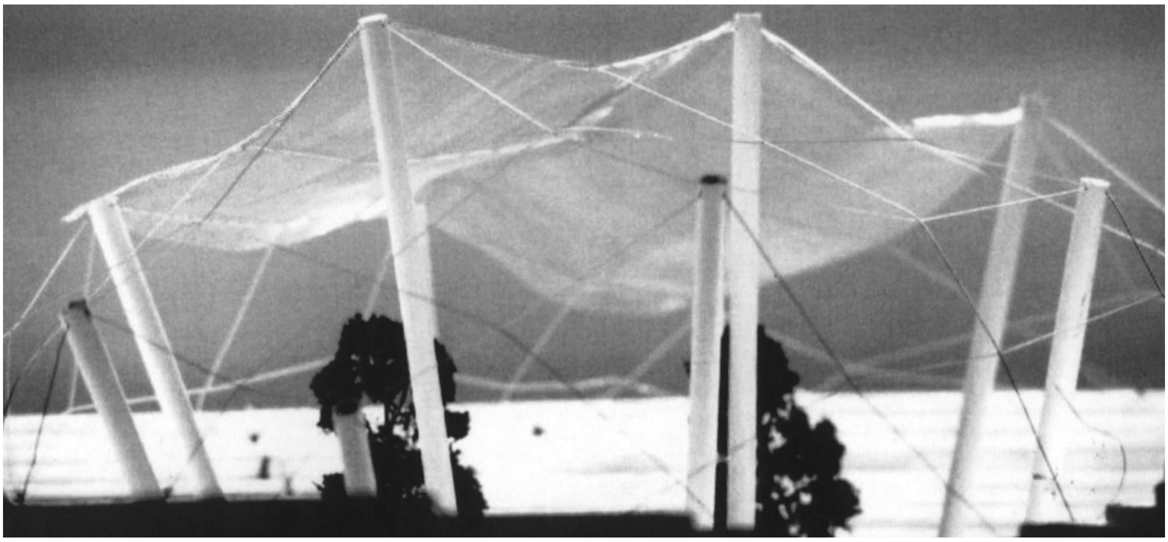

Figure 13 Physical Model of Cable Net

The surface of the torus defined the peak points of the cable net. The cable net was subsequently modelled on the surface of the torus in a regular grid and then the intersection points offset in alignment the radii of the torus. The drape of the cables was varied in orthogonal directions to ensure that across the width of the aviary the cables curved to resist uplift pressures without ‘popping’ of the panels i.e. we achieved an anticlastic shape.

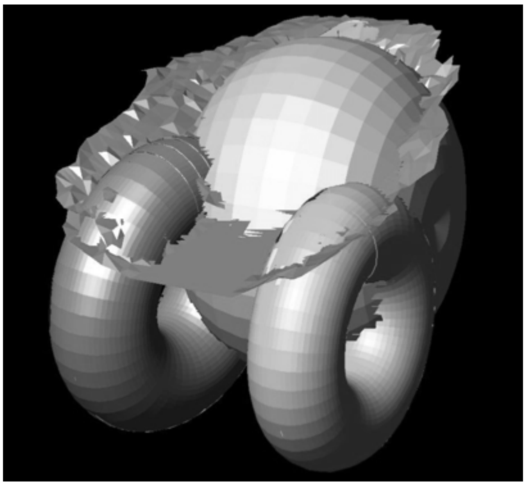

Figure 13 Preliminary Toroid Concept

This three dimensional model was then used as the basis of the final form finding and analysis by Birdair’s MCM software.

The side aviaries are also based on single toroidal geometries. The banana trusses are aligned with the circumferences of the surface of the torus. The cable net between each pair of banana trusses is identical.

The connection between the side and main aviaries was difficult to resolve. Eventually it was decided to form it with a continuous tubular beam which followed the boundary profile between them. The member resists bending, torsional and axial forces since the forces at the perimeter of each aviary do not balance. Hence it is also stiff enough to act as an anchor point.

DESIGN OF CABLE NET

The structure must resist self weight, wind loads, some services (e.g. artificial rainfall systems) and maintenance loads. Also loadings due to a build up of leaf litter and accidental loads from tree falls were considered.

The permeability of the structure meant that wind loads needed to be carefully assessed. Internal pressures will not build up significantly due to leakage of air out of the structure. Conversely, whilst there are no dominant openings air can be forced into the enclosure through the mesh. Wind drag is also an important issue. A comprehensive study of wind loads was carried out to BS6399 and a set of boundary values for uplift, downward and lateral pressures were derived.

The anticlastic form of the cable net ensures that both downward and uplift pressures could be resisted without significant deformation or change in geometry of the cable net. Draped cables in each panel distribute downward forces to the column positions. The cables running across the width of the enclosure in the centre of the panels are generally curved outwards and are therefore the primary uplift resisting elements. The anticlastic form of the cable net ensures that it distributes loads efficiently to these primary lines of resistance.

The model of the 3D cable net in Cad was imported into Birdair's MCM/MCAP form finding and analysis software. The main aviary and two side aviaries were modelled separately for ease of analysis and interpretation.

Initial cable sizes and prestresses were calculated and the software run to optimise the shape and member sizes. It was found that the shape derived from the Cad study was remarkably efficient and this final analysis did not result in much variation from the original.

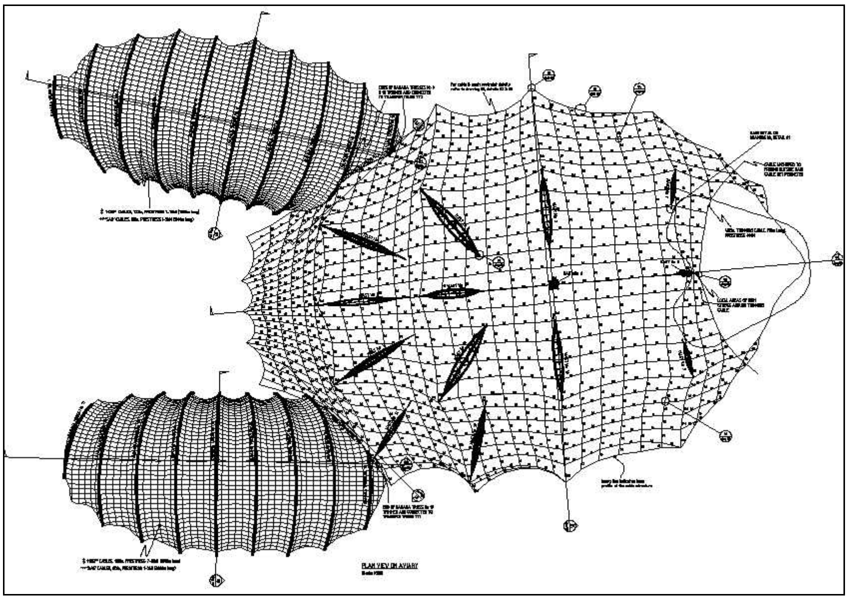

Figure 14 Final Structural Configuration

MCM/MCAP Software - Birdair's software is a large deflection finite element analysis programme based on the stiffness method which can be used for shape generation and stress analysis. Axial, membrane and beam elements can be modelled and therefore it is suitable for the analysis of the cable net. Loads are applied incrementally through out the analysis and the analysis iterated.

Geometry, stress, unbalanced forces, the material stiffness matrix and geometric stiffness matrix are updated at each iteration. In its shape generation mode it finds the equilibrium shape for a system that has a geometric configuration that is in static equilibrium with its own internal prestress forces.

MAINTENANCE ISSUES

The choice of mesh means that it should be generally free from maintenance. The cables and fittings will be galvanised . However a maintenance regime will be required to keep the structure free from leaf litter and wind blown debris, foliage encroachment, and vermin attack. Fittings and cables will need to be checked at regular intervals. The aviary will be protected from vandalism etc by an outer security fence.

CONSTRUCTION

The final detailing and method of construction will be developed with a specialist contractor upon appointment. The project is due to go out to tender in October 2002 and should commence on site in the new year. It is due for completion in 2004.