Maggie’s at the Christie

Fabricate Conference

Stuttgart, April 2017
1. Aims and Objectives

Located across Britain and abroad, Maggie’s Centres are conceived to provide a place of refuge where people affected by cancer can find emotional and practical support. Inspired by the blueprint set out by Maggie Keswick Jencks, they place great value upon the power of architecture to lift the spirits and help in the process of therapy. The design of the Manchester centre aims to establish a domestic atmosphere in a garden setting.

The building is arranged over a single storey, the roof rising in the centre to create a mezzanine level, naturally illuminated by triangular roof lights and supported by lightweight timber lattice beams. The beams act as natural partitions between different internal areas, visually dissolving the architecture into the surrounding gardens.

It was vital to create an atmosphere that would make visitors feel at ease, as if they were at home. The use of exposed timber for the structural elements enabled the creation of a homely, domestic ambience throughout the centre, exploiting the warmth and softness of the material.

Using the practice’s expertise in digital modelling and analysis, the structure is the protagonist – a cantilevered timber wing ‘tiptoeing’ lightly over the site. To that end, much work was undertaken to assess how the design intent could be realised with contemporary materials and digital fabrication methods. Investigations were carried out to explore the structural optimisation potential in minimising the material used. For the construction, an Airfix™ (Airfix, 2016) analogy was deemed desirable – a kit of parts fabricated onsite and assembled onsite, facilitating quick erection.

The result is an innovative use of a traditional material, taking advantage of a complete file-to-factory process to provide the driver of the building aesthetic.

2. Context

Functionally, the building is laid out to provide accessible open spaces along either side of a central zone: public spaces to the west, with the more private cellular spaces on the east. The centralised horizontal core houses the building’s services and an administrative zone on the mezzanine deck. The southern end of the building extends to embrace a greenhouse – a celebration of light and nature – which provides a garden retreat, a space for people to gather, to work with their hands and enjoy the therapeutic qualities of nature and the outdoors. It is a space to grow flowers and other produce that can be used at the centre giving the patients a sense of purpose at a time when they may feel at their most vulnerable.

Throughout the centre there is a focus on natural light, greenery and garden views, with a warm material palette. This spatial arrangement naturally led to a structural system where the primary support, a series of 17 identical frames repeated on a 3-metre grid, springs from a central spine, with a propped cantilevered roof on either side. Slender steel columns just beyond the façade
make the entire structural system more efficient. These elements significantly reduce the bending moment in the overhead span, and remove the need for a deflection head at the top of the glass in the roof lights.

Timber is the natural choice for this type of structure not only for its aesthetic value, cost and carbon efficiency, but also because it has high strength but low stiffness in comparison with steel. A propped cantilever benefits from exactly these properties – high strength for the large central bending moment, with low relative stiffness accounted for by the prop.

A more conventional approach might have used a glulam beam, however high self-weight is a drawback of this type of construction, resulting in large and heavy sections. In contrast, digital fabrication has allowed the timber to be provided exactly where required – at the top and bottom flanges for tension and compression and the minimum material in the web to provide adequate shear transfer. Any portion that is superfluous to structural requirements has been removed.

3. Questions

Wood-based H-beams have many advantages, displaying high stiffness and strength for their low weight (Hermelin, 2006), and sustainably sourced timber has the added benefit of being more environmentally friendly than steel. The design intent and structural analysis inferred that the beam webbing could have a number of openings such that the structural behaviour is reflected in its form and materials. It is relatively easy to cut holes in timber webbing, further reducing the weight of the beam. However, the effect of this is to reduce the shear capacity of the member. A central issue was the study of the webbing shear capacity, and how this was factored into the manufacturing of the Maggie’s timber beams.

The choice between CNC-machined timber beams or hand-crafted ones was made early in the design process. Whilst handcrafted beams would permit individual web members to have their grain aligned to the forces they would experience, thus providing a clearer load path, the longer manufacturing time and the need for multiple connections between each diagonal proved prohibitive. Although digitally fabricating beams from an engineered timber such as laminated veneer lumber (LVL) meant the grain orientation is fixed for each web member, requiring a denser web configuration, the faster manufacturing time, increased timber grade and the ability to easily and accurately produce complex geometry was deemed far more beneficial to the project. This also helped achieve the objective of an offsite-fabrication, onsite-assembly project.

The greenhouse ‘cockpit’ at the southern end of the building presented another structural challenge. In strong winds the building would rack up to 15mm longitudinally. However the triangulated geometry of the cockpit unintentionally acted to prevent this deflection, placing more load on the greenhouse timber members than they could handle, inducing buckling and thus shattering the glass. Thicker members would render the cockpit structure visually distinct and heavier in comparison to the rest of the building, and the option of making it an entirely separate structure was also deemed incompatible with aesthetic aims. Resolving this structural conundrum satisfactorily was critical to the success of the project and is outlined later in this paper.
4. Methods

An integral aspect of the practice’s working methods since its inception, physical prototyping was a key part of the design process. Full-scale elevations of the 8m timber beams were printed on paper and hung in the studio. The in-house 3D printing facilities produced many options of node, truss and beam details at multiple scales. Model makers created versions of the entire structure as well as focusing on details (figure 3), again operating at many scales. Three 1:1 prototypes of the key triangular node were produced for evaluation purposes: one by the Foster + Partners’ Modelshop team, and two by contractors bidding for the job: Bluhmer-Lehmann AG and Merk Timber. Upon appointment of Blumer-Lehmann AG, an entire full-size mock-up of the final truss was produced. Testing even extended to 3D printing and placing on site 1:1 models of the ceramic tiles at the foot of each column. These prototyping methods were invaluable, as the process of fabricating full-scale mock-ups greatly influenced the final design.

The main timber structure is formed of a series of portal frames pinned at the base with Y-shaped branches forming the apex. The frames carry both gravity and lateral loading in the transverse direction. Connections between members are achieved by means of hidden pre-embedded steel flitch plates (figure 4) with bolts and screws as fasteners (Bangash, 2009). Linear elastic static analysis in Oasys GSA (Oasys, 2012) was carried out for the basic load cases and superposition used to assess the load combinations (figure 5).

An analysis of the stresses caused by wind load (sideways) and snow and dead loads (vertically) indicated where the timber could be optimised. The beams thus have a top and bottom flange, and diagonals through the web, which vary in density as the shear force varies along the section (Munch-Andersen, J and Larsen, H., eds., 2011). The trusses taper in elevation as the bending forces reduce, towards to the cantilever tip, through the column to the pin connection at the ground, and at the central node above the spine. This taper provides the slope of the roof. The bottom flange of the beam varies in width, reflecting the structural demands upon it. This can be seen in the contouring of the LVL layers on the bottom flange.

In addition to the tapered form of the timber beams, with the shallowest ends corresponding to the points of minimum bending moment, the web also incorporates openings such that where shear demand is low, a higher percentage of material is removed, and vice-versa (Williams, 2008). For a given web thickness, the shear demand was transformed into a net area required at each section so the resulting stress did not exceed the material’s capacity (American Foster & Paper Association, 2006). The analysis undertaken demonstrated that a trellis-like geometric arrangement would be suitable, and a script was created in Rhinoceros and Grasshopper that generated the webbing geometry. In the final design, the webbing is solid as the beam crosses the building envelope. This also provides greater support for the hogging moment above the steel prop.

There was much experimentation with the form of the webbing in the trusses. One option was explored that aligned curved timber members to follow the tension and compression stress lines within the beam (figure 6). This would allow the members to work mostly axially. Despite producing an intriguing outcome the fabrication constraints were judged too great, although this work has informed a separate research project currently being undertaken by Foster + Partners’ Specialist Modelling Group.
A simpler solution was settled upon whereby the truss webbing is made from a pattern of straight elements whose frequency varies to match the material required to resist shear forces. As the shear force increases, the area of material required to counter it increases. The angle of the roof means the available cross-sectional area of the web decreases along its length, which creates a varying percentage of webbing that must be solid. Integrating this curve gives another curve whose slope is the required density. Distributing points evenly along this second curve and projecting them straight down defines the nodes of the struts. As the spacing varies the angles change accordingly, ensuring the requisite amount of cross-sectional material is provided (figure 7).

The node that links the beam and column trusses is a key connection in the entire structural system. It is at this node that the vertical loads from the roof – its self-weight and the snow loads – are transferred to the columns and subsequently down to the ground. Simultaneously, the node acts as a fixed portal frame haunch to provide the rigidity required to resist the horizontal wind forces acting across the structure, and to bring these forces down to ground as well. The forces at this critical connection resolve themselves into a set of pure axial stresses around the triangle, which provides the required rigidity and strength through the efficiency of its form (figure 8).

Each timber lattice truss is comprised of four CNC machine cut pieces that are glued together offsite to form one of the elements assembled on site as the complete portal frame (figure 9). Understanding the abilities of the 5-axis milling machine at Blumer-Lehmann’s disposal was paramount (figure 10). The limitations of drill bit size, cutting speed and cutting angle all informed final design decisions.

Offsite construction was essential to produce structural elements that were highly finished, precisely fabricated, and that could be assembled without need for tolerance adjustment on site (figure 11). The process was also cost efficient, and enabled rapid and predictable construction to fit within the tight programme.

The greenhouse cockpit problem was resolved using Oasys GSA, Rhinoceros and Grasshopper. A viable solution was devised whereby the two cockpit supports are placed on springs, allowing vertical movement to cater for the racking of the building. The final solution utilises a cantilevered sprung RHS beam to support the cockpit (figure 12). When the building racks in strong wind, the cockpit is free to move vertically so as not to absorb any load from the building.

5. Evaluation

The project required close collaboration between multiple teams at Foster + Partners and the contractors involved. The firm’s Specialist Modelling Group produced geometry with Rhinoceros and Grasshopper, which was analysed by the in-house structural engineering team using Oasys GSA, all the while liaising with Blumer-Lehmann and glass contractors Bennett Architectural Aluminium to ensure architectural aims were met and manufacturing constraints were incorporated. The interaction and dialogue between designers and contractors was key – learning and understanding the limitations of the cutting equipment so that the design intent responded creatively to the manufacturing process. The back-and-forth of 3D information helped the design and construction process, with CAD models shared from architects to contractors and vice-versa for review.
The diagonal arrangement of the trusses in plan across the central spine enables the primary timber structure to provide stability to the roof without the need for any additional bracing elements or stiffeners. The roof can act as a single diaphragm, transferring the wind loads into the trusses, which provide rigidity as a portal frame across the building. Along the length of the building, the diagonal trusses deliver load into the spine. In this way, the building's structure directly reflects the forces it resists.

The timber structure is sustainable and tactile, and was built quickly to a tight budget. The CNC-crafted LVL lattice beams are constructed from Kerto, a MetsäWood product. It is made from 3mm thick, rotary-peeled softwood veneers that are glued together. The spruce is sustainably sourced, using whole logs in the manufacturing process, with consequently minimal waste. The waste material generated by the milling of the trusses is used as fuel to heat Blumer-Lehmann's factory space (figure 13).

Removing material from the beam's webbing resulted in a truss that was a third the weight of a similar solid glulam beam. The behaviour of the web as affected by the removal of material was further investigated by a number of finite element analysis models in Oasys GSA in order to assess the maximum and minimum principal stress and the shear stresses at various locations in the web. These stresses compared favourably to the material strengths (ETA, 2010).

The use of 3D modelling and CNC manufacturing has unlocked new methods of working a traditional material. Crafting timber with these modern tools has resulted in an expressive structure that celebrates connections and details, whilst evoking horticultural references such as the garden trellis (Gould, 2001).

6. Conclusion

The product of the twin desires of design intent and structural requirements, the Maggie’s Manchester Centre continues the long history of actively integrating the two within Foster + Partners' work.

With a focus on the process of design evaluation through full-size mock-ups and prototyping, using the full range of capabilities at the firm’s disposal, the nature and fabrication of the final structure was evaluated at every step along the journey. Timber was chosen as the primary building material for its warmth and sculptural qualities, giving the building unique scale, depth and texture. There is no attempt at cladding or concealing the distinctive structure, the building is an open, honest exhibition of the material and its biophilic qualities.

The use of advanced manufacturing technologies allowed new ways of exploring the expressiveness of the material to be investigated. The exchange of 3D CAD models between teams within the office and to external contractors for architectural, structural and fabrication review was also vital to the project's success and contributes to a timber structure that is entirely digitally fabricated using a file-to-factory process.
The project combines fundamental design philosophies from the earliest days of the practice – prefabrication, dry construction, and the benefits of speed and quality that this process offers – with modern digital simulation and manufacturing technologies. The result is an innovative lightweight structure and therapeutic space that is a celebration of light and nature.

**Project Credits**

*Architects:* Foster + Partners; Norman Foster, David Nelson, Spencer de Grey, Stefan Behling, Darron Haylock, Diego Alejandro Teixeira Seisedos, Xavier De Kestelier, Mike Holland, Richard Maddock, Daniel Piker, Harri Lewis, Elisa Honkanen

*Client:* Maggie’s

*Structural engineering:* Foster + Partners; Roger Ridsdill Smith, Andrea Soligon, Karl Micallef, Mateusz Bloch

*Environmental engineering:* Piers Heath, Evangelos Giouvanos, Nathan Millar

*Fire engineering:* Thouria Istehpan, Michael Woodrow

*Landscape:* Dan Pearson Studio

*Timber fabrication:* Blumer-Lehmann AG

*Site area:* 1,922 sqm

*Built area:* 500 sqm
References


Axial force distribution in frame members under gravity loading

Axial force distribution in typical frame

Axial force distribution in web members
A beam prototype with curved timber members aligned to stress lines

Tension

Compression
Webbing boundary shape

Shear force diagram

Percentage of webbing to be solid

The integral defines the strut nodes

The final truss