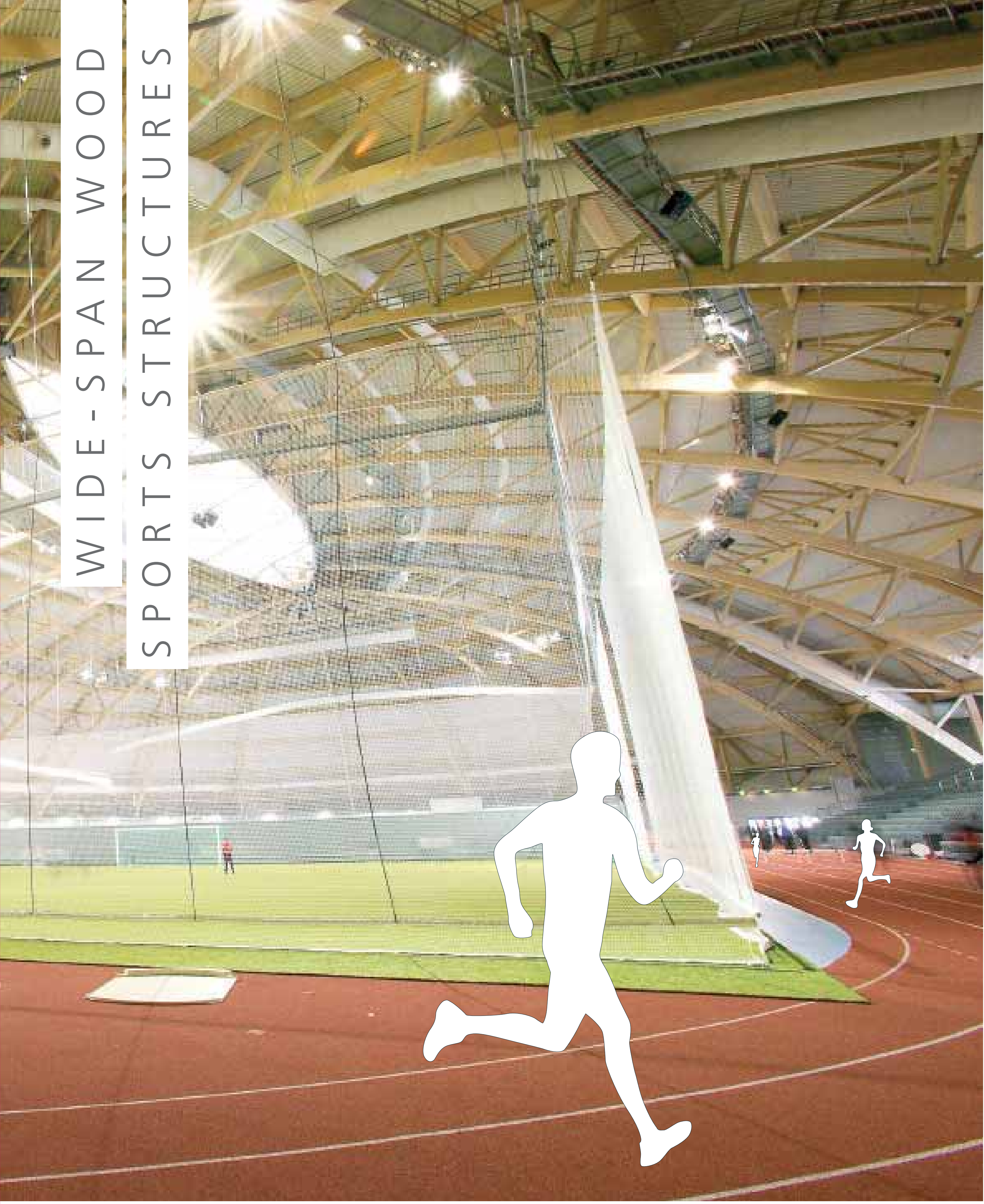
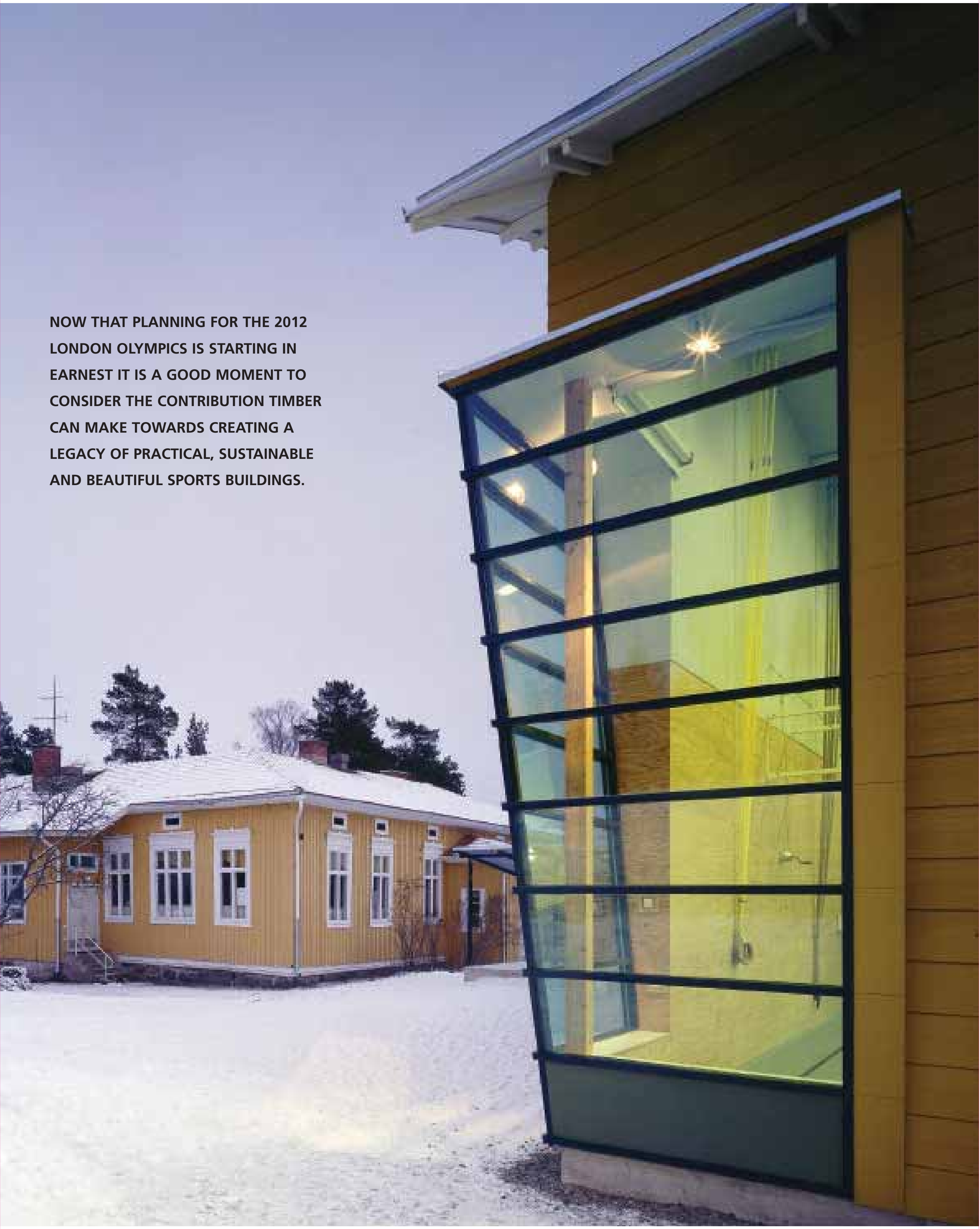
WIDE-SPAN WOOD SPORTS STRUCTURES



Versatility with wood

TRADA

wood for good



NOW THAT PLANNING FOR THE 2012 LONDON OLYMPICS IS STARTING IN EARNEST IT IS A GOOD MOMENT TO CONSIDER THE CONTRIBUTION TIMBER CAN MAKE TOWARDS CREATING A LEGACY OF PRACTICAL, SUSTAINABLE AND BEAUTIFUL SPORTS BUILDINGS.

WIDE SPANS

Today's engineered timber solutions have immense architectural potential, achieving the large, clear spaces crucial to major sports events with a variety of spans and forms, straight or curved, simple or compound.

LOW CARBON

Using wood from sustainably managed forests is one of the best ways to reduce a building's carbon footprint. It has the lowest CO_2 emissions of any major building material: every cubic metre of sawn softwood used instead of other materials saves on average almost 2 tonnes CO_2, made up of 0.9 tonnes CO_2 stored in the wood, together with an average of 1 tonne CO_2 which would have been produced by a substitute material[1]. Engineered wood, while requiring marginally greater energy inputs, shows similar savings. A 305mm x 165mm steel 'I' beam has the equivalent performance of a 550mm x 135mm softwood glulam beam but requires six times the energy to produce. A comparable 400mm x 250mm reinforced concrete beam requires five times as much energy to produce.

SUSTAINABLE

Over 90% of the wood used in Europe comes from European forests, which are in surplus production, stable and generally well-managed[2]. In addition, there is increasing availability of certified timber, in Europe mainly under the FSC and PEFC schemes[3].

AVAILABILITY

There is good availability of wood and wood products. Europe's forests are in surplus production, and there are many companies across the UK and Europe with the experience and capacity to deliver engineered wood solutions.

OFFSITE MANUFACTURE

Engineered wood solutions are manufactured under controlled factory conditions and erected on site with the minimum of labour, time and snagging. Products are uniformly dry throughout and resistant to fire and chemical exposure, a property of particular importance in swimming pools.

LIGHTWEIGHT

Wood is light and strong. A structural steel beam is typically 20% heavier, and a concrete beam 600% heavier than an equivalent glulam beam. Glulam's lower weight allows savings to be made on foundations, transport and erection.

DELIVERY AND ERECTION

The timber industry is fully committed to prefabrication and to scheduled delivery just-on-time. It has the capability to transport large but relatively light components to any extreme of location or site.

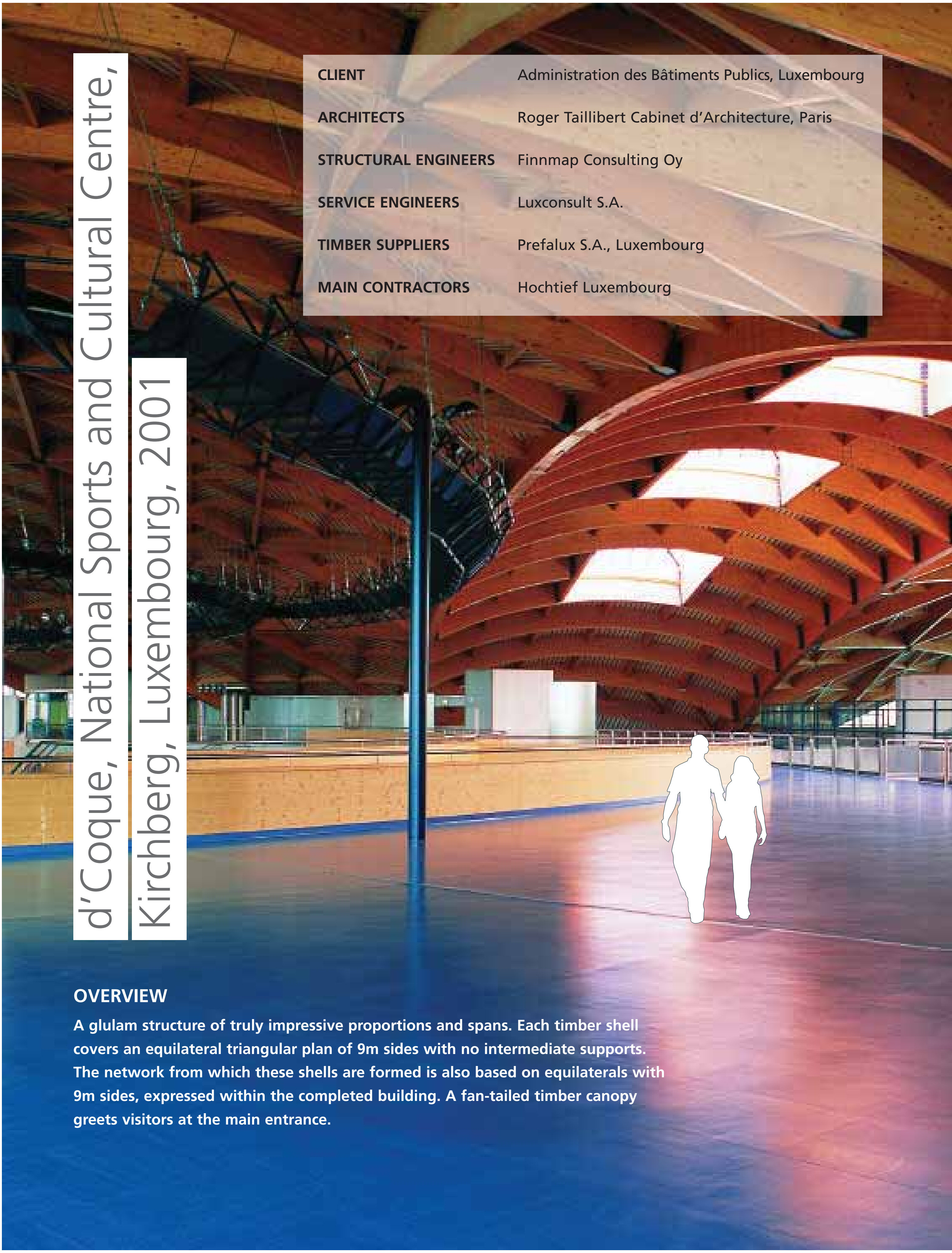
LEGACY

Major sporting events, including the Olympics, entail major improvements to the local infrastructure. It is important these developments are sustainable, with lasting benefits for the whole community.

AESTHETIC APPEAL

Engineered wood products combine structural and decorative finishes achieving lightness of structural mass and providing stunning visual solutions that can be complemented by the natural beauty and warmth of wood claddings and linings.

d'Coque, National Sports and Cultural Centre, Kirchberg, Luxembourg, 2001



CLIENT	Administration des Bâtiments Publics, Luxembourg
ARCHITECTS	Roger Taillibert Cabinet d'Architecture, Paris
STRUCTURAL ENGINEERS	Finnmap Consulting Oy
SERVICE ENGINEERS	Luxconsult S.A.
TIMBER SUPPLIERS	Prefalux S.A., Luxembourg
MAIN CONTRACTORS	Hochtief Luxembourg

OVERVIEW

A glulam structure of truly impressive proportions and spans. Each timber shell covers an equilateral triangular plan of 9m sides with no intermediate supports. The network from which these shells are formed is also based on equilaterals with 9m sides, expressed within the completed building. A fan-tailed timber canopy greets visitors at the main entrance.

The National Sports and Cultural Centre, completed in 2001, covers 13 hectares within the broad-leaved woods of a central city park in the Kirchberg region of the City of Luxembourg. Known as 'd'Coque', a French word for a hull, fuselage or shell, the building boasts one of the largest free spans in Europe, with its reticulated glulam roof spanning 95m.

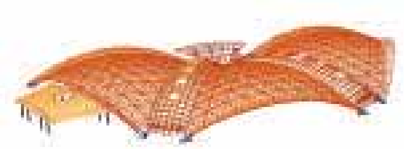
The complex is sheltered under three isosceles triangulated timber shells, each with a span of about 95m, boarded above the expressed structure with acoustic slats, thermally insulated and clad in copper. The cradles that link these structures have translucent clerestories, and the main supports to form the foundations comprise nine reinforced concrete abutments.

The total roof surface of 18,500m^2 collects all the precipitation for use within the complex and ultimately for return to the lake.

The Olympic sized indoor swimming pool was completed in 1984. The design for the multipurpose complex, completed in 2001, united the two stages of development by means of a common connecting entrance hall.

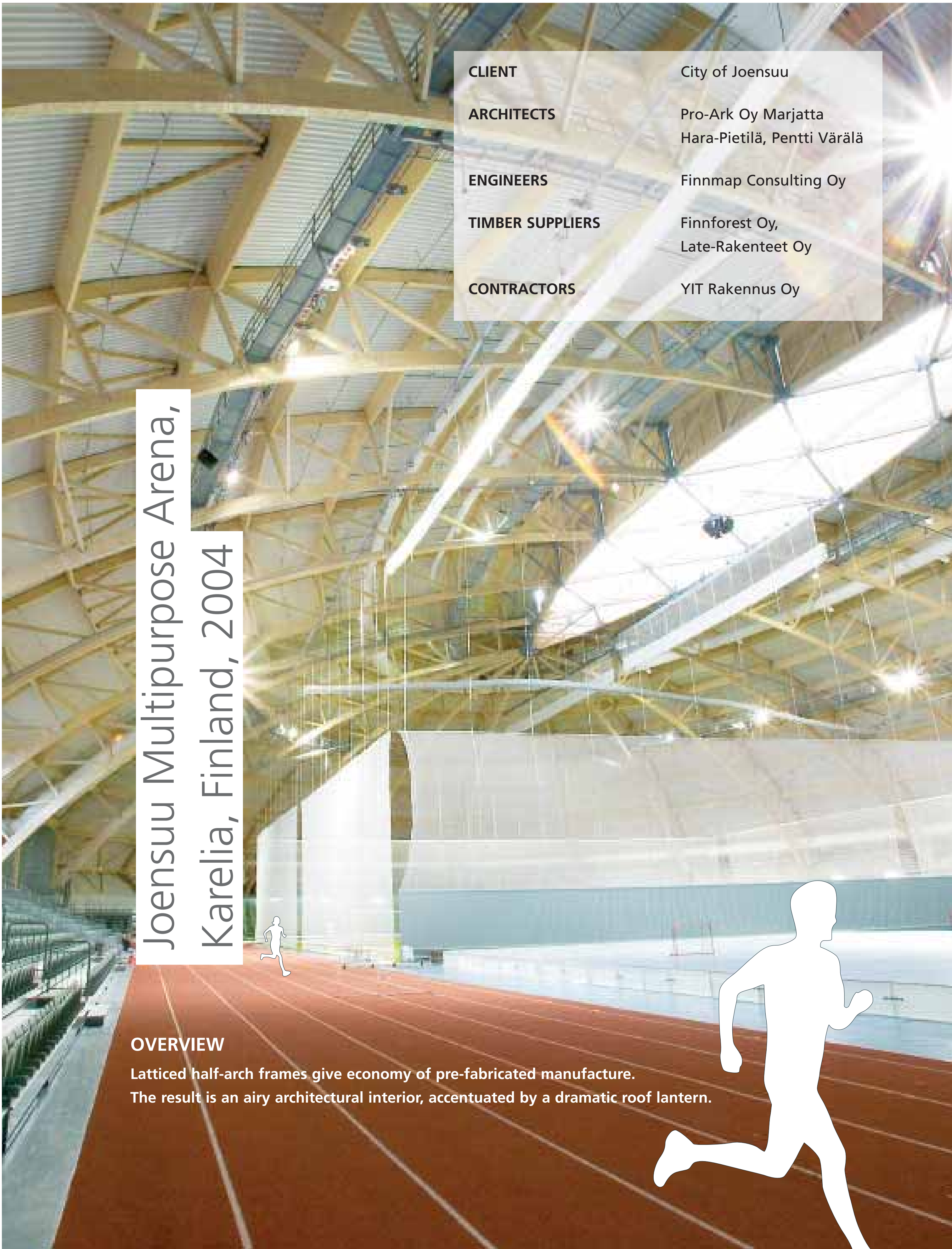
SWIMMING FACILITIES

- Olympic sized swimming pool
- Diving pool
- Children's pool
- Solarium
- Tiered seating for 800



ADJUSTABLE MULTI-SPORTS HALL OFFERING

- 400m athletics track
- Fixed and mobile seating for 8,000 spectators
- 44m x 24m gymnasium and tiers for 1,000 spectators
- 50m x 12m warm-up pool connected to the Olympic pool
- Numerous sports rooms for judo, boxing, weight lifting, body building and table tennis
- Changing rooms
- Staff and private facilities for technical equipment, press rooms, auditoria, referee area, athletes' accommodation, first aid and emergencies and security staff
- Entrance areas for exhibitions

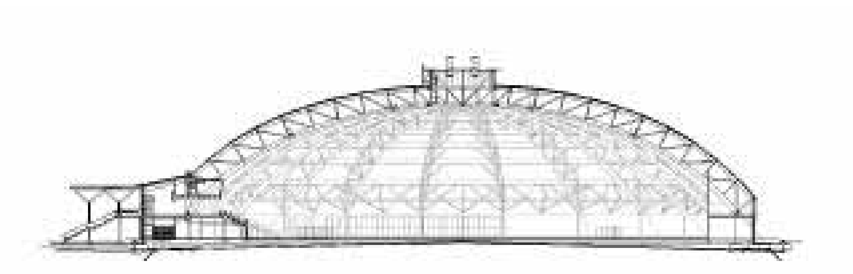


Joensuu Multipurpose Arena, Karelia, Finland, 2004

CLIENT	City of Joensuu
ARCHITECTS	Pro-Ark Oy Marjatta Hara-Pietilä, Pentti Värälä
ENGINEERS	Finnmap Consulting Oy
TIMBER SUPPLIERS	Finnforest Oy, Late-Rakenteet Oy
CONTRACTORS	YIT Rakennus Oy

OVERVIEW

Latticed half-arch frames give economy of pre-fabricated manufacture. The result is an airy architectural interior, accentuated by a dramatic roof lantern.



The City of Joensuu, in Karelia, eastern Finland, invited tenders for a new multisports arena in December 2001. The arena was to cater for mixed sporting events, physical recreation, conferences, concerts and other public events, all to a specified budget. The winning proposal was a timber structure, particularly appropriate in this area rich in forest products industries, close to large areas of sustainably managed forests.

Multipurpose, flexible usage was an important aspect of the design brief. A three-storey entry area includes offices, locker and changing rooms, and access to the stands.

The main hall is an oval timber dome, approximately 150m long, with a clear central height of 24m, created from a series of latticed arches up to 110m across. Large enough to accommodate 7,000 spectators, it also encompasses an enclosed soccer pitch, athletics track and areas for other track and field events, as well as various ball games. A grandstand area for 2,000 spectators can be adapted to suit different events or removed completely.

The timber engineering aspects of the project are impressive, with the repetitive use of 28 latticed half-arch frames making good use of prefabricated manufacture and allowing an orderly erection process.

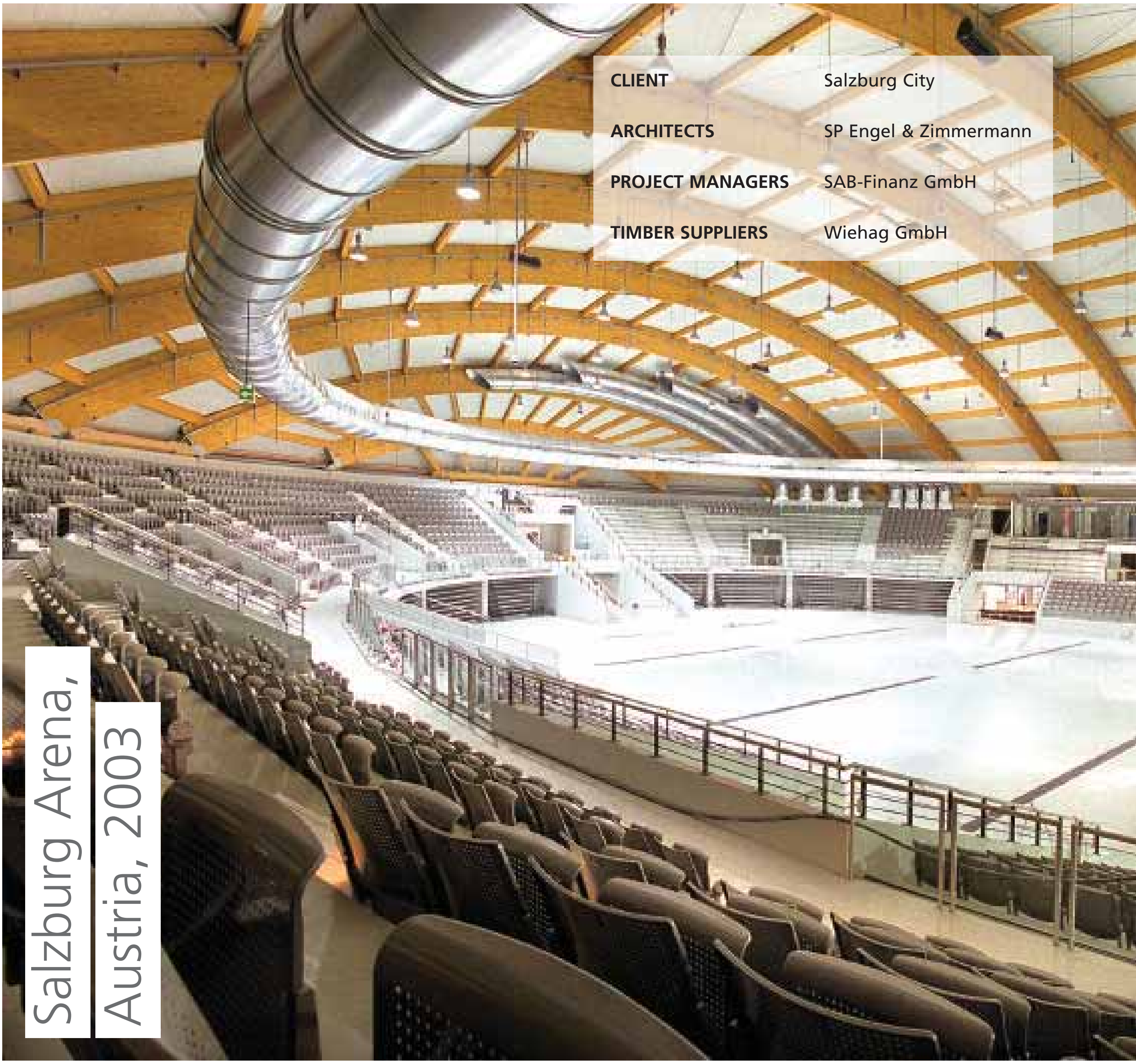
The central crown of the roof, receiving the thrust of the half-arches, is a boat-shaped glazed spaceframe, which introduces natural light over the main arena, enhanced by special reflective sails. The arches have glulam main chords, with LVL (Laminated Veneer Lumber) latticed web members and purlins.

Inconspicuous dowel-type fasteners are used to connect the majority of the web-to-chord nodes and the roof lantern structure. Some of the main arch connections, including the base-to-foundation details, use true pinned connections with forged and welded steelwork. This is attached to the timberwork with flitched-in dowel connections.

Approximately 1,300m^3 of glulam and LVL was incorporated in the main structure, using 39,000 dowel-type fasteners, together with about 150 tonnes of steelwork.

The construction and erection sequence involved the completion of the foundations and the arch bases as the initial stage. Next, the prefabricated 55m long x 10m wide crown unit, made in Finland mainly from LVL, was assembled on the ground and lifted in place using tower cranes. The half-arches were then partially assembled at a low level, including the addition of thermal insulation, waterproofing membranes, and HVAC equipment. Once connected to their reinforced concrete bases, the frames were raised in opposing pairs and locked into final position on the skylight structure.

The arena, covering 14,483m^2, was opened according to plan in 2004 and is thought to be the largest timber structure in Finland. It won the Finnish Association of Civil Engineers Award, 2004.



Salzburg Arena, Austria, 2003

CLIENT	Salzburg City
ARCHITECTS	SP Engel & Zimmermann
PROJECT MANAGERS	SAB-Finanz GmbH
TIMBER SUPPLIERS	Wiehag GmbH

OVERVIEW

Low rise glulam arches vary in span to thrust against a lower reinforced concrete ring of oval plan. The maximum span is 81m and the rise does not exceed 15m, creating a dome-like space.

This impressive timber structure, one of the largest recently constructed in Austria, was opened in November 2003. An architectural landmark, sited in the Congress Area of Salzburg, on the outskirts of the historic city, the building has an 81m x 107m envelope, giving an effective arena area of 2,650m² and a capacity of 6,700 spectators for sports events, where the city had previously been able to accommodate no more than 2,200 under one roof.

Today, local, national and international visitors are regularly hosted here, and cultural activities, entertainment, business events and television productions are regular alternatives to sports. As a result, the space is designed to be flexible, with the services and ancillaries to match, and format changes can be completed within a working day.

Typical sports events held in the Salzburg Arena include football, handball, volleyball, basketball, tennis, table tennis, boxing, judo and karate, wrestling, fencing, pistol shooting, gymnastics, and ‘fun events’. For the more serious sports, the facilities are arranged to international standards. For concerts, theatre, chamber opera, film festivals and conferences, audiences of up to about 5,000 can be accommodated. As Salzburg is one of the bidders for the 2014 Winter Olympics, the proposals include using the arena for international curling competitions.

The oval plan form comprises relatively low rise glulam arches, lightly steel braced and carrying timber purlins. The maximum span is 81m and the rise does not exceed 15m. This structural arrangement creates a space similar to that of an oval dome, with advantages in terms of ease of manufacture and erection, albeit with some sacrifice to pure structural efficiency compared with the true domes.

Norway Winter Olympics, 1994

OVERVIEW

All the structures for the 17th Winter Olympic Games in Norway were built in timber and have a number of features in common - full length curved and un-spliced glulam members, open webbed arches or trusses and connections using multiple flitched-in plates attached by plain-headed dowels.

CLIENT	Hamar Olympiske Anlegg AS
ARCHITECTS	Niels A. Torp AS Biong & Biong Arkitektfirma AS
ENGINEERS	Stormorken & Hamre AS
TIMBER SUPPLIERS	Moelven Limtre
MAIN CONTRACTORS	Ole K. Karlsen AS

VIKING SHIP - HAMAR OLYMPIC HALL

The ship's ribs are a succession of parallel open-webbed arches spanning up to 96m. The keel is 260m long and the entire structure used around 2,000m^3 of glulam.

Literally the flagship of the 1994 Norway Winter Olympics, this structure was inspired by the traditional Norwegian fishing boat which traces its roots back to the Viking ships that plied the North Atlantic.

The shape of the upturned boat, enclosing 40,000m^3, is formed from ten different spans and heights of three-pinned spruce glulam arch – the boat's ribs. Because of their size, these arches have triangulated webs. The structure depends upon its 'keel' - twin spine arches, whose composition follows that of the transverse frames, spaced at 12m intervals, requiring significant but crisply detailed timber and steel bracing. The node connections are all factory-fabricated using multiple flitched-in steel plates of relatively thin section, fastened unobtrusively by plain shank cylindrical steel dowels.

Buttressed reinforced concrete piers provide the supports and the horizontal resistances for the arched frames. Externally at the eaves, round, turned and tapered glulam props support the protruding tips of the upper chords, which are protected from rain by generous roof overhangs.

The size and geometry meant that cross-checking was required between large working models and computer-generated representations, first in 2D and then in 3D. Computer visualisation software was linked to CAD-CAM modelling for frame manufacture, subsequently supporting the contracting work.

CLIENT Hamar Olympiske Anlegg AS

ARCHITECT Niels A. Torp AS

ENGINEERS Martin M. Bakken AS

TIMBER SUPPLIERS Moelven Limtre

AMPHITHEATRE OF THE LIGHTS OF THE NORTH, HAMAR

70m spans are achieved using glulam trusses with parabolically-curved upper chords, rather than with the trussed arches used elsewhere in the Olympics complex.

The maximum chord-to-chord height of the trusses is 6.5m. This led to their being manufactured as pre-fabricated half-spans, transported more easily and connected in situ.

The curvature of the truss upper chords was calculated to allow for the mass of suspended HVAC ducts. The trusses are supported on slender reinforced concrete columns, making it necessary to provide true pinned supports, sliding at one end.

The exterior features larch and other durable wood-based forms. The main timber roof structure is an elegant and efficient solution of glulam frames, sub-tensioned by doubled steel tie rods. The paired timber principals are gently tapered cranked members of rectangular section. The crown area is curved glulam, with no structural pin at this position.

Triangulation of each frame is achieved by means of a central vertical timber strut. At its head, this strut is sandwiched between the crowns of the main beam halves. From here, it drops from beneath the crowns of the beams to provide central connections for the tie rod arrangement.

The columns on which these triangulated frames sit are reinforced concrete, their encastré bases achieving the required lateral building stability. The curtain walls are on a secondary timber framework concealed within the wood linings.

CLIENT Hamar Olympiske Anlegg AS

ARCHITECTS Svein H. Bergersen Olav Olsen AS

ENGINEERS A.S. Veidekke

TIMBER SUPPLIERS Moelven Limtre

HAMAR HÅKON HALL, LILLEHAMMER

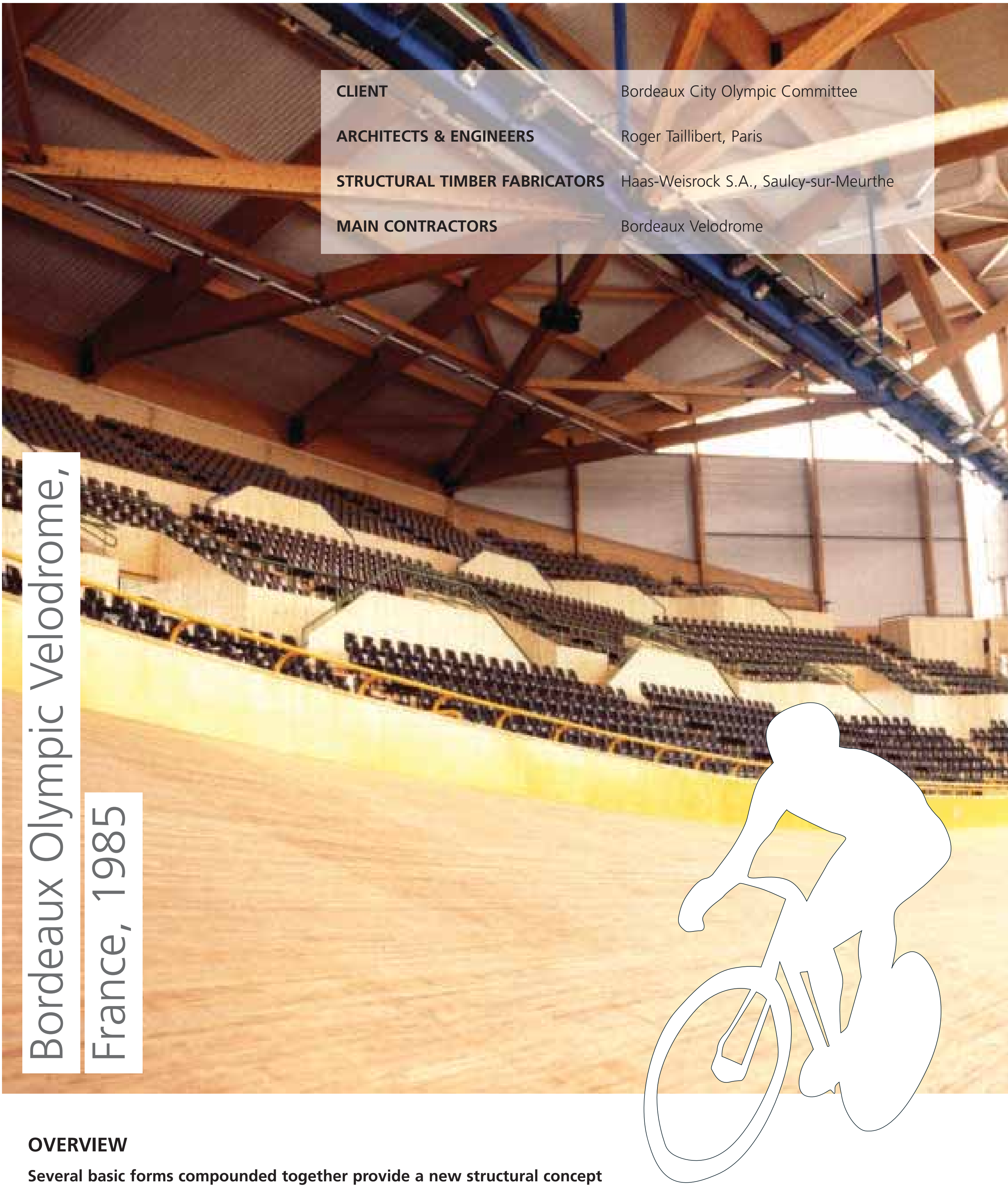
Almost as challenging in size as the Norse ship, this multi-sports arena succeeds through the bold expression of four positively curved and intersecting shell forms, using open-webbed arches, to achieve a length of 127m and a span of up to 83m.

Structurally, these are not true shells but trussed arches whose chords and node connections come from the same stable as the Viking Ship. The structural elements of the gable-end ‘egg shells’ connect to the main triangulated lateral end frames, taken to the ground through reinforced concrete pillars within glazed facades.

The entrance canopy has tapered, round glulam struts tilted in two planes to prop the cantilevered timber roof.

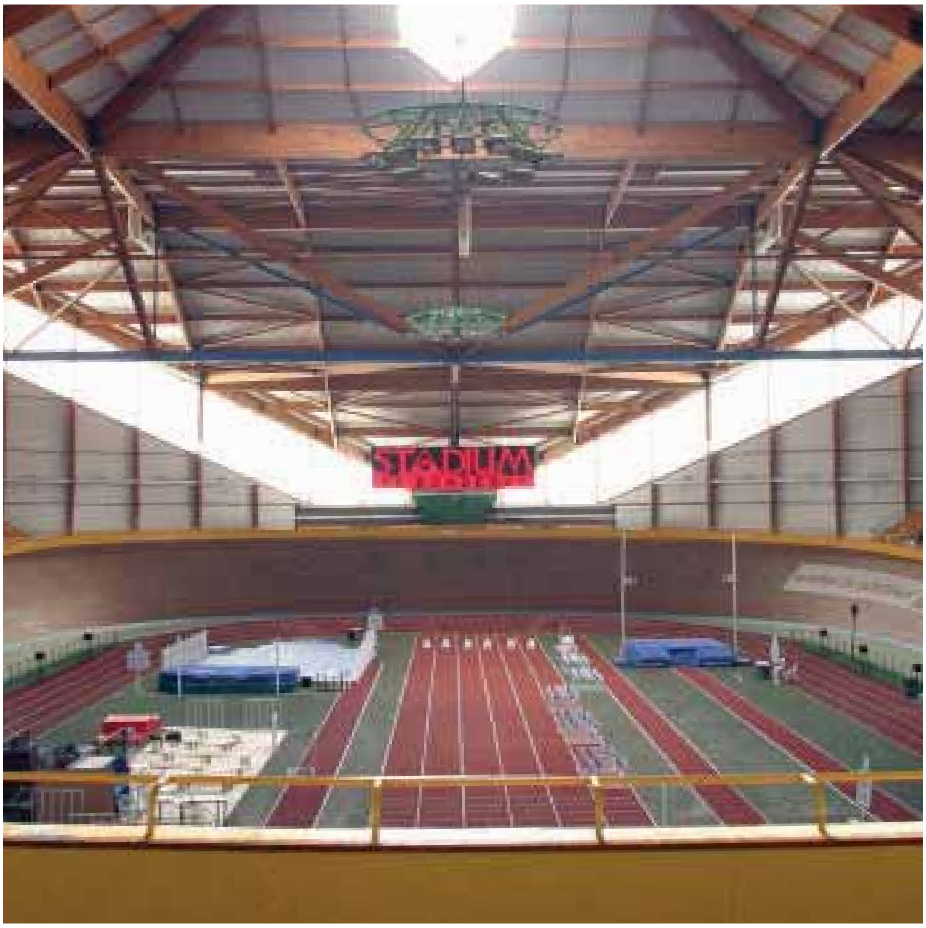
Bordeaux Olympic Velodrome, France, 1985

CLIENT	Bordeaux City Olympic Committee
ARCHITECTS & ENGINEERS	Roger Taillibert, Paris
STRUCTURAL TIMBER FABRICATORS	Haas-Weisrock S.A., Saulcy-sur-Meurthe
MAIN CONTRACTORS	Bordeaux Velodrome



OVERVIEW

Several basic forms compounded together provide a new structural concept for wide span sports structures. A clever diagonal plan has principal parallel glulam girders, with steel box section tension chords. This scheme enables a square space of 107m sides to be enclosed by forms that individually have shorter spans.

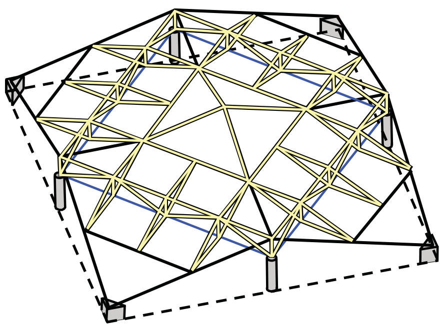


This purpose-built velodrome, seating 4,500 within a 107m square envelope, features a 250m steeply banked track. Both the structure and the surface of the track are timber. For the surface, the dense, durable, and stable tropical hardwood, Afzelia, was used, a frequent choice for such projects.

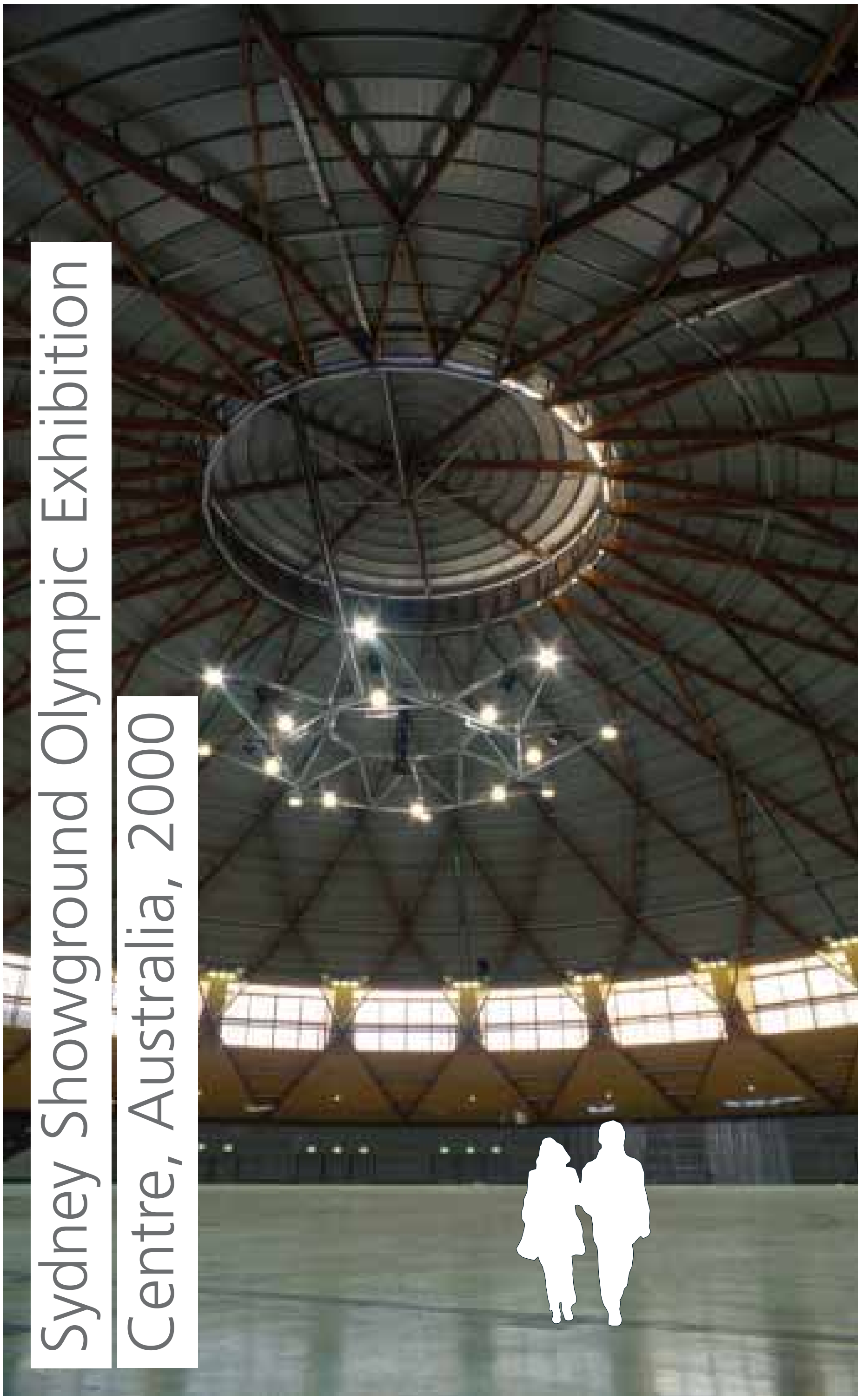
The banked seating is arranged diagonally across the corners of the square plan. The four principal reinforced concrete supports for the roof structure are located on the diagonal points, from which flat-topped composite timber-steel girders span 75m from pillar to pillar. On each of these girders are mounted three lozenge-shaped glulam trusses whose inner tips support a diagonally-square 37m wide roof pyramid.

The main girders are 8.68m deep, with upper chords of hollow box section. There are two 160mm x 1330mm vertical hollow sections over the most highly stressed zones, tapering to single 135mm x 1330mm elements in the outer bays of the girders. The lower steel tie chords are 400mm x 600mm x 8mm box sections.

The pyramid main roof comprises diagonal timber girders with steel tension chords, a series of secondary glulam trusses and a central lantern upper roof, also in glulam, with 37m sides.

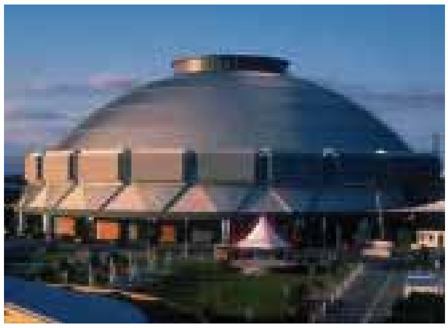


Sydney Showground Olympic Exhibition Centre, Australia, 2000



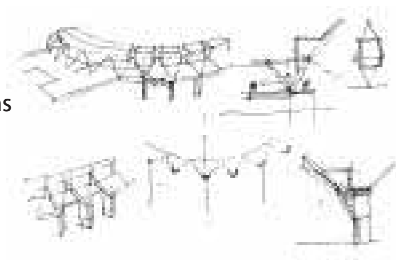
OVERVIEW

Timber was the obvious environmental choice for the first 'Green Games'. The dome is the largest clear span timber structure in Australia. Several features of the exhibition halls are also outstanding, notably their operable walls giving flexible subdivision of space, and their consequent roof stabilisation, achieved without relying on stiff shear walls through arched and trussed glulam bracing components.

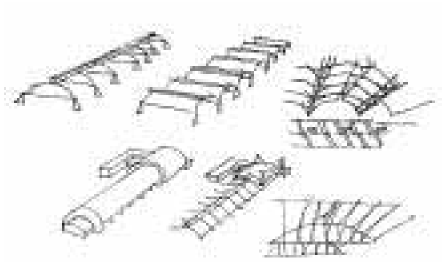


This magnificent timber dome, 97m across and 42m high, together with three linked, open-plan timber halls, forms a complex known as the Sydney Showground Exhibition Buildings. Covering a total area of 14,400m^2, this is one of the largest of the award-winning structures constructed for the 2000 Olympic Games. Since then, it has provided permanent facilities for the Royal Agricultural Society - an example of successful 'Games Legacy' planning.

The Olympic Exhibition Centre has two main sections, the dome itself, and a flexibly planned series of rectangular halls, with a total capacity of 18,000.



CLIENTS	Olympic Coordination Authority, Royal Agricultural Society
ARCHITECTS	Ancher, Mortlock & Wooley – Ken Wooley, Phil Baigent, Steve Thomas
ENGINEERS	Ove Arup & Partners
CONTRACTORS	Thiess Contractors
AWARDS	Finalist in Australian Constructors Awards, Award of Merit – Australian Timber Design Awards, 2000 Institution of Structural Engineers (UK) Special Awards, 1999 Association of Consulting Engineers of Australia - Special Merit Award, 1998



As the Sydney Olympics were identified at the early planning stages as the 'Green Games', the Olympic Coordination Authority pursued sustainable development principles. In particular, they looked for the conservation of indigenous species and natural resources, and careful pollution control. As a result it was decided at the concept design stage that timber should be used, both for the main structural elements and also for the greater part of the finishes. It was recognised that timber is a renewable building material with low embodied energy when compared with the alternatives. The Exhibition Buildings were thus designed and constructed using mainly glulam, for its unique aesthetics, cost-effectiveness and environmental credentials.

During the Olympics, the Exhibition Halls hosted events such as volleyball, handball, badminton and rhythmic gymnastics. Paralympics sports included basketball, handball and volleyball.

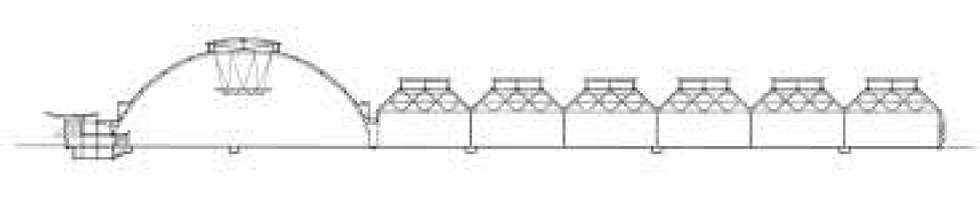
Energy-efficient air conditioning was specified, using an innovative displacement system, in which air, conditioned from a radiant cooling slab, is introduced at low velocity through a perimeter trench, entering by means of diffusers. The air then rises to extractors in the crown.

At the erection stage, advantage was taken of the prefabrication potential of timber to integrate structural assembly with roofing and service installation at ground level. The dome was then jacked into position, working from the centre outwards.

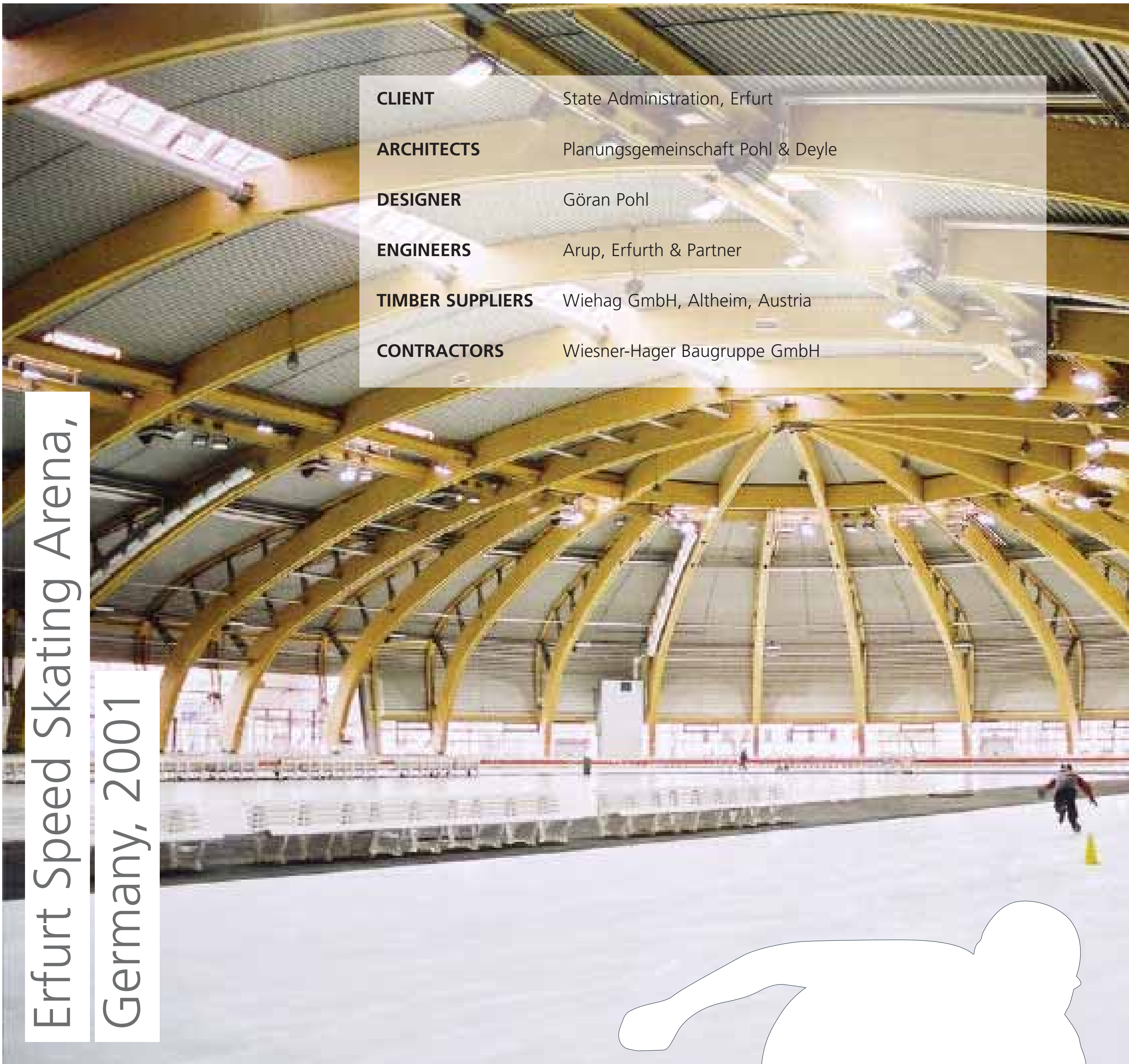
The dome is a relatively conventional geodesic structure, using Radiata pine glulam, sourced from South Australian plantations, for the principal compression members. These delineate the structural form, whilst steelwork has been used for the struts and connections.

All other elements have been scaled and detailed to complement the use of timber. The ribs meet at fabricated steel connection nodes where each timber element has eight couplers for threaded anchor rods. The latter were permanently bonded into the glulam, using epoxy adhesive. To resist the increased loads towards the base, the timber sections progressively increase from 800mm x 30mm in the top circle of the dome to 800mm x 230mm at the base.

The roof form for the rectangular halls was constrained by the partitions. Some distinction was required for each of the six, potentially separate, pavilions. At the same time, their structure needed to be capable of functioning with moveable walls. Also, the aesthetics demanded a roof structure in sympathy with the dome. The solution was again to use glulam elements, combined with steel struts, to arch down from the roof peak to steel support columns. At the perimeter, the steel and timber elements form a truss in the plane of the roof to receive the horizontal thrust from the arches, resolving the actions through transverse tension members placed on the operable wall support lines.



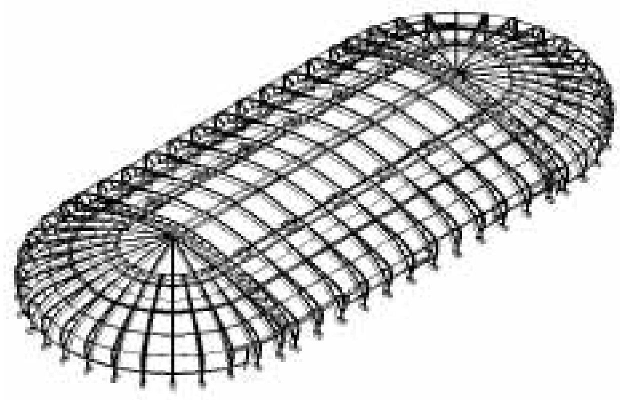
Erfurt Speed Skating Arena, Germany, 2001



CLIENT	State Administration, Erfurt
ARCHITECTS	Planungsgemeinschaft Pohl & Deyle
DESIGNER	Göran Pohl
ENGINEERS	Arup, Erfurth & Partner
TIMBER SUPPLIERS	Wiehag GmbH, Altheim, Austria
CONTRACTORS	Wiesner-Hager Baugruppe GmbH

OVERVIEW

This arena illustrates how low-pitched arches can be used economically for an 80m clear span. These frames create a classic lozenge-shaped arena, with the apsidal ends formed using radial half-arches of the same general shape as the main frames.



The requirements for this wide-span covered ice rink led logically to the choice of timber, mainly in the form of glulam. The roof structure, the enclosed space, and the principal dimensions were developed for optimum efficiency and economy of form and assembly. The building, with its 80m span, 186m length and 17m internal ridge height, has a classic shape for a competitive speed skating arena. In cross-section, the structure is developed as a series of flat arches, with 8m headroom at the outer edges of the track.

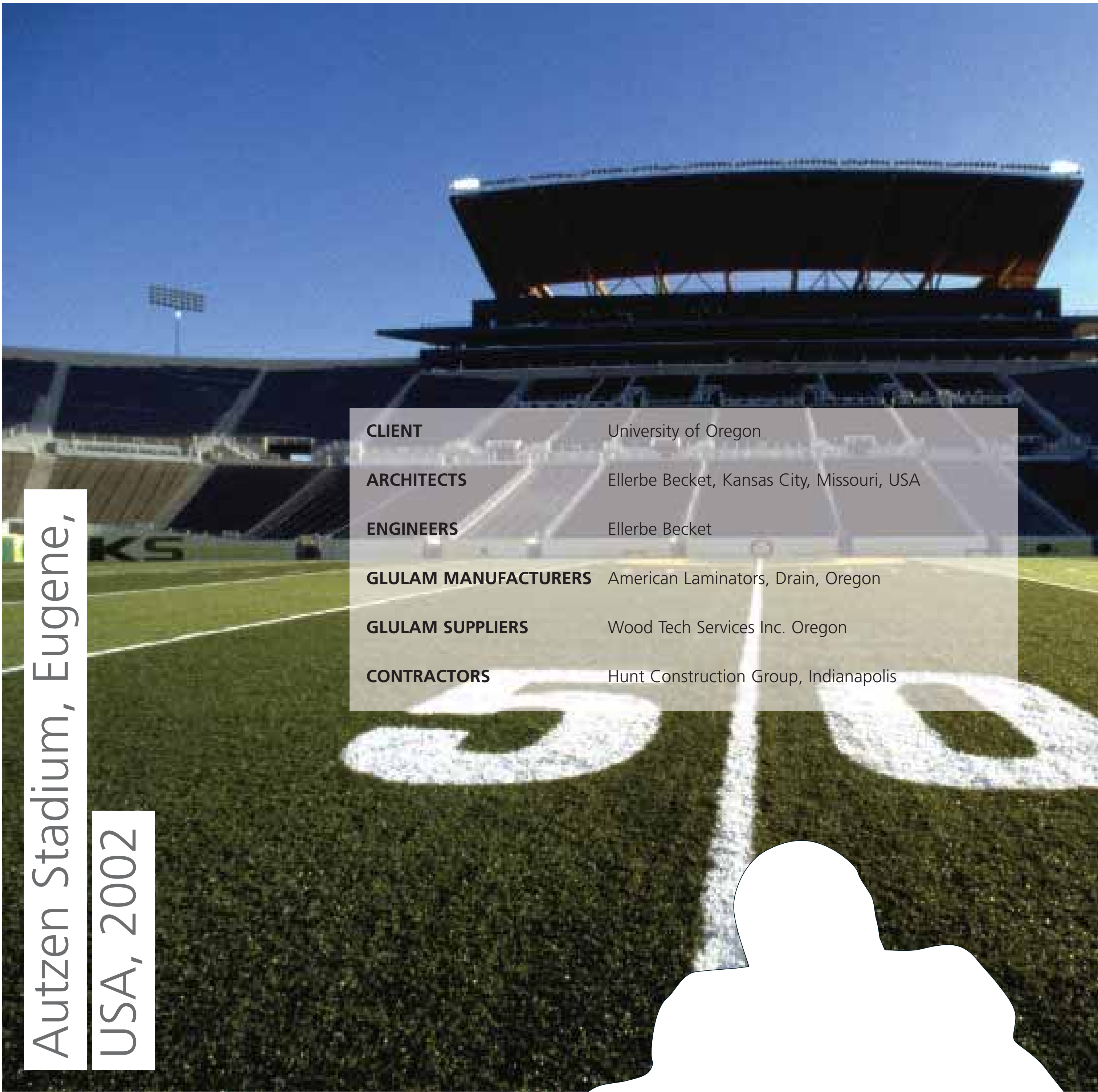
The main parallel arches span 80m, while the apsidal ends are created by means of two radial series of braced semi-arches with a common profile. At ground level, a reinforced concrete thrust ring is set over piled foundations. Poor soil conditions meant these had to be designed with care and driven deep. The lightness of the timber superstructure was of considerable benefit in reducing foundation pressures.

The straight central portion of the enclosure has its arches spaced at 8.70m. The arches have an interesting and rather unusual structural provision around the curved haunch regions. Here, metal struts are interleaved between inner arch faces, extending up to connect to curved thin glulam secondary chords. This arrangement reduces the depth that would otherwise have been necessary had standard curved glulam portals been used. This elegant device gives the structure an additional sense of freedom and lightness.

At each end of the parallel section are pairs of braced arches at the closer spacing of 5.33m. These form a bracing system that resists the longitudinal wind forces and that passes on, through the purlin arrangements, the main lateral bracing constraints to the rafter portions of the common principal arches. Sixteen structural bays occur within each apse, for here the main bay spacings are halved below the upper purlin levels, thus introducing an extra eight arch ribs. With purlins and lateral members located between the ribs, these end structures provide adequate bracing in themselves for the building to resist transverse wind effects.

Along the length of the hall are five main sets of elements: a roof spine, which has twin members; symmetrical pairs of upper purlin runs, also doubled; and two lower purlin runs. The paired sets at the ridge and upper purlin positions support roof light openings and electrical and lighting services.

For economy of structure, especially at the manufacturing and assembly stages, there is considerable replication. Arch profiles and the secondary roof structures have repeated cross-sections and details. The purlins and bracing blocks comprise adhesive bonded box units, each made up from several individual glulams. This helps conceal services, while ensuring lateral stability.

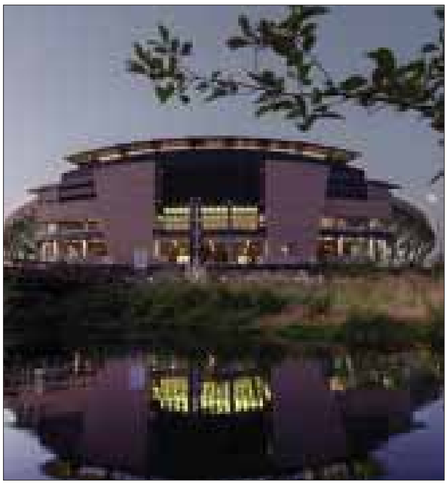


Autzen Stadium, Eugene, USA, 2002

CLIENT	University of Oregon
ARCHITECTS	Ellerbe Becket, Kansas City, Missouri, USA
ENGINEERS	Ellerbe Becket
GLULAM MANUFACTURERS	American Laminators, Drain, Oregon
GLULAM SUPPLIERS	Wood Tech Services Inc. Oregon
CONTRACTORS	Hunt Construction Group, Indianapolis

OVERVIEW

A spectacular timber canopy with a 30m cantilever. Constructed in laminated Douglas fir, the project was completed in nine months - on time, and on budget.



This $89.5 million project for the 'Oregon Ducks' involved adding 12,500 new covered seats, concession areas, new suites, a state-of-the-art press box, a wider concourse and a new glulam roof canopy, all in just nine months, in time for the opening game of the season - a tight schedule for such a large construction project.

The spectacular 52m timber roof canopy, cantilevered nearly 30m over the new seating, provides the completely uninterrupted vision of the game nowadays considered essential.

It was designed as a pre-cambered cantilever with the additional feature of curvature over its width (as seen from the pitch). Modern design codes make all necessary deflection calculations available to engineers, whether working within North American or Eurocode design codes. However, to achieve this successful result, close co-operation between the specialist glulam suppliers and the main contractors, a high degree of accuracy in the pre-fabrication process, site assembly and lifting, and careful orchestration of the erection process were necessary. Erection of the glulam beams took less than two weeks, with the roof structure completely enclosed and sealed in two months.

The size and sheer quantity of beams required was a challenge. The glulam members were manufactured from Douglas fir, using special lay-ups in which higher strength grades of laminations were arranged in the outer layers. The main elements were built-up by sandwiching, using concealed steel plates and connectors. Two 311mm breadths were doubled up in this manner. The completed composite cantilevers had a maximum depth of 1,830mm. The total length of the main members was approximately 52m, with key nodes at a 29.6m position. The purlins were also Douglas fir glulam, with a 130mm x 380mm section.

Accuracy was critical for the final drilling and assembly at the area near the site, although considerable factory preparation had already been made. Because of the combination of camber and arch, detailed coordination was required to ensure that each beam took the correct shape before the next was assembled. A portion of the roof was left open over the top of the suites, and in this zone, the exposed beams had been pressure preservative treated at a specialist plant, prior to delivery.

Connections for the glulam purlins were installed on the main members prior to lifting. The purlins were shaped and attached in segments, with plywood roof sheathing pre-installed on the ground. The glulam units were then lifted by crane onto their supporting steel columns, and connected by steel knee braces.

Douglas fir cladding was also included in the project, and glulams from an older structure were cleaned up and re-machined for use as signage columns.

Nanterre Stadia, Ile-de-France, France, 2003

CLIENT	Ville de Nanterre
ARCHITECTS	Barthelemy Grino Architectes SA, Paris
ENGINEERS	RFR, Paris
CONTRACTORS	Charpente Houot (SAS), Gerardmer

OVERVIEW

Small but skilfully designed and built, using lattices of lightweight home-grown Douglas fir.

Douglas fir, a naturally durable sap-free material, is used to create the simple grid structures that form the roofs of these stadia. Thin solid laths of Douglas fir are connected neatly to one another in relatively short lengths. The major elements, including the round propping struts, are Douglas fir glulam. The rear-facing balancing canopy is tied down using steel rods.

The complex geometry was achieved using computer generated design linked to computer assisted manufacture. The result is a very lightweight network, with a fir-coloured natural finish that will weather to silver. At each node connection, the fasteners are sensitively detailed to complement the precision and airiness of the whole structure.

The shell was fabricated in sections in the workshop. The prefabricated units are rectangular in plan, each with an outline of 2m x 10m. Tapering ribs are suspended from the upper rectangles to create sets of v-shaped trough profiles. The fine grillage is arranged in a triangular latticed format, giving in-plane shear stiffness. The boundary shape comprises a doubly-curved envelope, which is displayed in the completed structures thanks to the translucent roof coverings.

Pohjola Stadium, Vantaa Finland, 1999

CLIENT	Vantaan Silva Stadion Oy
ARCHITECTS	Arkkitehtuuritoimisto Seppo Valjus Oy
ENGINEERS	Finnmap Consulting Oy
CONTRACTORS	Insinööritoimisto Niemi & Co. Oy
TIMBER SUPPLIERS	Finnforest Oy

OVERVIEW

Box-sectioned cantilevered Kerto LVL half-portals provide a high degree of stiffness.

It's not only premier clubs that need football stadia. There is a growing need for smaller buildings, whether for football or for international field events which draw more modest crowds.

This stadium was designed to fit a sloping, wooded site and to provide flexible capacity. The stands have eight banked rows seating 1,100. There are dressing rooms for three or four teams, clubrooms and toilet facilities, press boxes and administrative rooms.

Exploring the use of modern structural timber and timber composites such as Kerto LVL, the stadium also makes use of structural plywood with special coatings and finishes, as can be seen in the stairway. Engineering calculations can be made for all of these materials using BS EN 1995 and other British standards.

Prien Swimming Pool, Bavaria, Germany, 1999

CLIENT	Municipal Authority, Prien
ARCHITECTS	Zeller & Romstätter, Traunstein
STRUCTURAL ENGINEERS	Haumann-Fuchs, Traunstein & Peter Zeller, Ruhpolding

OVERVIEW

The roof trees are simple but elegant. The curved timbers of the verticals complement the graceful roof ribs.

At certain seasons the Chiemgau region of Bavaria experiences a cold alpine wind. It was decided, therefore, to redevelop the outdated Prien outdoor swimming pool into a new all-year-round indoor leisure pool.

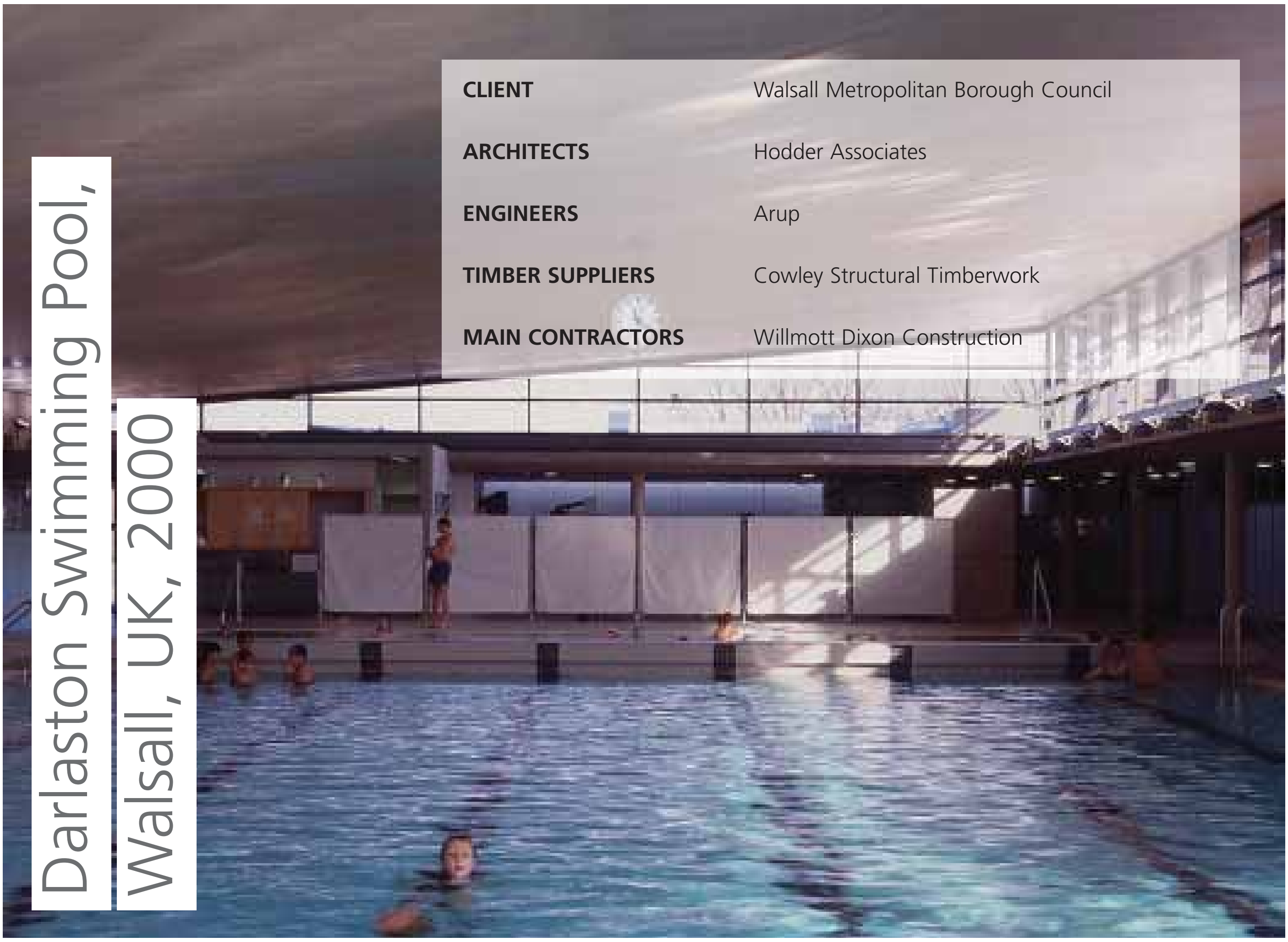
Curved laminated timber 'roof trees' and a shell-shaped plan have resulted in a dramatic building which achieves excellent natural lighting through its 1,800m^2 transparent roof, has a low mass to help overcome problems with difficult foundation conditions, and is resistant to the chemicals and humidity associated with indoor pools.

The shell-like appearance is achieved using relatively simple, curved glulam ribs. These linear elements are mounted above the roof trees, so structurally speaking this is not a true grid shell or skin shell. There are eighteen principal radiating ribs, each of which is designed as a curved continuous beam in three segments. These segments are neatly connected to one another with flitched-in true pin connections, similar to those used in glulam arches. Between the timber ribs are draped transparent roof coverings, triple-layered air-filled membranes maintained at an air pressure between 250 and 350 Pa. The pneumatics pass via light alloy valves and connectors that are associated with condensate drainage channels mounted on the ribs. The transparent membrane system is resistant to surface spread of flame and was also assessed for long-term behaviour in a pool atmosphere.

At the rear, or thin end of the fan-shaped plan, the radial timber structure is anchored to a reinforced concrete construction. The tapered rib tips protrude slightly from the front of the envelope and have corrosion-protected metallic coverings. At this outer façade the slight droop and inwards curvature of the transparent roof membrane is displayed, giving the architectural appearance of a scalloped shell.

There are 65 different shapes making up the glulam roof trees and ribs, with the greatest radius of a single principal element being 47.2m. The roof tree forms vary, some having six 'branches' and others only four. At their bases they are connected rigidly to low pillars of reinforced concrete. Hence there are both radial and transverse encastré conditions that provide lateral stability to the structures.

Darlaston Swimming Pool, Walsall, UK, 2000



CLIENT	Walsall Metropolitan Borough Council
ARCHITECTS	Hodder Associates
ENGINEERS	Arup
TIMBER SUPPLIERS	Cowley Structural Timberwork
MAIN CONTRACTORS	Willmott Dixon Construction

OVERVIEW

This building is enclosed by one of the largest stressed skin timber roofs in the UK, formed from factory prefabricated components with LVL stringers and structural plywood skins. The solution gave rapid erection, providing fully finished soffits immediately upon lifting. Chain of custody certified tropical timber has been used for the external screens.

This 32.5m x 68m building houses a 25m x 13m pool, a 7m x 13m instruction and disabled pool, a cafeteria and leisure zone.

The building's transparency allows users to enjoy views of the surrounding landscaping, even from the pool, while at night the illuminated pool provides a dramatically enticing view for passers-by.

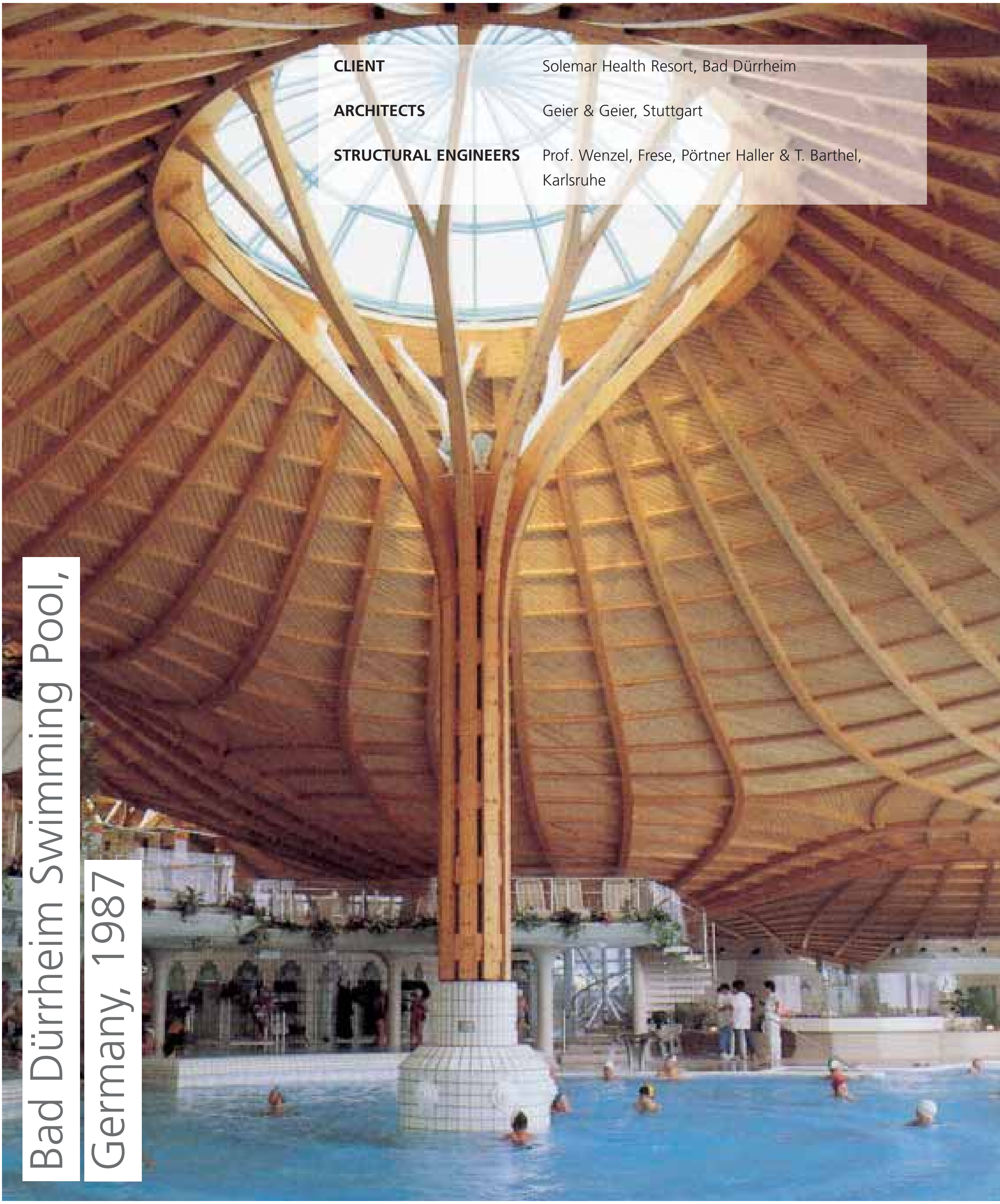
The open-plan interior, with the pool area visible from the cafeteria and leisure zone, scored well in a Centre for Architecture in the Built Environment (CABE) assessment and full disabled access is provided, with well-planned entry areas and ramps.

The building is enclosed by what is believed to be the largest stressed-skin timber roof span in the UK, made up of a series of 1.8m x 25m LVL (laminated veneer lumber) and plywood panels, providing fully finished soffits, prior to erection. Thermal and acoustic insulation was factory-fitted in the panel voids. The roof cladding is stainless steel. Iroko, a durable tropical timber carrying certification, has been used for the external sun and weather screening.

Stressed skin timber roofs are also being used in other swimming pool projects – for example the award-winning design by Bednarski Architects for a centre with a number of similar features, to be located at Thrapston, in East Anglia.

Bad Dürrheim Swimming Pool, Germany, 1987

CLIENT	Solemar Health Resort, Bad Dürrheim
ARCHITECTS	Geier & Geier, Stuttgart
STRUCTURAL ENGINEERS	Prof. Wenzel, Frese, Pörtner Haller & T. Barthel, Karlsruhe



OVERVIEW

A 'draped' lattice-shell, whose thin timber elements are suspended in tension, and supported off laminated rings held aloft by the roof trees.

The exciting roof of this Black Forest salt water health spa is a fine example of freedom of design and economy of material. The project pioneered a number of subsequent German spas with timber roofs. As timber grid-shells are now beginning to be used in the UK, it is only a matter of time before they appear in our sports and leisure structures.

This type of freely expressed suspended timber shell owes its origins to the architect-engineer Frei Otto, who began working in the 1950's on structures with minimal mass and form. His theme is 'Shape = Structure', and requires the acceptance that catenary forces can be resisted in simple tension, rather than fighting the more unnatural forces that are created by formal, stiff shapes. Provided it is straight-grained and free from gross defects, timber has excellent tensile strength-to-mass ratios. Since Otto's experiments, the timber industry has come a long way in developing accurate grade selection techniques, complex laminating methods and reliable end-jointing procedures, so that the advantages that he proposed are increasingly easily attained.

Timber's natural resistance to highly alkaline and corrosive atmospheres makes it an ideal material for roofing swimming pools and salt water baths. In such conditions plain steel fasteners should be avoided completely. An appropriate grade of stainless steel is an option, but completely metal-free connections are much to be preferred.

In this dramatic building, five 'roof trees' between 9.1m and 11.5m tall are placed around an inner court in an irregular plan shape, providing a total roofed area of 2,500m^2. The vertical structures support a lattice shell over 6m to 8m diameter rings of hollow box section. The shell itself comprises suspended meridian and annular ribs. Two layers of diagonally offset sheathing are attached to these ribs via shear connections. The meridian elements hang on their natural catenary lines, traversing from ring to ring or from ring to perimeter arch. Following their primary stress trajectories, they are thus stressed mainly in pure tension. Each rib measures just 200mm x 205mm in cross section. Stepped into the meridians are thin annular laths of 80mm x 80mm or 120mm x 140mm section, spaced at 800mm centres. The ribs are glulam, and since many are in double curvature and twisted, they are built up from large numbers of individual laminates. These have to be carefully assessed for strength and for the reliability of their end joints. The manufacturing technique involves re-sawing elements that are already laminated, and are hence curved in one direction and flat in the other. These pieces are then bonded a second time, to create the complex curvature.

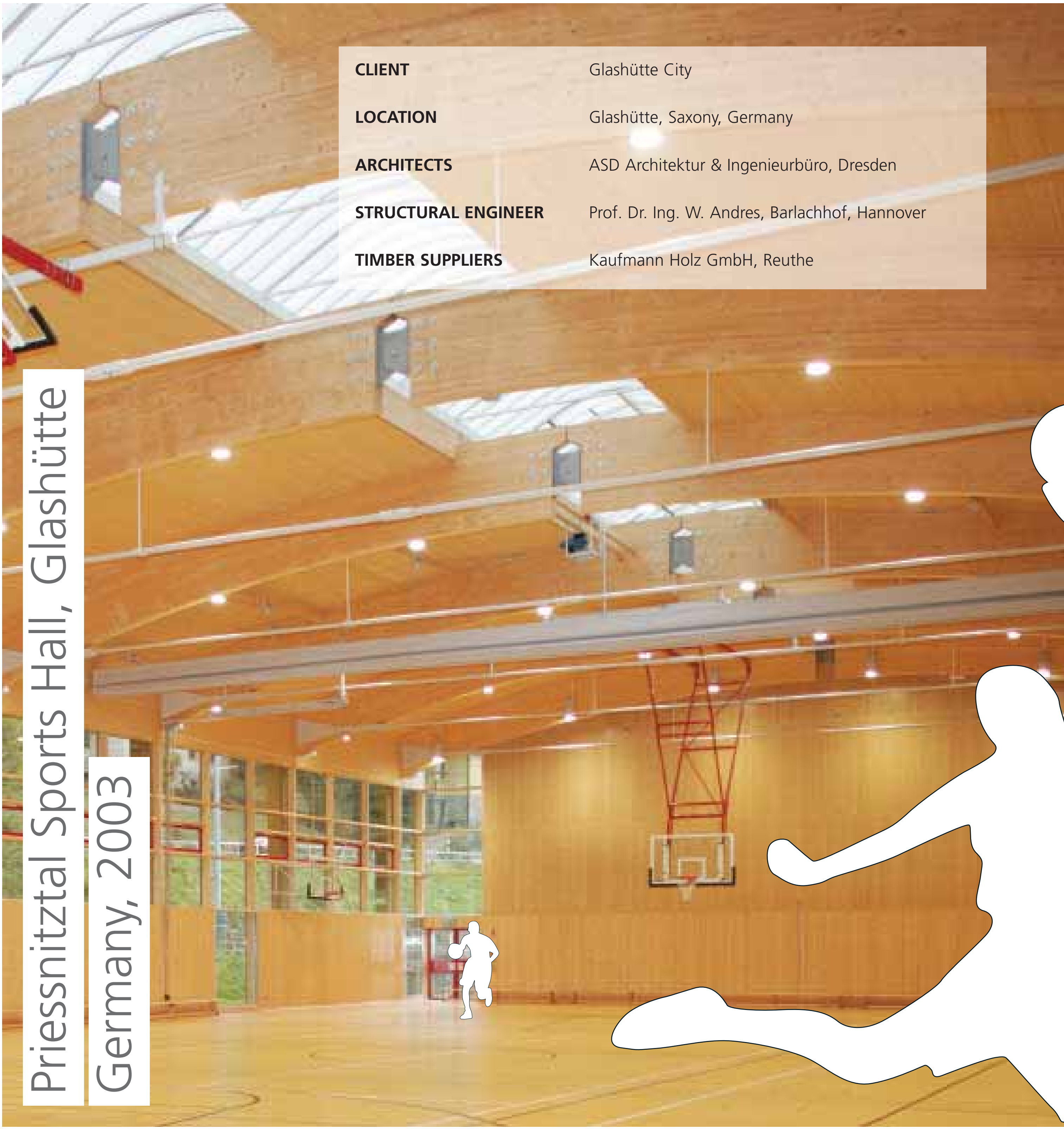
To connect the meridian ribs to the box sections of the tension rings and the perimeter arches, true pins are required, and adjustable pads are incorporated in the tree supports. These two measures ensure as far as possible a true membrane, with the lattice shell forces being kept to a minimum. For durability, special fixings have been used, for example the hardwood dowels that connect the tenons within the branching roof tree structures.

Despite their transparency, the façades incorporate a load-bearing structure, which provides the horizontal as well as the vertical reactions to the roof. There are simpler solutions, but suspended shells and grid-shells make an enormous aesthetic impact, and, as much of the structure is prefabricated, there are no erection time penalties for this level of sophistication. Through care, the volume of structural material, and hence the supported mass, is kept to an absolute minimum, making elements light to lift.

Timber shell technology is constantly improving; some of the laminating complications described above are now avoided, while the rapid progress in computing power facilitates three-dimensional modeling at the design stage, linked to accurate laser monitoring of the true spatial dimensions during erection.

Priessnitztal Sports Hall, Glashütte
Germany, 2003

CLIENT	Glashütte City
LOCATION	Glashütte, Saxony, Germany
ARCHITECTS	ASD Architektur & Ingenieurbüro, Dresden
STRUCTURAL ENGINEER	Prof. Dr. Ing. W. Andres, Barlachhof, Hannover
TIMBER SUPPLIERS	Kaufmann Holz GmbH, Reuthe



OVERVIEW

The main roof structure comprises efficient tied glulam arches with neatly expressed connection details.

Close to the border with the Czech Republic and to the south-west of Dresden, this new double-pitch multipurpose hall in Glashütte has an interesting background. 2006 was planned as a year of celebration for the 500th anniversary of the granting of the city's Charter by the Duke George of Saxony. However, in August 2002 tragedy struck, with a flood on the scale of Boscastle in the South West of England. As a result, plans for the project were developed with great care and given added impetus by the redevelopment work associated with the flooding. A great deal of cleaning up and removal of mud and debris had to be taken into account in the construction scheduling, and flood protection needed to be considered for the surroundings of the site and its foundations.

This is an outstanding example of an environmentally sensitive timber design. Timber was the natural choice, as the Priessnitztal is rich in forestry and timber framing has a long history here. The building even incorporates a 'living roof' of drought-surviving sedum plants and small grasses.

The sports hall is mainly for the city's schools and colleges, but it also hosts local and visiting sports associations. Training facilities are available for competitive events up to national or semi-international standards. In Germany the classifications are defined in DIN 18032 Part 1. There is a spectator gallery for 120, while the hall can seat 600 for conferences, performances and social events.

The main roof structure is comprised of tied glulam arches of 25.5m span, at 6.0m centres, with neatly expressed connection details, and a structural decking of K1 – Multiplan – Platten, a Type-Approved timber composite intended for such panelform applications. Here it provides both the cavity-insulated structural skin and the lateral bracing for the arches against horizontal wind actions. Ventilated details are included in the external cladding, parts of which are finished in the red earth colour traditional for Saxon historic framing, whilst other façades are clear-stained.

Externally, the structural elements which protrude beyond the envelope are protected with neat metal corrosion-proof covers. Internally, the sports floors are finished in sprung hardwood strip with under-floor heating. Wall linings are natural spruce with acoustic paneling incorporated as necessary.

Pyhämaa Community Sports Centre, Finland, 2000

CLIENT	Uusikaupunki local authority
ARCHITECTS	SAFA - Pia Helin, Kimmo Salmela
ENGINEERS	Narmaplan Oy - Juha Junttila
CONTRACTORS	Ukiplan Oy

OVERVIEW

The load-bearing structure consists of Kerto Q LVL wall units. The roof uses simple glulam arches. For both thermal and acoustic purposes, both horizontal and vertical voids are accurately ventilated and well insulated, providing very low running costs.

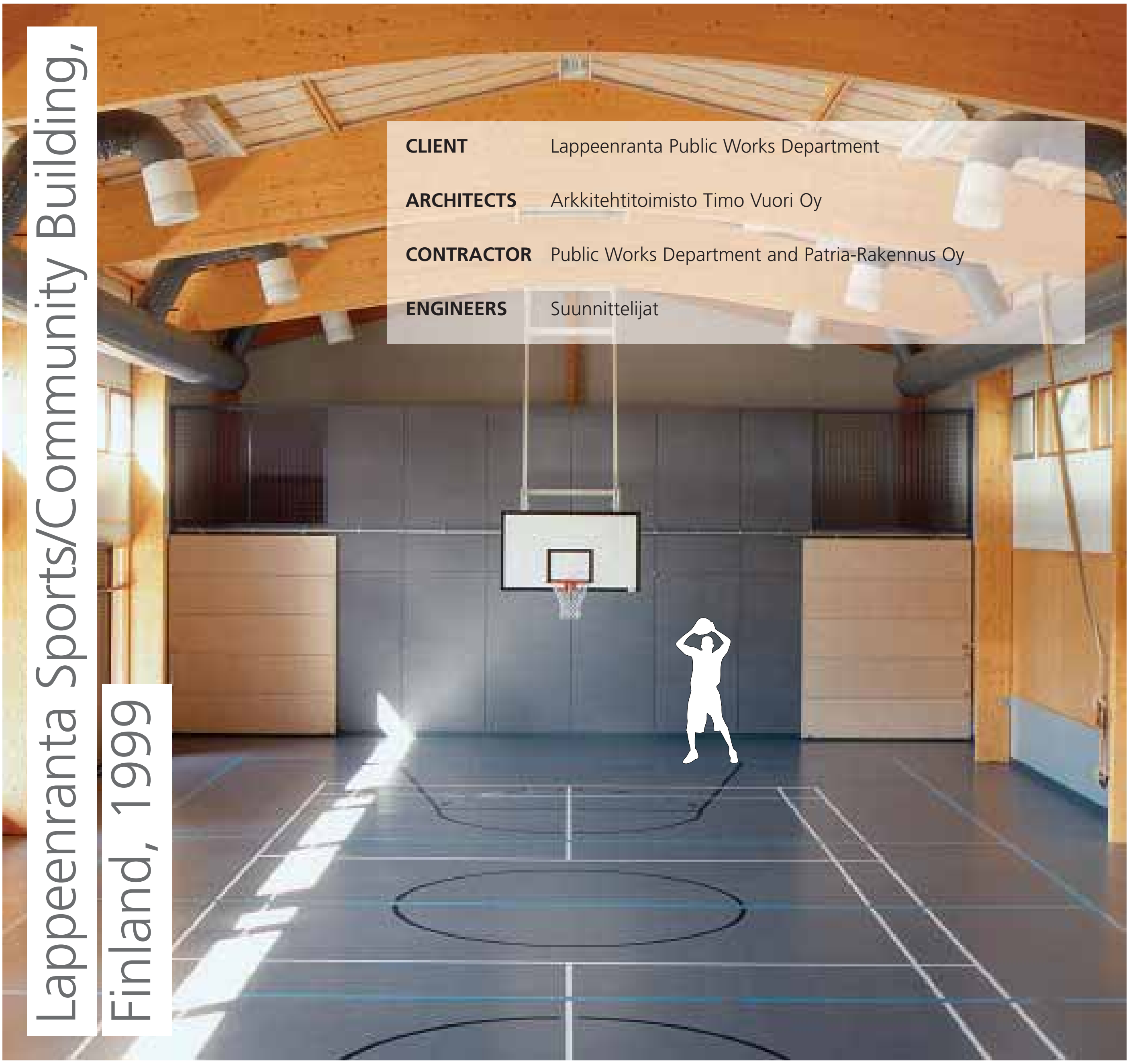
Pyhämaa Islet is an ancient Baltic fishing village near the town of Uusikaupunki, below the Gulf of Bothnia, a place of historic timber buildings, including a 17th century church, and a school which dates to the start of the twentieth century. A new hall for the school and community sports and activities was required. It had to fit in with this cultural area and was to be placed next to existing playing fields, woven into the school complex which sits prominently on a hill.

This was the challenge for the architects and planners. The solution was a modern design, using the latest structural timber materials and timber cladding. Although providing a contrast with its older neighbours, the materials used were naturally sympathetic, decorated in the pastel shades appropriate for the northern context. The centre is of great beauty – an example of Nordic design flair, in contrast, yet in harmony, with its natural and architectural surroundings.

For the exterior cladding, timber was the natural choice, finished in traditional shades of linseed oil paint. Three different colours were applied to create the impression of a cluster of buildings rather than a single large block.

The load-bearing structure of the hall consists of Kerto Q wall units. This is a two-way spanning version of laminated veneer lumber, recently approved for design with the Eurocode through BS EN 14279. It is cut to shape in the factory, including all openings and profile variations. After prefabrication, it is simply and quickly assembled on site. The roof structure includes glulam arches and wood wool fibre insulation is used for the floors, mineral wool for the walls. Internal wall linings are lacquered plywood, while acoustic performance is enhanced with a cotton-based compound spray applied to the ceiling and the upper wall sections.

Lappeenranta Sports/Community Building, Finland, 1999



CLIENT	Lappeenranta Public Works Department
ARCHITECTS	Arkkitehtitoimisto Timo Vuori Oy
CONTRACTOR	Public Works Department and Patria-Rakennus Oy
ENGINEERS	Suunnittelijat

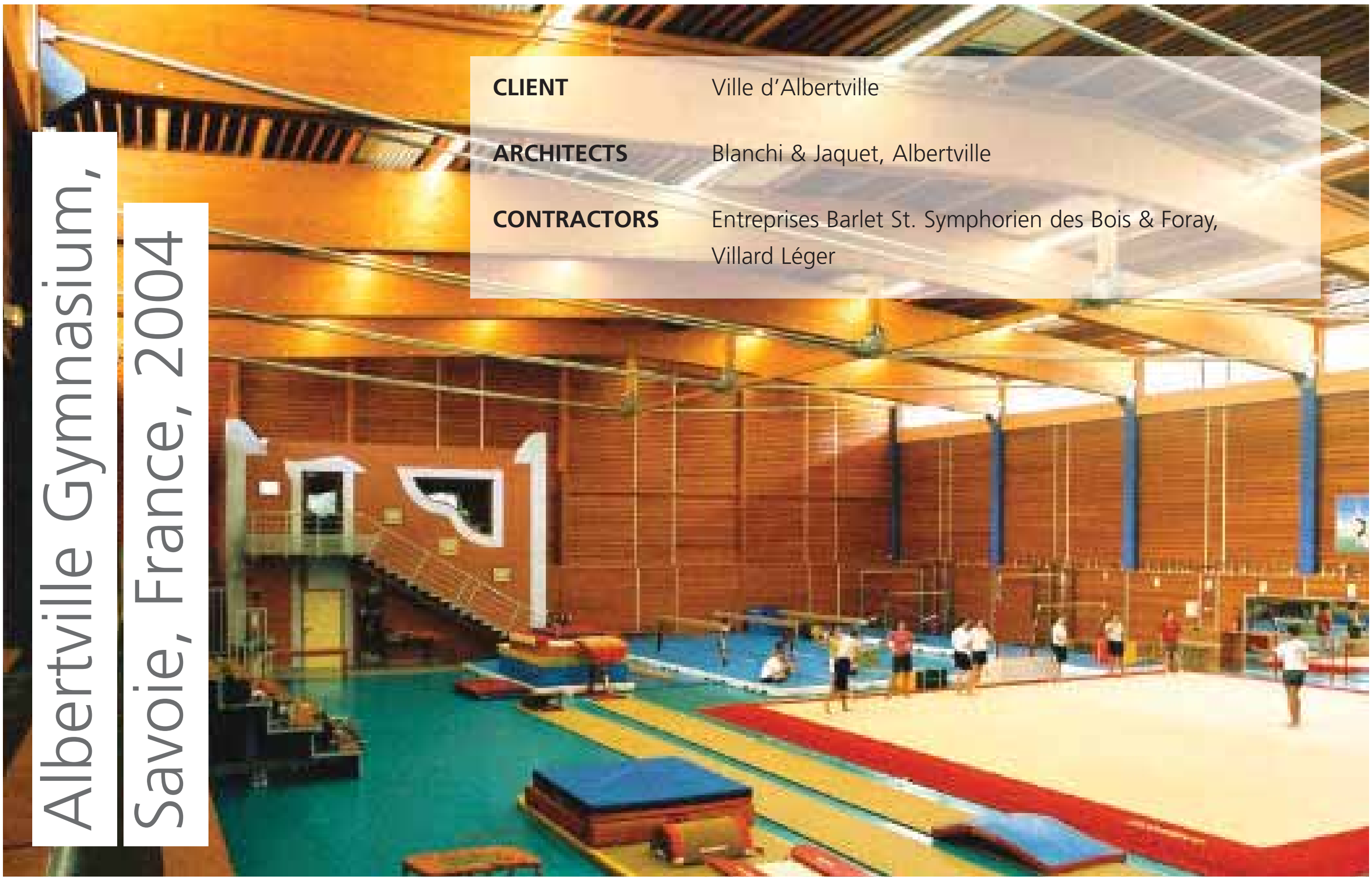
OVERVIEW

Designed for rapid completion using modern structural timber composites, it uses simple pitched tapered glulam roof beams.

A multi-purpose sports and community building was required in Lappeenranta, and since a housing exhibition was held there in 1999, the space was initially used to stage part of the exhibition. Subsequently the structure was completed as a gymnasium and assembly hall for the nearby school. Housing association tenants and other residents living in the district also enjoy the facilities.

The location is adjacent to an existing school, also timber. The building's plan and elevations took advantage of the sloping site to avoid overpowering the vernacular appearance of the older buildings and the colours of the exterior were chosen to complement the surroundings. As the construction timetable was extremely tight, extensive use was made of prefabricated units. However, the wall and roof details were sensitively designed to present a sophisticated overall appearance.

Albertville Gymnasium, Savoie, France, 2004



CLIENT	Ville d'Albertville
ARCHITECTS	Blanchi & Jaquet, Albertville
CONTRACTORS	Entreprises Barlet St. Symphorien des Bois & Foray, Villard Léger

OVERVIEW

Elegant glulam roof frames are sub-tensioned using doubled steel tie rods. Timber clad curtain walls are supported on a secondary framework between reinforced concrete columns. A tilted timber canopy overhangs the more prominent elevation.

The main timber roof structure of this gymnasium is an elegant and efficient solution using glulam frames, sub-tensioned by doubled steel tie rods. The paired timber principals are cranked members of rectangular section, having a slight taper from crown to tip. The crown area is curved laminated – there is no structural pin at this position.

Triangulation of each frame is achieved by means of a central vertical timber strut, sandwiched at its head between the crowns of the main beam halves. From here it drops from beneath the crowns of the beams to provide central connections for the tie rod arrangement.

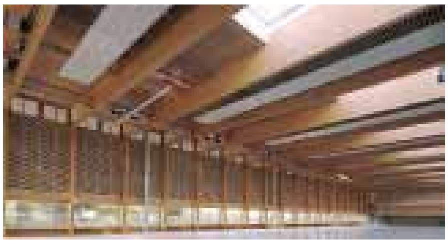
The reinforced concrete columns on which these simple triangulated frames sit achieve lateral building stability through their encastré bases. The curtain walls are on a secondary timber framework concealed within the inner and outer wood linings, while cavity insulation, vapour barriers, breather membranes and correct ventilation are, of course, incorporated. Without being inaccessible, or causing potential water-trapping, the rainwater drainage is integrated into the structure and its cladding, and, for aesthetic reasons, hollow non-structural timber posts cover the down-pipes, which are located at the main reinforced concrete verticals.

A flat topped, slightly tilted timber canopy overhangs one elevation, its glulam cantilever supports carrying straight longitudinal purlins, with the tips of the cantilevers protected by means of capping and tied down to the reinforced concrete posts to prevent wind uplift.

To avoid external views at the athletes' eye level, horizontal slit windows are placed at the tops of the walls and on the open façade, where a cantilevered canopy shades them from too much sunlight.

Sports Complex and Martial Arts Centre, Saint-Pierre-des-Corps, France, 2004

CLIENT	Ville de Saint-Pierre-des-Corps
CONTRACTORS	Bouvard Samoun
TIMBER STRUCTURE	IMC^2
SUPPLIERS	Construction Millet Bois



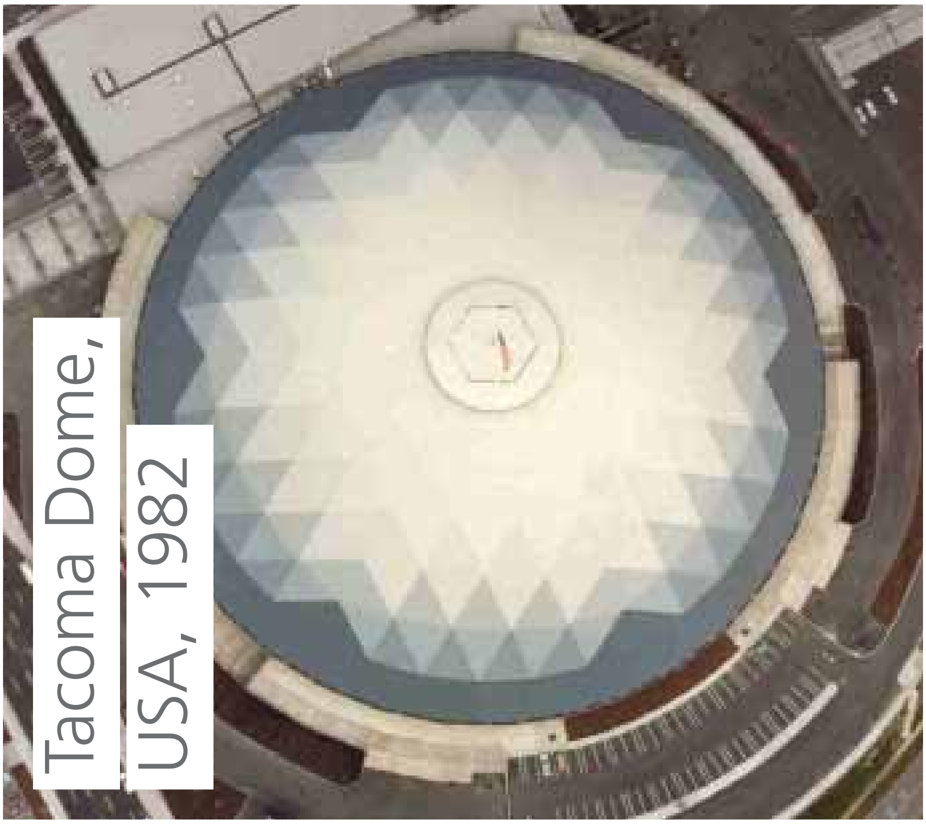
OVERVIEW

This classic post and beam structure is clad in 'Lamibois', a structural timber composite with natural spruce appearance. Timber slatted walls are used to filter the natural lighting.

This classic beam and post structure is another simple but pleasing scheme, providing satisfaction to competitors and trainees in a number of different sports. The building, with its parallel glulams portalised at the column heads, has close-centred bays, giving a distinct rhythm to the architecture.

Internal linings and vaulted roof glazing are directly supported by the paired roof beams and timber columns. 'Lamibois', a structural timber composite with natural spruce appearance, has been used for the external cladding, treated with a grey translucent stain to ensure even weathering. The reception and training spaces have timber slatted walls, breaking up what would otherwise be excessive plainness, whilst allowing natural daylight to percolate through.

Tacoma Dome, USA, 1982



With a span of 161.5m and a height of 48m, this is one of the world's largest timber structures. Designed for 23,000 seated spectators, the Dome is home to American football, rodeo, ice hockey, basketball, tennis and moto-cross. This 'ensphere dome' is a practical modification of the geodesic domes pioneered by Buckminster Fuller (1895 - 1983). A pure geodesic dome is achieved by projecting an icosahedron (a figure of 20 sides, each surface comprising equilateral triangles) onto a sphere. Unless it is hemispherical, there are irregular lengths amongst the edge members at the base, which is inconvenient in forming entries to the building and in making connections to the ring beam. Also, when a sports dome of more that 100m diameter is required, it would produce too high a structure, both practically and for the economy of the materials. The ensphere system, developed by Wendell Rossmann, solves these problems.

CLIENT	City of Tacoma Public Assembly Facilities Department
ARCHITECTS	McGranahan, Messenger Associates; Wendell Rossman – Rossman, Schneider & Gadberry – Ensphere dome concept
CONTRACTORS	Merit Construction – Jim Zarrelli
GLULAM SUPPLIERS	Western Wood Structures, Inc.
STRUCTURAL ENGINEERS	Hine, Wessel & Associates, Tacoma

The system involves a combination of hexagonal and triangular shapes. The outermost, bottom ring of the network is purely triangular, with the appearance from the inside of a circular Warren truss. Higher up, the network looks like a series of diamonds. At the nodes there are six incoming members, and the hexagonal pattern is emphasised when looking up at the crown. The overall resolution of the geometry is thus aesthetically satisfying, as well as practical.

To interpret these geometrical concepts in timber, ribs are necessary, and these are generally formed with glulam, as is the case with the Tacoma Dome, where the primary members are laminated Douglas fir. These ribs measure from 170mm to 220mm in width, and 750mm in depth. Typically, the principal members are 15m long. For erection, units were connected on the ground to create modules that were light enough for craning, but stable enough to gradually add to the increasing 'giant igloo'. Only two months were required to complete this erection process.

Layers of 50mm tongued and grooved Douglas fir, selected, dried and end-jointed using finger joints, is used for the structural sheathing. The external membrane is an advanced polyurethane material, self-coloured to display the geometry. At the base of the dome, a pre-stressed concrete ring beam acts to resist the structure's outward thrust.

Timber Sports Domes

SUPERIOR DOME, MICHIGAN, USA

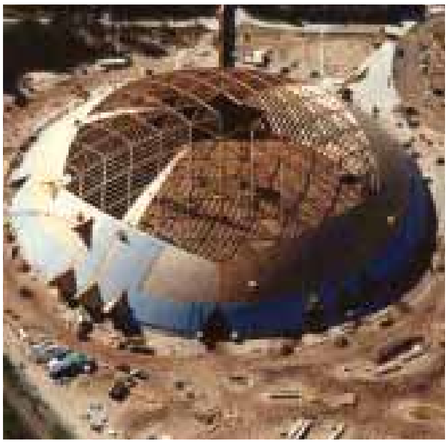
The same structural system as the Tacoma Dome but on a 2m plinth, making the structure seem shallower. Areas of the roof are revealed to emphasise the timber structure.

WALKUP SKYDOME, ARIZONA, USA

The Walkup Skydome uses the ensphere system. Its reticulated pattern of triangles, diamonds and hexagons is achieved using glulam ribs of Southern Yellow pine.

ODATE JUKAI DOME, JUKAI, JAPAN

This 3-D Grillage Dome is the largest timber building in the world. It boasts a fully expressed structure and a translucent Teflon-based envelope.



Name	Location	Date completed	Diameter/ span (m)	Height (m)	Area (m^2)	Structural form	Timber type/species
Izumo Dome	Izumo City, Shimane Prefecture, Japan	1992	143m	49m	16,277m^2	Radial arches, trussed near the base, with V rim girder supporting 'parasol' membrane	Douglas fir glulam (Pseudotsuga menziesii)
Konohana Dome	Miyazaki City, Miyazaki Prefecture, Japan	2004	118m	38m	10,966m^2	3-D Grillage dome, Teflon covered	Sugi glulam (Cryptomeria japonica)
Odate Jukai Dome	Odate, Akita Prefecture, Japan	1997	Oval plan 178m long x 157m wide	52m	23,218m^2	3-D Grillage dome, Translucent, covered in Teflon	Sugi glulam
Oguni Dome	Oguni, Kumamoto Prefecture, Japan	1988	47m x 63.5m	18.3m	2,985m^2	3-D Grillage dome	Douglas fir glulam
Oulu Dome	Oulu City, Upper Gulf of Bothnia, Finland	1985	115m	23.9m	10 400m^2	Glulam main arched ribs + LVL secondary reticulated ribs	European whitewood glulam + spruce LVL
Superior Dome	Northern Michigan University, Marquette, USA	1991	163m	49m	20,900m^2 Reticulated	Ensphere. Glulam ribs	Douglas fir glulam
Tacoma Dome	Washington State, USA	1982	161.5m	48m	20,500m^2	Ensphere. Glulam reticulated ribs	Douglas fir glulam
Walkup Skydome	Flagstaff, Northern Arizona, USA	1977	153m	43.3m interior	18,400m^2	Ensphere. Glulam reticulated ribs	Southern Yellow pine glulam (Pinus Palustris & spp.)

Structural Materials

Use Structural Timber Composites (STCs)[4] for:

- Open-plan and flexible buildings with heavy loadings and wide spans
- Large cross-sections, including tapered and curved shapes
- Applications where appearance is paramount; revealed structure is architecturally significant in many wide-span sports structures

Structural timber panels and diaphragms can also be included to further extend the range of structural forms and solutions.

STCs are Quality Certified to harmonised European standards. Designs are conceived and calculated using a fully published basis – the Eurocodes suite[5] – that now applies throughout the EU and the European Free Trade Area. This code relates to the whole range of major production and fabrication facilities in Western Europe, the Nordic region and beyond.

In conjunction with STCs, solid sawn timber is also used, particularly for secondary elements such as joists, bracing members and purlins. Strength graded timber, correctly dried and processed, must be used for structures of any size. The key Harmonised European Standard, BS EN 14081[6], is essential for designs using solid timber in conjunction with Eurocode 5. Its strength classes are classified in BS EN 338[7] Since this material is well known and supported by extensive documentation[8], it is not necessary to discuss it further.

GLULAM

STANDARDS, SIZES AND FORMS

The manufacturing technology for glulam (glued laminated timber) permits considerable variations in the cross-sectional form, geometry, and size of the structural elements[9]. The limits on dimensions are set by practical considerations, such as the size of the production area, capacity of the manufacturing equipment, and transport. The standard for permissible deviations on glulam sizes is BS EN 390[10]. Rectangular cross-sections are usual, but other cross-sections are manufactured, e.g. H, I, T and L sections. Round, polygonal and other hollow sections are also produced. These may be solid, round (but turned from glulam), tubes or boxes. However with hollows, care in the design details is necessary to avoid water traps.

Colling[11] gives a description of the production process for glulam. Strength classes for this material are referenced by Eurocode 5 in a similar way to solid timber. The standard containing the strength classifications is BS EN 1194[12]. A recent Harmonised European Standard, BS EN 14080[13], is essential for full compliance. This states the requirements for marking and certification documentation.

As well as straight elements, curved profiles are possible. These include components such as portals with curved haunches, and tapered, curved and pitched cambered beams. Calculations for such components are made with Eurocode 5, but the designer should contact potential manufacturers early on, since they have experience of the normal span ranges, proportions and pitches.

Transport and erection, including delivering large sub-assemblies to site, are also aspects over which producers should be consulted. Because of the adaptability of the product, provided there is consultation, glulam can be supplied in non-standard shapes, including three-dimensional curves. It can also be made in nonstandard species, including a variety of hardwoods.

GLULAM SPECIES

Most standard glulam is produced from laminates of European whitewood (Picea abies and Abies alba), a timber of moderate density (510kg/m^3 at 20% moisture content). The laminations are strength graded, kiln dried, end jointed and planed, so that at the time of manufacture they do not exceed 15% moisture content. Glulam from other, more durable, softwoods, including larch and Douglas fir is also available. Standard sizes in these species are now shipped rapidly, although not treated as 'landed stocks' by UK agents - enquiries should be initiated at the preliminary design stage.

STOCK SIZES

Straight glulam elements of rectangular cross-section are normally made from 45mm or 33.3mm laminations in widths corresponding to the sawmills' standard ranges. After completion of most of the manufacturing, the side faces of the glulam are planed. Hence the finished width of the horizontally laminated glulam member (normally dimension 'b' i.e. structural breadth) is a few millimetres less than the width of the original board laminates. The exact finished size depends upon whether the side faces of the glulam are planed and sanded or only planed - in which case occasional patches of unplaned laminate are accepted. Producers' tables of sizes are available, generally indicating a full range of sections from approximately 42mm x 180mm to 215mm x 1620mm.

MAXIMUM DIMENSIONS

The maximum lateral dimension 'b', measured parallel with the plane of the glue line in the finished member, is restricted by the difficulty of obtaining softwood boards wider than 225mm. After planing, this corresponds to a width of 215mm. However elements up to 500mm wide are produced as specials by edge-gluing laminates or by gluing smaller sizes together. This should only be performed by the original glulam manufacturer.

Designs often include paired elements, especially in flexure, but also as spaced columns, for instance. This is an efficient way of achieving wider stable sections that do not require special manufacture. The availability of planing equipment in the factory limits the maximum depth (cross-sectional dimension 'h', measured at right angles to the plane of the glue line) to about 2,000mm. Larger depths are achieved by e.g. gluing on the ridge piece of a pitched cambered beam at a later stage. Up to 3,000mm deep glulam beams have been made in this way, but only the original manufacturer should do this, and he should be consulted before specification. Under no circumstances should re-gluing to increase the size of glulam be contemplated in the workshop of a general manufacturer.

Maximum length is up to 60m. However, this is likely to be restricted by transport considerations, where a limit of 24m is suggested for delivery by a tractor vehicle with telescopic semi-trailer. Greater lengths are delivered by water transport where the site permits. Guidance on transport and erection for large timber engineering components is given in *Transportation and Erection*[14].

CURVED GLULAM

Round sections and curved shapes offer many possibilities for readily made glulam 'specials'. Such products are versatile, but communication with manufacturers at an early stage is advisable. For curved glulam, it is necessary to diminish the thickness of the individual laminations. An expression in BS EN 386 Cl. 6.2.3[15] relates thickness to the desired radius of curvature and the characteristic bending strength of the finger joints in the individual laminations. Curved and/or round-sections are less likely to invoke a significant cost premium if there is replication in the design, to amortize the cost of setting up the jig over a number of components. Lightly cambered beams are a regular product - with a typical 600m radius. This does not involve reducing the lamination thickness. Very tight radii, e.g. under about 9.0m, involve significantly thinner laminations - down to 19mm is quite common. The higher cost may nevertheless be good value when components such as glulam portals are compared with alternative materials or techniques.

LVL

Laminated Veneer Lumber is a commonly available type of STC that is now referenced in Eurocode 5 as a generic material. Its new Harmonised European Standard for applications in structures is BS EN 14374[16].

LVL LAY-UPS & ARRANGEMENTS

The manufacturing lay-ups mean LVL may be used in elements subjected to edgewise bending or flat-wise bending, i.e. acting as a strip, or as a plate, or diaphragm. In the latter case, another standard, BS EN 142791[17] should be consulted. Both structural arrangements can be met with a type of LVL marketed as 'Kerto', and available as Types S and Q – all parallel veneers, or some cross veneers, respectively. Normally the former is used as beams and other flexural elements, the latter as plates.

LVL SIZES

Both Kerto S and Kerto Q are available in standard production sections of 27mm x 200mm to 69mm x 600mm. Kerto S is also produced in 75mm thicknesses up to 600mm, with Kerto Q sawn to order in widths up to 2,500mm. These LVL types are also supplied to specific order in tapers and pre-prepared portal columns and rafters. Second-stage manufacturers of timber engineering will cut large stock LVL sheets to special shapes such as curved ribs, adding proprietary tested connectors such as bonded-in threads.

FINISHES

LVL is naturally attractive, although it does not have a fine sanded finish. However, it is available sanded and decorated with a wide range of finishes and colours. The main species used in Europe is spruce, which is not particularly durable. However, in hot pressed and bonded form, untreated LVL is slightly more durable than natural spruce. For correctly detailed and built Service class 1 situations, its durability is therefore perfectly adequate. For special exposure, pressure preservative treatment can be used. Ask the manufacturer's advice.

PANEL PRODUCTS

Wood-based panels used for permanent incorporation in construction works now have to meet the requirements of the Construction Products Directive. The easiest way for a designer or specifier to comply is to specify one that carries a CE mark as required by BS EN 13986[18]. The types and grades of panel suitable for structural use are discussed in[19]. This includes fibreboards, OSB, particleboards, plywoods and solid wood panels. Correct specification is important, since there are dangers of 'passing off' and of innocent mistaken identity. Another guide[20] is available to assist here, containing examples of CE marks on acceptable structural panel products.

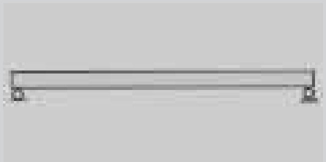
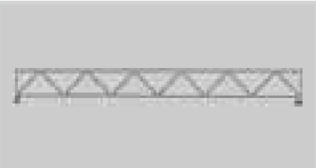
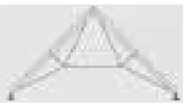
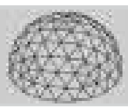
For reasons of tradition, a reputation for robustness and durability (including that of the glue lines) and of visual compatibility with other parts of the structure, designers and specialist manufacturers of wide-span timberwork tend to prefer the long-established plywood types. This indicates principally the range listed for many years in BS 5268 Part 2. For example the range of 'Finnish Birch Throughout' and 'Finnish Birch Faced' specifications and grades[21]. Both of these families of structural wood-based panels are available in a wide range of thicknesses, addressing all requirements for open framing construction, including the often-necessary structural sheathing and horizontal and vertical diaphragms. Certain Finnish plywood specifications are available to order in exceptional sheet sizes, useful for applications in large gusset connections or diaphragms, for instance. Canadian Douglas fir and Douglas fir faced plywood types of appropriate structural grades are also indicated[22].

Structural Forms

Manufacturers produce many different timber elements and components which may be readily designed and specified. Table 1 shows a selection from this range, along with suggested spans appropriate for each solution, linking them back to the case studies in this publication.

Table 2 provides a graphical illustration of the solutions suitable for different spans. A structural forms gallery is included on the following pages to illustrate these ranges more fully.

TABLE 1

Forms & materials family		Span range or height (for columns)		Examples
Basic beams Continuous beams Curved & profiled beams Cantilevered beams	S, L, G S, L, G G S, L, G	2 to 18 6 to 24 8 to 30 8 to 30		Saint-Pierre-des-Corps Sports Complex; Pyhämaa Sports Centre; Nanterre; Autzen Stadium; Pohjola Stadium.
Basic columns Spaced columns Roof trees Trussed columns	S, L, G S, L, G G L, G	3 to 5 4 to 8 6 to 12 8 to 24		Bad Dürrheim; Prien Spa.
Built-up beams & stressed skin panels Under-tied beams Triangulated girders	S, L, G L, G S, L, G	6 to 28 8 to 30 12 to 80		Darlaston Swimming Pool; Albertville Gymnasium; Priessnitzel Sports Hall; Bordeaux Velodrome.
Trusses Tied frame	S, L, G L, G	12 to 60 20 to 82		Norway Olympics – Amphitheatre of the Lights of the North.
Portals – single propped Portals – full	L, G L, G	12 to 25 12 to 40		See Structural Elements Gallery pages 39-42
Arches – full-depth glulam Arches – latticed	G L, G	24 to 98 48 to 120		Salzburg & Joensuu Arena; Erfurt Speed Skating Arena; Norway Olympics – Viking Ship; Håkon Hall.
Domes – reticulated Domes – tridesic	L, G L, G	32 to 150 80 to 180		Sydney Showground Olympic Exhibition Centre; Tacoma Dome; Odate Dome.
Three-dimensional & compound structures	L, G	Generally in higher ranges above, e.g. 40 to 120		Bordeaux Velodrome; d'Coque.
KEY: Principal materials family to consider for each type: S = Solid timber; L = Laminated Veneer Lumber (LVL); G = Glulam.				

Major components like trusses, portals and arches provide architects with close to ready-made, economical solutions. Using domes, extremely large spans are possible. For immense sports structures, where arenas of simple plan-shape are required – round, oval or apsidal-ended – there are precedents for timber dome solutions of at least 150m diameter. A new generation of 'tridesic' domes has been developed in Japan, using indigenous softwood glulam, notably Sugi, a species of cedar, to cover 200m without intermediate supports, for baseball and other sports[23].

TABLE 2

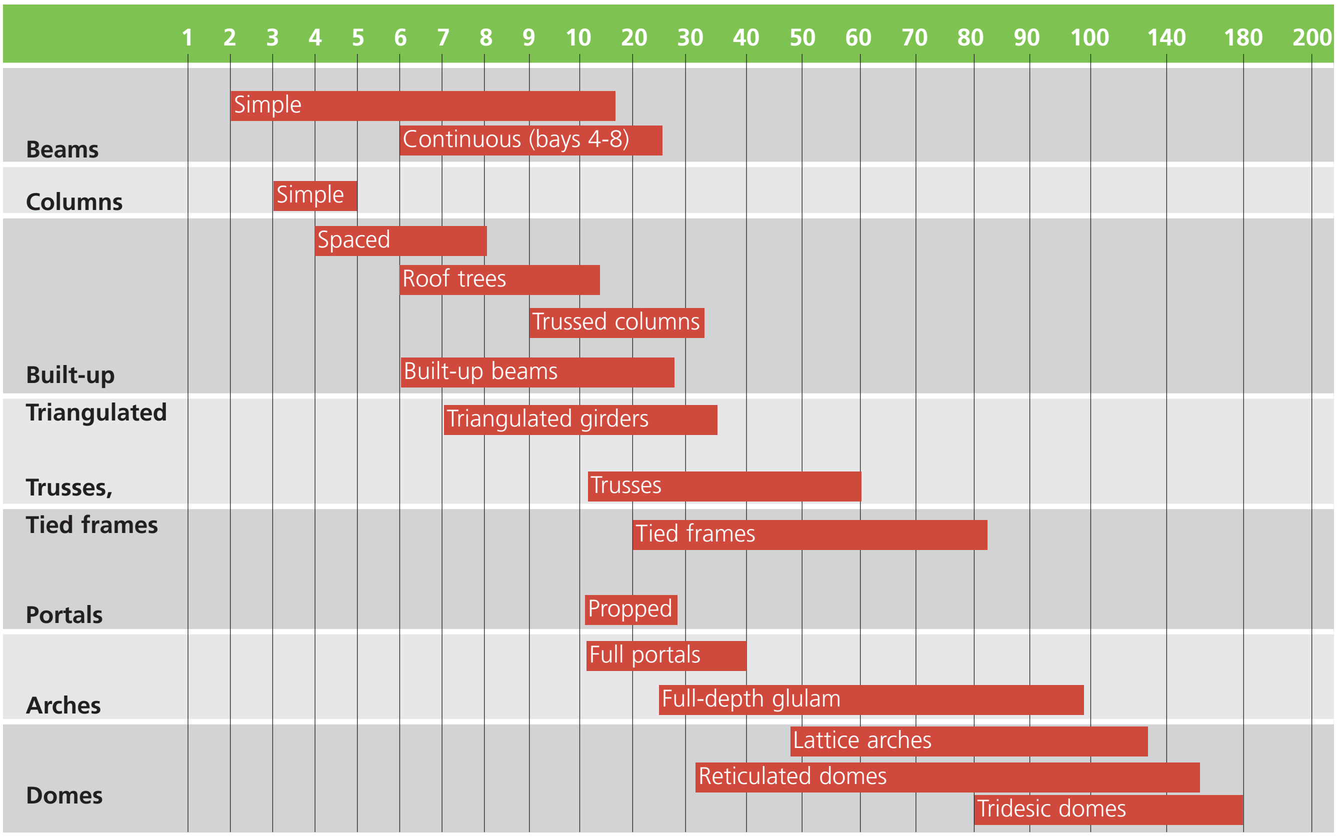


Table 3 concerns the manner in which the various forms must act. For example, the designer should consider with the team, whether the solution should be simple flexural frameworks with axially-acting chords, such as the bowstring trusses over the Norway Olympics' Amphitheatre of the Lights of the North, or shells in tension (Bad Dürrheim), or in compression (d'Coque). The classifications broadly follow those given in introducing structural concepts, but they are not definitive – and sometimes interchangeable.

TABLE 3
CONFIGURATIONS & STRUCTURAL ACTIONS

Basic flexural forms	Flexural forms with axial elements	Flexural forms adding in-plane shear rigidity	Axially-acting chord components	Axial chords, rigid nodes & arching action	Axial forms with shear rigidity
Simple flexural braced frameworks	Basic beams on posts & columns	Grillages	Basic trusses	Basic portals – repeated bay systems	Lamella vaults
Basic profiled beams	Multi-propped column & beam systems	Networks	Parallel trussed girders Tapered trussed girders Curved-chorded girders	Basic arches – repeated bay systems	Reticulated domes
Continuous beam system	Roof trees	Stressed skins & plates	Concave-chorded girders – inducing tension	Latticed arches	Tridesic domes
Pin-ended beams on encastré columns	Curved flexural elements supported on either of above	Vertical plates	Lenticular bowstring trusses	Mono-pitch (tied-back) portals	Membrane shells
Orthogonal flexural grids	Sub-tensioned beams & frames	Tension-assisted plates	Latticed grillages	Portals or arches arranged radially	Cones
	Suspended flexo-tensile elements	Folded plates	Tridesic grids	Arches as spines or 'keels'	
	Tension-assisted flexural forms			Arches crossed – vaulted forms	Gridshells

The tabulation does not address other important preliminary design, arrangement and spatial layout considerations, which are not timber-specific. These are briefly discussed in Natterer/Holzbau Atlas[24] and STEP[25]. There may well be fire safety engineering considerations also, a challenge timber is well able to meet. Introductory information can be found in *Introduction to the fire safety engineering of structures*[26], while *Behaviour of timber and wood-based materials in fire*[27] also introduces calculations for fire resistance in accordance with Eurocode 5 Part 1-2, Fire.

Structural Elements

BASIC ELEMENTS - BEAMS

A - CANTILEVERED AND BACK-TIED TAPERED BEAM

B - FOUR BAY CONTINUOUS BEAM SYSTEM

C - SIMPLE BEAMS

D - PROFILED BEAMS

BASIC ELEMENTS - COLUMNS

A - ARCADE OF BRACED COLUMNS - PAIRS OF DOUBLY TRIANGLATED BRACES

B - SIMPLE COLUMNS

C - ARCADE OF BRACED COLUMNS - SIMPLE PAIRS OF TRIANGLATED BRACES

D - TRUSSED COLUMN

TRUSSES & GIRDERS

A - SIMPLE FINK TRUSS

B - SIMPLE SIX BAY TRUSS

C - TIED FRAME TRUSS

D - UNDER TRUSSED BEAMS

PORTALS

A - HAUNCHES USING CIRCULAR PATTERNS OF LATERAL DOWELS

B - MACRO FINGER-JOINTED HAUNCHES

C - TRIANGULAR PROPPED HAUNCHES

D - CURVED GLULAM HAUNCHES

ARCHES & DOMES

A - ENSPHERE DOME

B - FREEFORM DOME WITH EDGE BEAMS

C - GEODESIC DOME

D - COMPRESSION GRIDSHELL - FREI OTTO

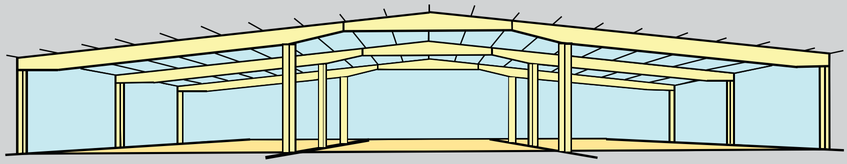
THREE-DIMENSIONAL & COMPOUND STRUCTURES

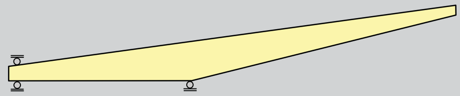
A - SUSPENDED TENSION CONE: DIAPHRAGM-STIFFENED RIBS OFF CENTRAL PILLAR

B - LAMELLA ROOF

C - GRILLAGE BEAMS

D - SUSPENDED TENSION STRUCTURE: DIAPHRAGM-STIFFENED RIBS OFF PRINCIPAL SPINE ARCH





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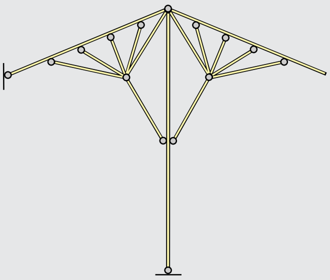

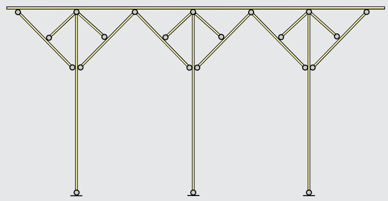

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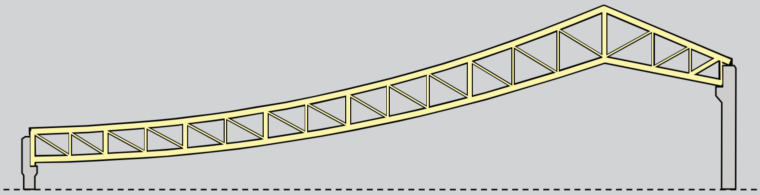

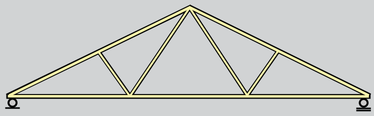

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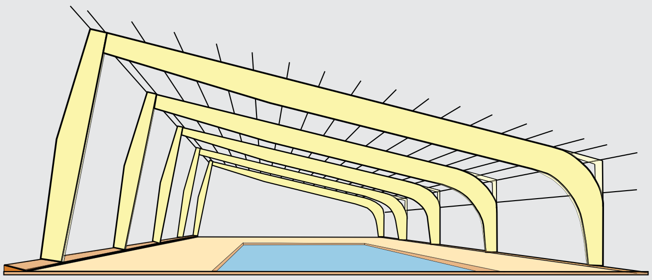

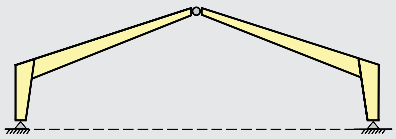

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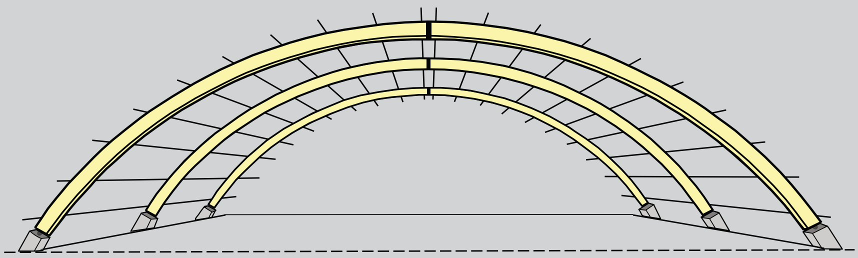

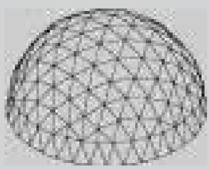

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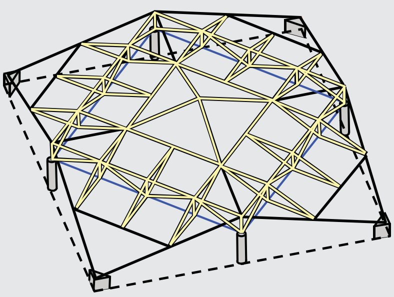

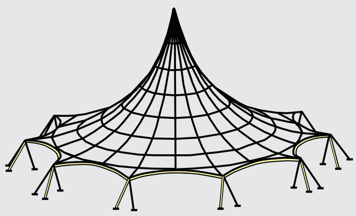

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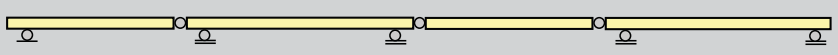

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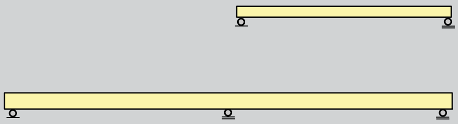

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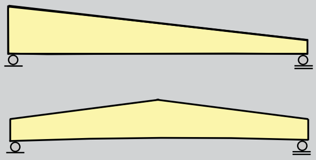

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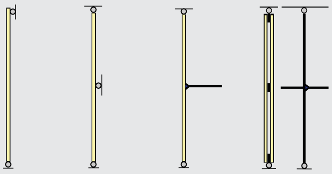

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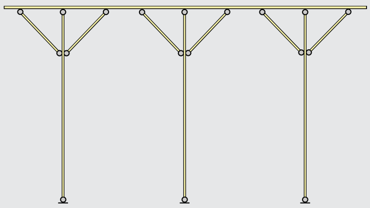

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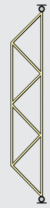

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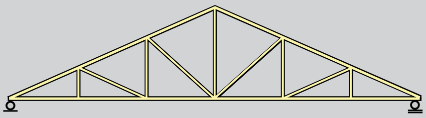

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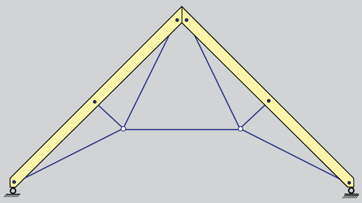

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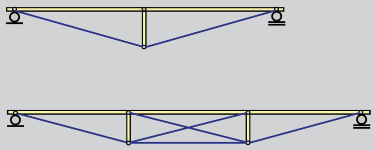

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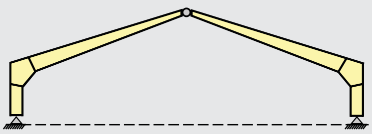

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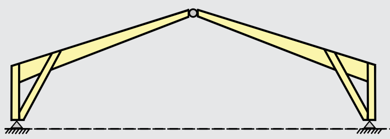

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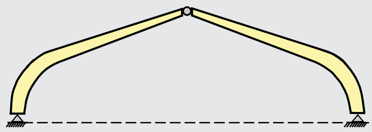

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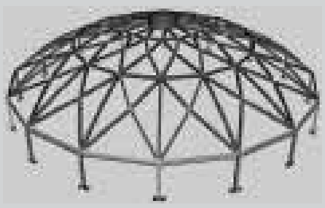

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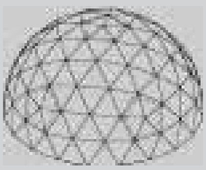

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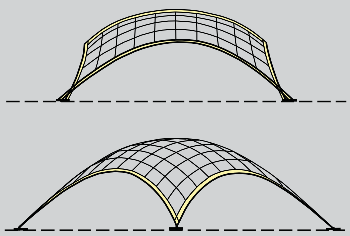

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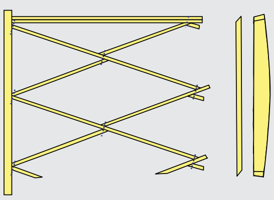

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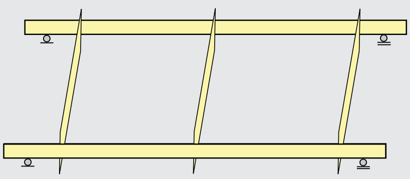

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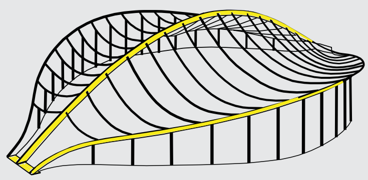

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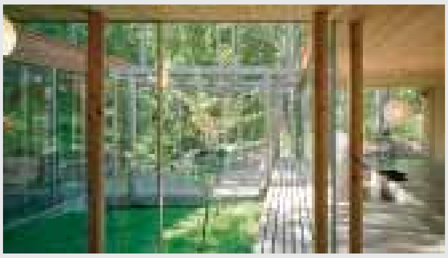













Connections

For even the simplest structures, connections are essential. Fastener types, connectors and connection arrangements are more varied when building with timber than with other framed materials, such as steel. Fabricators are less able to respond to a design proposal which just gives member sizes with the expectation that repetitive standard details be filled-in by the producer. On the other hand, well-designed timber connections complement the appearance of the elements and contribute to the expressed forms characteristic of this architecture.

According to Eurocode 5, which represents a significant advance over older national standards, connections must be 'Safe' and 'Serviceable'. Its unified design expressions rely on extensively researched and well developed theories[28]. This means that all dowel-type fasteners – nails, screws, bolts, plain dowels – have a common basis of design, thus removing a number of anomalies encountered in earlier theories associated with the tabulated connection properties found in older codes.

At first sight, the Eurocode 5 appears complex. However, software is readily available to assist in preliminary design - for example from TRADA Technology. And manufacturers offer specialist programs, often linked to computer-assisted manufacturing facilities.

Designers should consult manufacturers early on, since there are many possible solutions. Proposals can then be drawn up which relate to the exact architectural requirements and the general nature of the timber and/or wood-based materials, finishes, the distance of spectators from the building's frames etc.

The end-use of the sports structure will influence the choice of connections. For example a large, multipurpose arena such as d'Coque or Joensuu will need a different approach to a riding school or a simple portal building for games such as tennis or basketball. Swimming and other water sports facilities indicate further connection detailing considerations - protection from splashing (including water containing alkalis) and from wetting during cleaning[29].

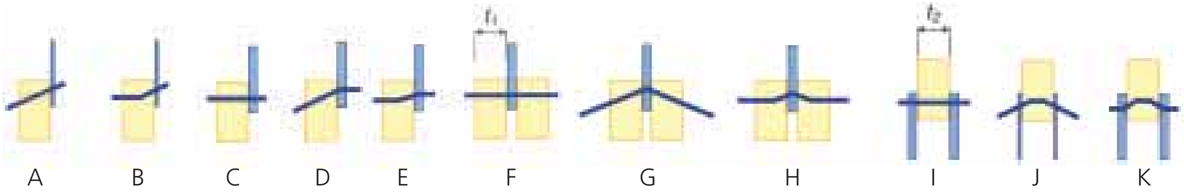
Connections for timber engineering have developed significantly and are now:

- Visually appealing, reliable and easy to assemble
- Often largely concealed - metalwork corrosion protected and hidden within the elements
- Mainly prefabricated, with designated nodes pre-planned for site assembly
- Predictable in terms of long-term performance, stiffness and serviceability
- Durable and fire resistant, where required

As well as fasteners that carry the forces through lateral shear transfer, timber engineering employs bonded-in rods and other devices that carry significant forces parallel to the fastener itself. Not all are yet fully codified in the generic sense, so the mainstream engineer may not be aware of their potential. Nevertheless extensive applied research has been conducted, covering all aspects, including cross-checking recommendations by experienced laboratories and universities across the European Standards community[30]. The available design procedures are thus compatible with Eurocode 5 and with the general basis of design given in Eurocode 0. At the same time, although still included in codes such as Eurocode 5, several of the connector devices, like split rings, shear plates and toothed plates, that were regarded as 'modern' in the 1950's, are now little used. They have fallen out of favour because the structural nodes they form are bulky. Also, both their design and their manufacture is labour intensive and incompatible with modern techniques such as CAD/CAM.

As illustrated in the Connections Picture Gallery, dowel-type fasteners are now the bread and butter of timber engineering manufacture. These are the laterally loaded types mentioned above. Also shown is a range of connections with bonded-in devices. Hence it will be seen that, with modern timber connections in open framing – i.e. the type generally considered for wide spans such as sports structures - it is expected to:

- Optimise structural efficiency, leading to materials savings and structural reliability
- Minimise design time, reducing cost
- Encourage prefabrication, reducing errors and waste
- Deliver and erect with ease



ENGINEERING DESIGN

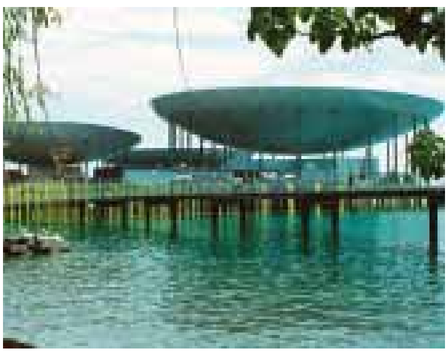
The approach to the engineering design of timber connections given in Eurocode 5 depends upon assumptions that relate to a series of potential failure modes.

EXAMPLES OF 'FAILURE MODES' THAT ARE CHECKED IN ENGINEERING DESIGN

Each sketch has a series of design expressions ('equations') that have to be checked. Parameters included are the material's family – solid timber, glulam or LVL - and the geometrical aspects, such as relative thicknesses and fastener diameter. These are assessed along with further factors such as the service class conditions – average humidity and temperature of the location in the structure - and the duration of load of the combinations. The intention of this publication is to illustrate the possibilities and advantages, rather than explain all this in detail, but from the above an architect for example will appreciate these salient features:

- There are many different types of timber engineering connection
- Arrangements present significant choices – e.g. whether the steel is on the surface as in A) to E) above, or embedded, as in F) to K)
- Connections may be timber to timber, plywood to timber to plywood, glulam to glulam to glulam, various LVL permutations etc. All of these have their diagrams and respective design expressions
- Calculations occupy significant engineering office time, therefore even with software assistance, design team choices should be clarified and agreed early in the project

At each node in a wide span building, multiple fasteners are usually required. In timber engineering generally, there also need to be further strength and stiffness modifications that depend upon the relative angles to the grain of the forces and the incoming members. These complexities reinforce the message that it is important to ensure proposals match expectations before embarking on the details.



DEMOUNTABLE AND ADAPTABLE STRUCTURES

With major sporting events, there is often concern about 'legacy', ensuring that structures are demountable and adaptable. Timber enjoys particular benefits in this respect, being easy to fix and capable of being connected with reversible devices such as screws or bonded-in threaded tubes. Some structures may need to be completely dismantled, in which case it will be a great advantage, and a much more sustainable approach, for its elements to be capable of being re-used elsewhere. An alternative is often to plan in advance for structures to be altered in size and/or shape, volume and precise purpose, after the event, so that they continue to serve community needs. A number of the Case Studies have experienced legacy alterations, including the Royal Agricultural Halls, initially built for the Sydney Olympics. Another recent example in Switzerland is illustrated below.

Swiss National Expo.02. Temporary deck at Neuchâtel, designed to re-use elements after the exhibition. Screwed laminated 60mm x 210mm softwood; 6mm x 100mm SFS screws; 27mm Kerto Q decking - 6.10m span; distributed load 5 kN/m², concentrated load 4 x 75 kN + 3 kN/m².

Connections gallery

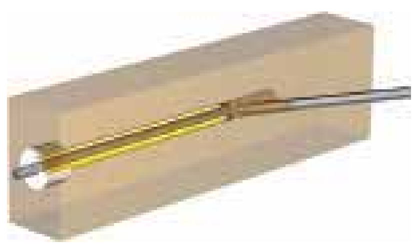

True pinned arch bases

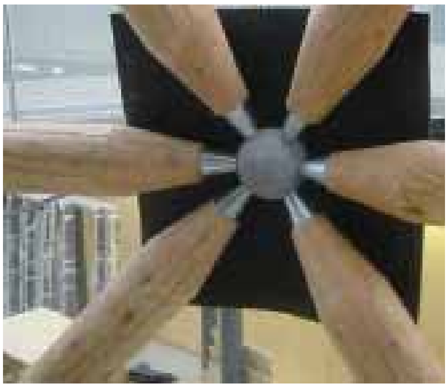

Dowel-type connections with round-surface washers

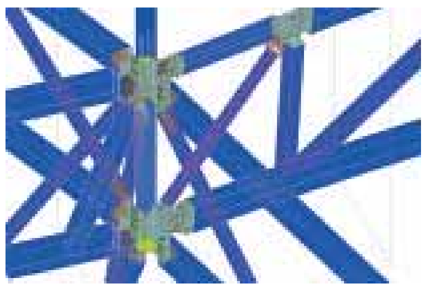

Plain dowel-type fasteners

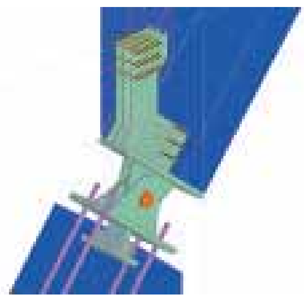

Purlin to rafter, using shoes


Bonded-in threaded tubes

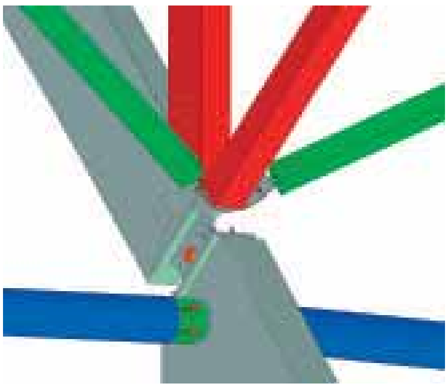

Bonded-in threaded tube


Ball node for dome


Girder junction details


True arch hinge attached with bonded-in rods and flitched-in plates


Roof tree node


True arch hinge attached with bonded-in rods and flitched-in plates


True pinned arch crown

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