THE JOHN HOPE GATEWAY BIODIVERSITY CENTRE

Richard Harris[1], Paul Roberts[2], Ian Hargreaves[3]

ABSTRACT:

The architectural concept of the John Hope Gateway is that of a floating timber canopy over the entrance to the Royal Botanic Garden, Edinburgh.

This paper presents the Engineering challenges encountered and the bespoke solutions that were generated, which include an interesting diagrid of tapering glulam beams at roof level and the use of cross-laminated timber floors and walls. Slim cruciform steel columns are used to emphasise the elegance of the supported timber structure.

The building is on two storeys with an overall dimension of approximately 100 metres x 50 metres. Spans between columns vary between 8 and 6 metres. It uses 2750 square metres of cross-laminated timber slabs, 226mm thick on the first floor and 146mm at roof level.

Although timber is becoming used more and more regularly for structures in Scotland, this building is not only very high profile, but it is also one of the most demanding structurally. Amongst the structural issues discussed in the paper are: Connection details at the tops of the column heads, where the roof is carried on thin steel rods; the manufacturing challenges relating to tolerances in fabrication and erection; the use of large areas of exposed cross-laminated timber in a building with public access; fire resistance and the use of timber in an external environment.

KEYWORDS: Glued laminated timber; Glulam; Cross-laminated timber; Tolerances; Sustainability;

1 INTRODUCTION

The John Hope Gateway Biodiversity Centre was won in an architectural competition in July 2003 and opened to the public in October 2009.

The overall mission of the Client, The Royal Botanic Gardens Edinburgh (RBGE) is "to explore and explain the world of plants". Their Edinburgh site was established was established in 1670 as a physic garden. The organisation has grown substantially since then and is now a world-renowned centre for plant science, research and education.

The new building combines the practical need for improved visitor facilities with an opportunity to engage visitors in the work of RBGE and the exploration of the relevance of plants to the critical issues of our time. Thus, as well as office space, a restaurant, an outdoor café, a plant sales area and visitor restrooms, the new centre houses exhibitions and a studio space for demonstrations and exploration into the world of plants.

The Client challenged the design team to use ecological construction materials and environmentally friendly building services.

Buro Happold worked closely with Edward Cullinan Architects, aiming to repeat the success that the same team achieved in 2003 for the Weald and Downland Museum [1]. The exposed structure is a key feature of the building, consisting of intricate cruciform steel columns supporting a series of glulam timber beams and cross laminated solid timber floor slabs.

Edward Cullinan Architects claim that in all their architecture they aim to reveal a story about how the building is made. They wanted to achieve a visual sense of a roof that floats over the space below. The cross-

[1] Richard Harris. Prof of Timber Engineering, BRE Centre for Innovative Construction Materials Dept of Architecture and Civil Engineering, University of Bath, Bath, BA1 5QP, England. Email: r.harris@bath.ac.uk
[2] Paul Roberts. Structural Engineer, Buro Happold ApS, Lavendelstraede 17D, DK-1462 Copenhagen K, Denmark. Email: paul.roberts@burohappold.com
[3] Ian Hargreaves, Associate Director, Buro Happold, 57-59 Bread St. Edinburgh, EH3 9AH, Scotland. Email: ian.hargreaves@burohappold.com

laminated slabs, supported by deep timber beams, are the key elements of the structure and much of the architectural expression is in the structural components and their connections.

2 CONCEPT DESIGN

2.1 CONTEXT AND LAYOUT

The new building is located within a garden landscape and sits comfortably within its surroundings. Rather than using the streets and squares of the City, it reflects the contours, paths and trees of the Botanic Garden as a whole. It forms the new front door to one of the world's most important botanical institutions and captures the spirit and enthusiasm of that organisation.

The pre-eminence of the Garden is the conceptual driver for the design. The Gateway marks the entrance to the gardens by facing a road to the west. On the garden side, stepped biodiversity ponds extend from the glass wall of the exhibition space and blend into the surrounding landscape. The glass wall is some 60 metres long and enables the message of the interpretation delivered within the building to be extended into the Garden and vice versa.

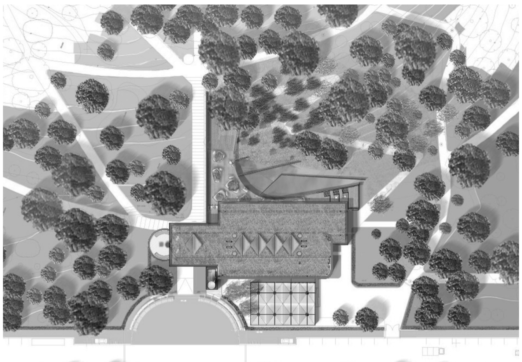

Figure 1: *The building in context (Image copyright: Edward Cullinan Architects)*

The building is located on an important crossing of the entrance path leading up to the centre of the garden and the circular perimeter path (Figure 1). The entrance is not an object in the landscape; it is a frame to a view of the Garden. The building does not have a traditional 'front and back' layout, entry doors allow for it to be approached from all directions, creating a unity with its surroundings.

The site was previously occupied by a collection of individual buildings housing shops and restroom facilities, which no longer met the needs of the Client. By regenerating the site, the loss of land was able to be minimised.

The building is on two floors and is topped by a sedum blanket. The exhibition and shop are overlooked by offices and a restaurant at first floor level, which surround a double-storey atrium (Figure 2).

Figure 2: *The double-height atrium and exhibition space (Image copyright: Buro Happold)*

Whilst people visiting the Garden wish to be outside, the building is able to provide various levels of shelter from the Scottish weather. The roof extends beyond the façade overlooking the gardens and biodiversity ponds, allowing visitors to choose to be fully protected inside, or be outside on the terrace, partially protected from the weather (Figure 3). Roddy Langmuir, Edward Cullinan's Project Director has written [2] "For us it is the margins that are interesting, the places where you can sit with a warm cup outside, protected from winds and drizzle to watch and smell the garden. In the Gateway are places where you feel outside when inside and places where you are outside but are sheltered by deep overhangs."

Figure 3: *The garden terrace and biodiversity ponds (Image copyright: Buro Happold)*

2.2 FORM AND MATERIAL

The main intent for the new building was that it should be an outstanding example of green construction and sustainability.

Given the botanical nature of the project, it seemed natural that the structure should use timber extensively. It uses an innovative combination of glued-laminated timber and cross-laminated timber for its walls, floors and roof. Although timber was considered for the columns, they are made from slender fabricated steel elements. Project Architect, Alex Abbey says [3] “We wanted this visually weighty timber roof to appear as if it is floating.”

***Figure 4:** The roof construction over the entrance lobby (Image copyright: Buro Happold)*

Timber is the material that binds the building together. Architecturally, it compliments a variety of other exposed materials such as steel (columns), concrete (stability walls) and glass (balustrades and cladding).

The timber structure is designed to create coffered roof spaces (Figure 4) that give an individual identity to the restaurant and other areas. The roof beams are placed on the most slender columns possible, created from four battened steel angles. Columns of this nature have been used historically to create compression elements of minimum material, yet here they are expressed and celebrated, allowing glimpses through the column and portraying a fluted form to emphasise their verticality.

Augmenting the theme of biodiversity, the upper floor of the building is topped with a flat green roof planted with sedum, accompanied by solar collectors and a vertical axis wind turbine. The sedum roof has the benefit of reducing heat gains to the building in summer, slowing rainwater run-off to the drains and providing an extra blanket of insulation to the building.

3 STRUCTURE

3.1 MATERIALS

The building has been designed for a long lifespan and uses materials that are durable and stable, such as carefully detailed engineered timber. Three types of engineered timber are used throughout the building:

- Glue-laminated timber (glulam) is used for beams to the first floor and roof. The timber comes from Sweden and is made into glulam in France, using 45mm thick laminations.
- The first floor and roof decks are made of cross-laminated timber panels. In addition, exposed partitions also use these panels. They are manufactured by KLH, in Austria.
- Douglas Fir Structural Veneer Lumber (SVL) from Germany has been used for the mullions and transoms of the timber-framed glazing system. To keep a consistent palette of materials SVL is also used for the public staircase and major items of furniture such as the reception desk and bar. SVL is made of thin veneers of timber, (approx 2mm wide), glued together into large sheets. The standard sheet size is 2440mm long, 1220mm deep and 42mm thick. Thicker sections can be built up by gluing a number of sheets together.

3.2 STRUCTURAL DETAILS

3.2.1 Floors

The substructure, ground floor and stability walls are made from reinforced concrete. The suspended first floor uses pairs of glulam beams and one-way spanning cross-laminated panels as shown in Figure 5.

***Figure 5:** Cross-laminated panels spanning between glulam beams (Image copyright: Buro Happold)*

The structural layout is co-ordinated with both the architecture and the environmental design. Natural light and ventilation dictate the direction of the primary beams.

Figure 6 shows the plan layout of the building at first floor level. The façade of the building facing the road is to the west and the east side of the building uses a glass façade to look over the biodiversity garden. The beams span from east to west, allowing light and air to cross the building in this direction.

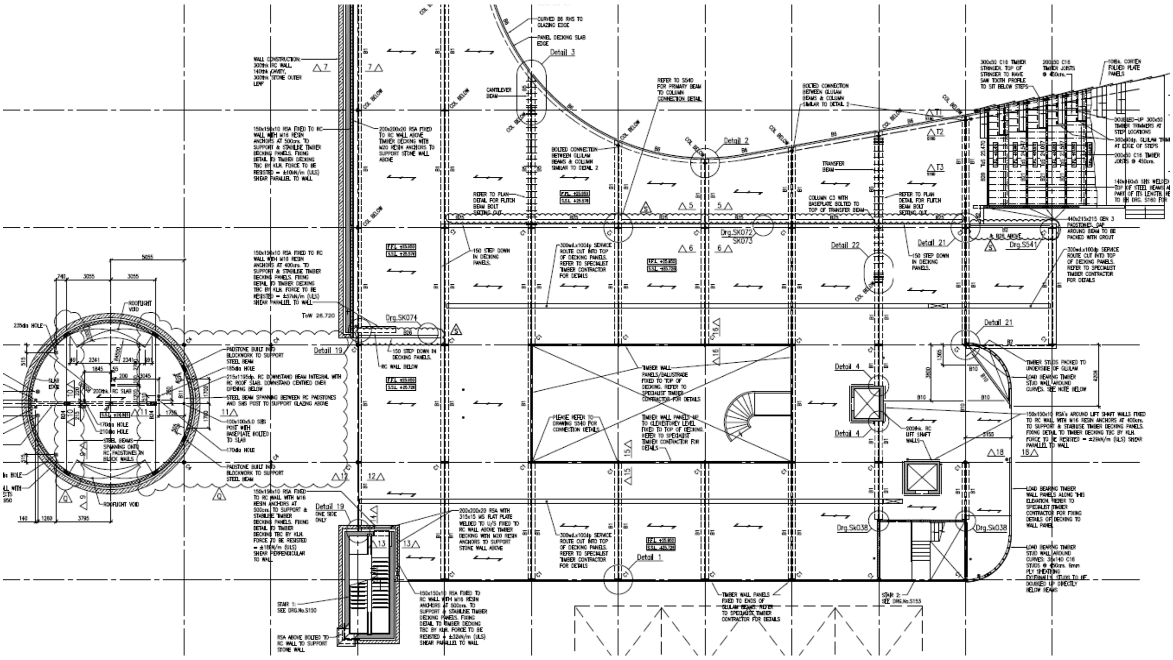

Figure 6: *Structural arrangement at first floor level (Image copyright: Buro Happold)*

The primary beams are 210 x 815mm deep GL24h in pairs at 6 metre grid centres, spanning 8 metres. For a visually discrete connection, they are supported using steel flitch plates welded between the angles of the cruciform columns, which are bolted to the beams (Figure 7). This provides continuity past the columns, to help control deflection.

Figure 7: *Column flitch plate connection detail at the corner of the atrium (Image copyright: Buro Happold)*

The connections are carefully tailored to the building. The use of pairs of glulam beams gives the option to reinforce the primary beams with additional steel flitch plates for special situations that arise in the design. These include cantilever ends and in one location, load transfer of a column that supports the roof but does not extend to the ground in order to create a column free space for the educational studio area. Figures 8 and 9 show the composition of the structural elements.

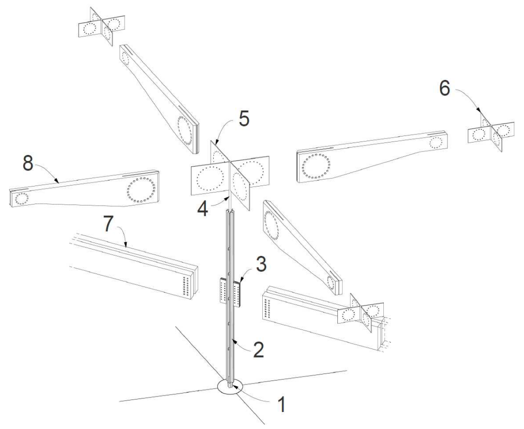

Figure 8*: Primary structural elements (Image copyright: Edward Cullinan Architects) 1. Steel column foot; 2. Steel column; 3. 1st floor flitch plates with rectangular bolt pattern; 4. Steel column top rod; 5. Roof flitch plates with circular bolt pattern; 6. Roof centre span flitch node; 7. Glulam floor beams;8. Glulam tapered roof beams*

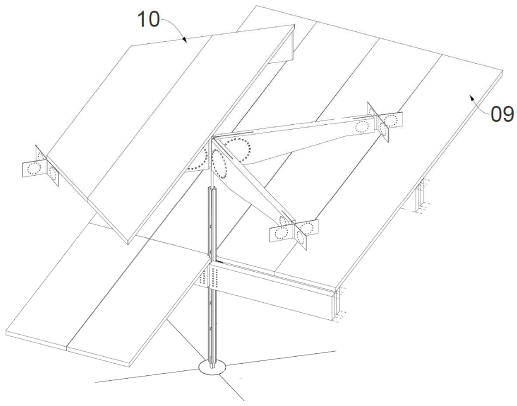

Figure 9: *Secondary structural elements (Image copyright: Edward Cullinan Architects) 9. Cross-laminated floor panels: 226mm thick; 10. Cross-laminated roof panels: 146mm thick*

The cross-laminated panels span onto the beams in one direction and at first floor level they are 226mm thick. At the supports, the thickness of the KLH is adjusted to suit the floor finishes, which are thicker in the outside terrace area (Figure 10). In this way, the glulam beams can be maintained at same size and level throughout.

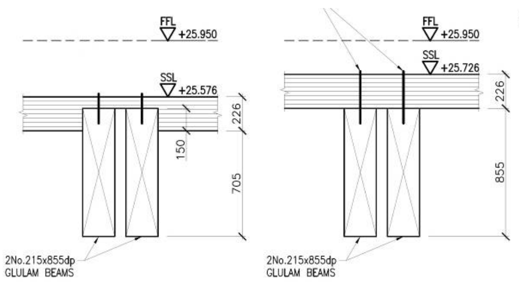

Figure 10: *Glulam to Cross-Laminated Panel – Detail showing adjustment for finishes thickness (Image Copyright Buro Happold)*

3.2.2 Columns

Although for sustainability reasons the design called for the use of as much timber as possible, timber columns were not selected. The use of very slender steel columns gives an impression of the floors and roof floating above the building. The columns were pared down to an assembly of the fewest parts possible.

Each of the thirty six columns supporting the roof is 250mm square. Structurally, this is not a particularly small column but each comprises four 100 x 100mm rolled steel angles, with a 50mm gap between the flanges and battened at 880mm vertical spacing.

It was important to keep the glazed elevation overlooking the gardens as clear as possible. The cruciform columns offered the ideal solution to this as they allow a clear view right through the middle of them, creating the illusion of an uninterrupted landscape.

3.2.3 Roof Structure

The roof is a lattice of one hundred and seventeen tapered GL24h glulam beams with cross-laminated spruce (KLH) panels, 146mm thick, on top. The beams are 210mm wide and taper from 1035mm deep to 500mm. At the top of the columns, steel rods receive the vertical load from the roof. In architectural terms, this rod is the opposite of the classical capital; rather than expressing and celebrating the connection between column and beam, the junction is visually diminished.

Being on a diagonal grid, the beams meet at the centre of the rectangular grid. Steel flitch plates bolted into the timber are welded to a steel bar. This provides moment continuity in the structure and creates a strong visual location to the centre of the coffered slab.

Whilst at first floor the bolts to the column flitch plates are arranged in rectangular groups, at roof level, for visual reasons and for structural efficiency, the bolts are arranged in circular groups. This provides a strong visual contrast. (Figure 11)

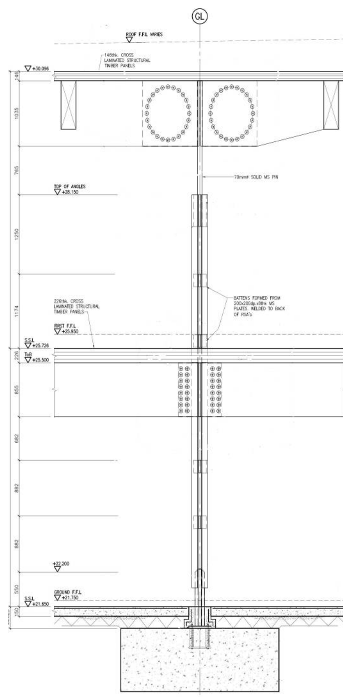

Figure 11: *Column elevation showing glulam to column connections at roof (circular bolt arrangement) and first floor (rectangular bolt arrangement)(Image copyright: Buro Happold)*

Particular features of the roof structure are as follows:

- Diagonal grid arrangement (Figure 12).
- Flitch plates allow moment continuity across the column head detail: Large hogging moments are resisted over the supports and low sagging moments occur at centre span locations.
- The low stiffness of the column leads to small moment transfer from the beam into the column. By reducing the bending moment, the use of a slender steel rod is permitted at the tip of the column.
- As an equal and large lever arm is provided from the centre of the beam to each fixing, the annular ring of dowels resists the bending applied to the beam in a very efficient manner. It also creates a striking visual effect when contrasting with the orthogonal arrangement at first floor level.
- Connection design to EC5.
- Countersunk bolt detail leads to a loss of section, which affects the local stress in the timber
- Great care was taken to ensure that edge distances complied with the minimum spacing requirements of EC5.

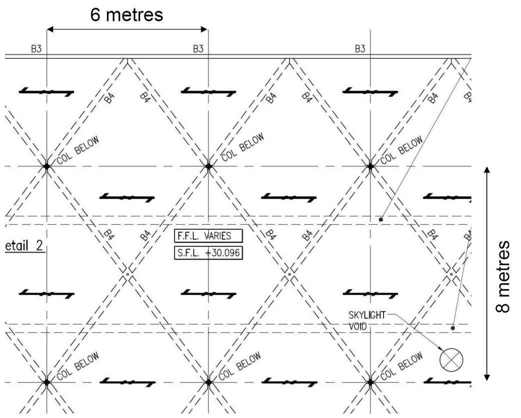

Figure 12: *Typical bays of diagonal roof grid (Image copyright: Buro Happold)*

3.2.4 Stability

Due to the fact that the column heads are rather flexible in the horizontal direction, it was important to provide a stiff diaphragm action to transmit lateral loads to the various concrete walls and cores, which carry lateral loads down to the foundations.

The cross-laminated panels are screwed into the glulam beams and to adjacent panels to form these stability diaphragms at first floor and roof levels.

3.2.5 Fire Resistance

At first floor, the timber beams and slabs have inherent charring resistance of the first floor glulam beams and their associated connections. The Scottish Regulations only require that the first floor has a fire rating and no special measures, other than intumescent paint to the steel structure, were required to achieve this.

The regulations require that the cross-laminated panels be treated to achieve a spread-of-flame rating to their underside.

3.3 CONSTRUCTION OF TIMBER STRUCTURE

3.3.1 Relationship with Specialist Sub-Contractors

Due to the intricacy of the structure, Buro Happold engaged in early workshops with the steel and timber subcontractors to discuss fabrication and installation. Slight adjustments were made to the design to ease these processes, whilst retaining the technical and aesthetic requirements.

The Contractor believed that the design meant that tolerances in the frame would need to be small and that strict measures of control would be required to erect the frame. They wished to simplify the annular connection at the intersection between the column flitch plates and glulam roof beams, but an orthogonal arrangement would not only affect the appearance, it would double the number of dowels. Adjustable connections at the head and base of the columns were discussed but, through careful investigation of the design, it was shown that the structural frame could be constructed using standard building tolerances.

The Architect had specified a surface treatment stain to the glulam beams. The beams were treated by the fabricator with a water repellent prior to delivery to site. This meant that all beams had to be sanded on site prior to application of the stain.

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3.3.2 Fabrication, Transportation and Installation of Glulam and Cross-Laminated Timber Panels

The panels ware manufactured and processed by KLH, in Austria. The benefits to the project of the cross-laminated panels were clear. They are strong but light, provide good acoustic separation, provide a finished surface and are quick to install.

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The timber construction has clear sustainable benefits of renewable availability and carbon absorption. However, for the glulam elements, the timber came from Scandinavia and was transported to France for fabrication prior to arrival on-site.

It was disappointing that some of the sustainability-related benefits were lost as a result of the large transportation routes involved in the glulam procurement. It would have been preferable to reduce the environmental impact of the transportation process and, for future projects, Buro Happold are considering specifying a limited travel distance for timber elements.

Site assembly in the wet Scottish climate provided a serious challenge. It was inevitable that work would be carried out in wet weather and unfortunately, water penetration did occur. However, the structural frame was erected without any tolerance related issues occurring and the superstructure was erected quickly.

The project demonstrated the benefits of prefabrication in relation to reducing health and safety hazards on construction sites. Site activities for steel and timber were limited to lifting and fitting bolted connections and the speed of construction achieved through the use of prefabricated structural elements was very beneficial to the project.

4 CLADDING AND GLAZING

The challenge of the glazing system was to enclose the building, whilst maintain the strong expression of the structure. This was achieved through the connection of timber mullions to the structure at the column positions. The glazing system is by Seufert Niklaus and the SVL (Structural Veneered Lumber) was supplied by Woodtrade of Germany. The solution is deceptively simple. It succeeds through great attention to detail. (Figure 13)

Figure 13: *Glazing mullions, showing the detailing that maintains visual expression of the steel column and timber structure (Image copyright: Buro Happold)*

The building is clad with vertical boards of Siberian larch, ship-lapped in a vertical manner. (Figure 14)

Figure 14: *Larch cladding (Image copyright: Buro Happold)*

5 ENVIRONMENTAL DESIGN

Through the carbon compounds and the oxygen produced in photosynthesis, human life is completely dependent on plants. The building is constructed within a botanical garden and the Client is a world-leading institution in the collection and study of plants. It is natural that the building should be designed and constructed for sustainability, low-energy and minimum waste. Thus the building has been designed to reduce its carbon footprint through passive design methods including careful orientation, good daylighting, high insulation levels, rainwater harvesting and the use of local materials. There are active low-energy systems as well, including a biomass-fuelled boiler, wind and photovoltaic power generation and solar water heating.

The building is naturally ventilated using both cross and stack vent with windows opening automatically depending on internal and external conditions. The sedum roof has been introduced for its biodiversity advantages as well as to help attenuate stormwater. Rainwater, used for WC flushing, is collected from the main building roof in a large and prominent agricultural-style storage vessel located on the roof of the toilet drum. The rainwater falls under gravity to fill the tank, which serves the WC's below. This simply arrangement further underlines the sustainable credentials of the Gardens

In accordance with methods in the Scottish Building Regulations, The Gateway is predicted to achieve an EPC rating of "A", with a score of 7 $Kg/CO_2/m^2/year$. This does not include display lighting (in the exhibition area of restaurant) or small power (computers etc). (Figure 15)

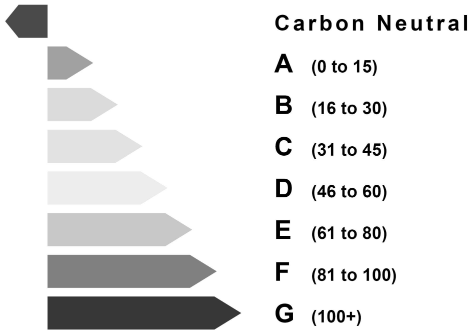

Figure 15: *Energy Performance Certificate (EPC) Ratings*

The integration of architecture with structural and building services design has been highly important throughout the design of the building. This relationship is expressed and emphasised by the decorative lighting/acoustic panels located within the coffers of the roof structure. (Figure 16).

6 CONCLUSIONS

A clear concept remained a consistent driver of design from the competition through to the completion of the building. However it was hard to maintain this clarity. Many of the details appear to be simple, but the variations in a building of this shape, which is moulded to fit the contours of the landscape of the site, lead to many permutations of the "standard" details.

The final building maintains clarity in the expression of the structure, particularly in the use of timber. Success in projects of this type can only be achieved by close integrated working of the design team with the Client, contractor and specialist sub-contractors.

Figure 16: *Completed roof structure showing suspended modular lighting/acoustic panels decorated with patterns of the microscopic images of cellulose (Image copyright: Buro Happold)*

The chosen solution meets the client's goals in a variety of manners, including the sustainable nature of the materials used and the exciting, eye-catching structure that has raised great interest amongst the visitors to the Gardens. Upon completion, the client was overwhelmed with the amount of people who came to visit: over 13000 members of the public used the building within the first week of opening.

ACKNOWELEDGEMENTS

Client: Royal Botanic Garden, Edinburgh
Architect: Edward Cullinan Architects
Structural Engineer: Buro Happold Ltd.
Building Services Engineer: Max Fordham
Main Contractor: Xircon
Timber Sub-Contractor: Donaldson & McConnell
Cross- Laminated Floors: KLH

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