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Front cover:

The 200in mirror disc and support structure as viewed from the retail level of the Innovation Center, Corning Glass Center, New York. (pp3-9)
(Photo: Scott Frances/Esto)

Back cover:

Dundee Contemporary Arts Centre (pp14-18)
(Photo: Keith Hunter)

The Corning Glass Center, New York

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Leo Argiris
Gregory Giammalvo
Ricardo Pittella

Scott Frances/Esto

Arup's New York office were structural and building services engineers for this complex, multi-phase renovation and expansion of Corning Inc's cultural centre in New York State. The project included refurbishment of the auditorium for state-of-the-art multiple usage, provision of new entrance, lobby, refreshment, and orientation areas, and the creation of several new galleries within the existing space.

Managing the HIPP programme

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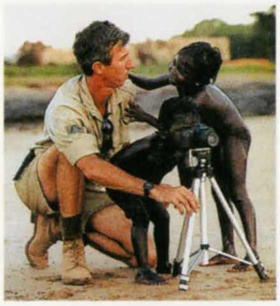
John Tsoukas



CPL Patrina Malone

In mid-1994 Australia's Aboriginal and Torres Strait Islander Commission implemented the first of a series of programmes to improve the environmental health infrastructure of indigenous Australians. Ove Arup & Partners Australia was appointed as National Program Manager for the Health Infrastructure Priority Projects programme, the firm's continuing responsibilities embracing the many technical, contractual, social, and human issues involved.

Dundee Contemporary Arts Centre, Scotland

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Charles Moodie

David Churchill

This major new facility for the city of Dundee includes two cinemas, art galleries, artists' and printmakers' facilities, public areas, and researchers' facilities for Dundee University. The full structural and building services engineering for the entire project was carried out by Ove Arup & Partners Scotland.

California College of Arts and Crafts

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Fiona Cousins
John Worley

Fiona Cousins

These new premises for the California College of Arts & Crafts in San Francisco were created from a disused Greyhound bus garage, originally designed by SOM in 1954. Engineers from Arup's San Francisco office designed the structural upgrade to make the building seismic-resistant, as well as heating and ventilating systems based upon sustainable energy sources.

The Mashantucket Pequot Museum and Research Center, Connecticut

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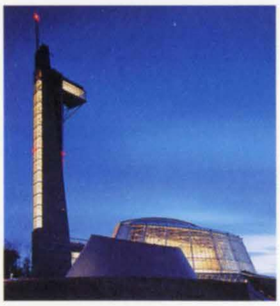
Melbourne Garber
Liam O'Hanlon
Richmond So



Jeff Goldberg/Esto

Arup's New York office were structural engineers for a new museum and research facility for the Mashantucket Pequot Nation of eastern Connecticut. The Center's varied buildings include a five-storey administrative and research wing, the large double-height Museum, and The Gathering Space, a 23m high glass hall based on the offset semi-circle form of the 1630 Pequot fort.

The Corning Glass Center, New York

Leo Argiris Gregory Giammalvo Ricardo Pittella

Background

The Corning Glass Center, in the Corning Inc HQ in Corning, New York, recently completed its most significant renovation and expansion. The complex, a cultural centre for the community and the third most visited tourist facility in New York State, began in 1951 with the opening of the visitors' centre and the Steuben factory shed designed by Harrison & Abramowitz. In 1972 Gunnar Birkerts designed the Corning Museum of Glass for a corner of the visitors' centre.

The Center attracted a peak 500 000 visitors per year in the early 1980s, but additions and changes over the years made circulation and orientation increasingly difficult. That, plus tired buildings and exhibits, reduced annual numbers to below 300 000. Realising the importance of the Glass Center, Corning - a 'Fortune 500' company noted for its innovative and revolutionary ideas - decided on major renovation and expansion. To revive, inject innovation, and tie all the existing buildings together, their ambitious program included 31 000ft^2 (2880m^2) of new exhibition and retail spaces, a high-tech auditorium, and a new front entrance. Still a patron of quality architectural design and engineering excellence, in 1994 Corning hired Smith-Miller + Hawkinson Architects, Arup's New York office as structural and building services engineer, and Ralph Appelbaum Associates as exhibit designer.

Phased design and construction

At the outset Corning decided that the \$62M project had to be phased to keep a substantial part of the Glass Center continuously open to the public. Food service and retail also needed to operate throughout construction. The original 1950s-designed and constructed Center had no air-conditioning; this was added piecemeal, and the building lacked the infrastructure to cope with a system suitable for the proposed use.

Phase 1

Completed in 1997, this involved renovating the existing 1950s auditorium, adding the West Bridge (a connector building between the existing Glass Center and Glass Museum), and creating a services infrastructure to support the expanded facility. The auditorium was transformed into a 21st century facility with 800 seats, including a new balcony and floor retractable seating at orchestra level. Corning required a high quality and flexible space that could be converted from fixed seat performance to a large banquet hall.

For musical and theatrical performance, stringent noise control and new sound, lighting, and air-conditioning systems were needed.

The two-storey 10 000ft^2 (930m^2) West Bridge doubles as the theatre lobby. It features a glass-floor bridge, a glass threaded stair, an inclined glass façade, and a 40-seat café on its ground floor. The West Bridge also served as a temporary entrance during Phase 2 construction.

Phase 2

This focused on renovating the old exhibition space. The existing visitors' centre became the Innovation Center - 11 000ft^2 (1020m^2) of space for exhibits - designed by Ralph Appelbaum Associates. The existing two-level, flat-roofed space in the heart of the complex was demolished and replaced by three mezzanines: the Windows Gallery, the Vessels Gallery, and the Optics Gallery, each at a different elevation and interconnected by a sloping ramp called the Glassway.

1 top:
Glass Center entrance from Center Way Drive.

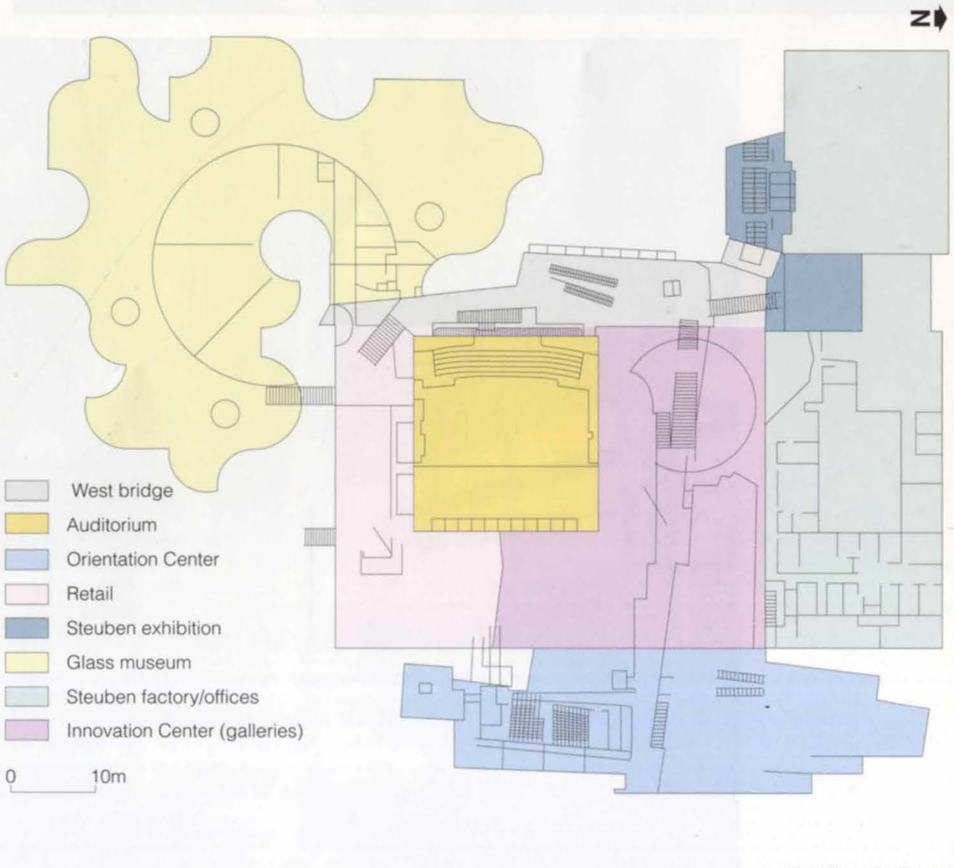
2.
Site masterplan.

Below the galleries is the complex's main retail space, and over the Center was constructed a new roof of V-shaped steel trusses with wide-plated bottom chords forming sloped planes above the galleries.

These three galleries house interactive exhibits of the evolution of glass technology. A prime feature is the 200in (5.08m) diameter disc, the world's largest single piece of cast glass, made for the Mount Palomar Telescope in 1934 by Corning. One of the original exhibits, the disc was remounted in a special structure and is now prominently displayed in the Optics Gallery.

Phase 3

Completed simultaneously with Phase 2 in June 1999, this is the new Orientation Center, a 10 000ft^2 (930m^2) new entrance to the complex, where touch-screen computer systems and the staffed tourist information desk supply visitor information. This building is a bold 'glass box' topped with a multi-faceted sloping roof, and also contains the 80-seat Orientation Theater.



The engineering challenge

Arup's main challenges related to complex geometry, structure / services co-ordination, constraints from existing conditions, phased construction, and the demanding programme.

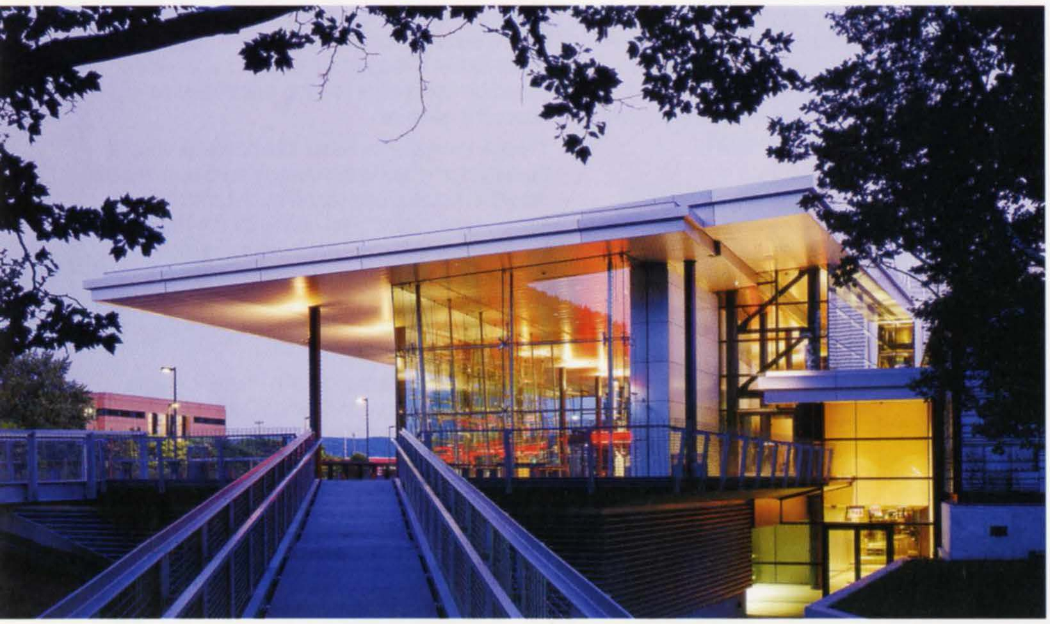
3.
The West Bridge during an evening function.

The structure: Phase 1

The existing Glass Center was a two-storey, steel-framed structure with an in situ concrete slab and concrete encasement of the structural beams. In the auditorium, the second floor framing had been eliminated and the roof was supported by a series of plate girders spanning 100ft (30.5m) and made of steel plates for the web and steel angles for the flanges, riveted together.

Phase 1's greatest structural challenges were in reconfiguring the auditorium. Several programme elements combined to complicate the process. Firstly, the decision was made to construct the mechanical rooms for the auditorium and Innovation Center over the existing auditorium framing. Secondly, there was the new balcony. Finally, to accommodate fully retractable seating, a large orchestra pit was needed in front of the stage. This required the footings supporting the existing roof girders to be underpinned.

4 below:
The Orientation Center seen at night from parking area.



Steel structure was chosen for the renovation and additions to match the existing structure, which generally was a partially moment-connected steel frame. Since much existing floor would be demolished in future phases, the frame was stiffened by adding cross-bracing in the auditorium walls. Also, the columns around the auditorium interfacing Phase 2 had to be reinforced to carry the latter's additional loads.

The new 90ft x 30ft (27.4m x 9.1m) balcony consists of a reinforced concrete slab spanning between main steel beams that cantilever from columns at the auditorium rear. For geometric and visual reasons, the balcony's structural depth had to be kept to a minimum. To control deflection and vibration, and help the long steel cantilevers carry the loads, a two-way action structure was created in which both balcony ends are supported by hangers connected to the roof girders.

Because of the hanger loads and the new topping slab on the existing auditorium roof, the 100ft (30.5m) span steel girders had to be reinforced. A detailed field survey confirmed information from existing drawings and the main girders were reinforced with top and bottom plates. As they were riveted built-up girders, welded shims were specified to avoid interference between the reinforcing plates and the existing rivets. Erection and field welding of the reinforcing plates went very successfully.

The Corning theme of glass and transparency was translated into the pedestrian glass bridge spanning between the West Bridge and the Steuben retail area, which is built of glass panel decks supported by transverse light steel plates framing to main built-up channels. Most of the steel structure of the West Bridge is exposed, except where perforated ceiling panels are used to conceal main services and distribution. Curtain wall glass panels span horizontally between vertical mullions.

5 below:
Glass curtain wall at entry level of Orientation Center.

The structure: Phases 2 and 3

The two-storey Orientation Center is an addition to the Glass Center, with a floor structure mostly of composite deck on composite steel beams, and steel columns generally spaced at 20ft (6.1m). The lateral load system is a two-storey combination of moment frames, shear walls, and steel braced frames. The structural steel and the building services are exposed under the galleries, inviting comparison with the adjacent Steuben glass factory.

The Orientation Center 'glass box' has single-glazed curtain walls supported by delicate post-tensioned stainless steel exposed trusses at the north side, and a double-glazed system at the south side. The trusses are hung off the roof cantilevers; this required tight deflection control and co-ordination between suppliers. In some areas the stainless steel trusses are outside the curtain instead of inside, adding to the project's 'unexpected' features. The roof slopes and cantilevers impressively up to over 20ft (6.1m) at the front and side of the building, supported by 12in - 16in (305mm - 406mm) tubular steel columns on a 20 x 40ft (6.1m x 12.2m) grid. The main roof girders are rolled W36s, moment-connected to the columns.

8.
Exterior of Vessels Gallery, including the video theatre nicknamed 'Egg'.

9.
Interior of Vessels Gallery 'Egg' video theatre.

6.
Orientation Theater and entrance ramp.
The theatre screen is retracted allowing participants full view of the Orientation Center entry level.

7.
Underside of cantilevered glass floor of Windows Gallery.

Since the roofs are at several different elevations, an in-plane diaphragm transfer structure was needed to maintain stability and tie the roof columns together.

To access the Orientation Theater inside, a ramp supported by roof hangers runs adjacent to the curtain wall. Protruding from the box is a 24 x 30ft (7.3 x 9.1m) mechanical room serving the café and Orientation Theater, supported by a single external tubular steel column.

The Innovation Center is surrounded by existing structures and connected to the Orientation Center. Structurally, it is similar except that it has the three mezzanine galleries. The roof is a continuation of the Phase 1 auditorium roof, and consists of truss lines spaced at 20ft (6.1m), on top of which are steel purlins. Each truss line is supported by perimeter columns at each side and by a spine truss line at the centre. The spine trusses are skewed at 7° and span 20ft (6.1m) to a new line of columns; the trusses are exposed and consist of a rolled W14 top flange, a rolled W8 post and a 24in x $^{3}/_{4}$ in (610 x 19mm) thick bottom chord. The wide bottom chord plates are an architectural feature intended to convey a ceiling effect.

The galleries were conceived as floating exhibition spaces inside the Innovation Center roof enclosure, connected by the 'Glassway' ramp.

For lightness, most slab edges are cantilevered and have architecturally exposed concrete.

A concrete cradle at its lower edge originally supported the 200in disc. Now within the Optics Gallery, the disc was moved to its new prominent steel support in the centre of a circular opening in the slab - a special challenge to the design team. At the west end of the Optics Gallery a small theatre is supported by cantilevers.

The Windows Gallery has a ragged plan shape and its different levels are continuously connected by sloping ramps. To increase the headroom beneath the gallery and minimise the visible edges, the slab was conceived as a cantilevered flat concrete slab directly connected to the steel columns without beams. The design required finite element analysis and careful determination of the elastic and long term deflections. One of the cantilever edges has a steel cantilevered glass floor attached to it, creating an exciting place to stand at the edge (Fig 7).

The Vessels Gallery is circular in plan, and constructed of steel composite slabs supported by composite steel beams that cantilever from the column grid to form the cantilevered edges. To the west a bridge connects it to the Phase 1 West Bridge. To the south, and floating above the retail space below, is an ellipsoid-shaped video room created by Ralph Appelbaum Associates, readily nicknamed 'The Egg' (Figs 8 & 9). The ellipsoid surface is formed by doubly-curved glass pieces supported by elliptically-curved longitudinal steel built-up T-sections connected to transverse tubular steel circles. The whole structure is connected to the Innovation Center roof by four steel hangers. Both glass and steel fabricators had to meet stringent tolerances. The Vessels Gallery Theater is connected to the Gallery by a hinged bridge that provides the required lateral restraint. ▶

The 200in glass mirror disc

A prime challenge was to engineer the new support for the 200in glass mirror disc, still the largest glass artifact in the world, made of 26in (660mm) thick Pyrex and weighing around 20 tonnes. The disc is part of Corning history - the first (flawed and rejected) casting attempt in 1934 for the mirror for the Mount Palomar telescope. When the Glass Center opened in 1952, the disc was mounted on a concrete cradle with only one face exposed to the public, and had sat there ever since.

Corning's main requirement was that the disc be among the exhibits in the renovated Glass Center, and have a support that gave it prominence. The second requirement, of course, was that it be not damaged during demolition and remounting. These requirements were coupled with a gallery design, elevated above the existing exhibit floor, that required it to be raised 6ft (1.83m) above its former elevation. The disc also had to be supported from the ground, as the future Optical Gallery would have a large circular opening around it, cutting off any support at that level.

Given the disc's historical importance, Corning brought in Watson & Henry Associates as expert consultant in preservationist issues affecting the disc, such as protection during construction, handling it, and environmental issues. They also acted as a project co-ordinator. Corning also brought in some of its own glass experts and scientists. Later in the process, International Chimney, the designated contractor, who specialise in moving large structures, also joined the design team. The key issues to be addressed by the team were:

- Given that the disc was already cracked and fragmented, how could cracks be prevented from developing further, and new ones avoided?
- What compliant material was to be used between the structure and the glass surface?
- How was the disc to be moved to its new support without damage?
- What design for the new supporting structure would be prominent, expose most of the disc surface, and be aesthetically acceptable?
- How could the the disc erection sequence be co-ordinated with the demolition around it and construction of the Optical Gallery?

The solutions followed several brainstorming design sessions, which took as their guiding motto 'avoid changing the existing state of stress in the glass at all costs'.

The new supporting structure was conceived before the erection sequence was fully developed. The existing disc support was a concrete curb 9in (230mm) thick on its lower 120° edge. Since the disc edge is about 26in (660mm) wide and was centered on the curb, a large portion of its edge was accessible. The idea, therefore, was to suspend the disc by 1/4in x 3in (6.4mm x 76mm) steel belt plates or 'slings' around its lower edge. Urethane, a compressible material that can be molded and is available at several degrees of hardness and strength, was chosen as the compliant material between the plates and the glass surface. In this case urethane strips were shop-attached to the sling plates. Steel I-section built-up arms connected to an I-section steel base then support the slings from above the disc equator. The steel base is connected to the top of a 2ft x 7ft (610mm x 2.13m), 16ft (4.88m) tall concrete pier. The disc structure is laterally restrained at the Optical Gallery slab. A telescope was cantilevered from the base of the steel structure at Corning's request.

A circumferential structural element was also devised to protect the edges, and contain and prevent separation of the disc's major cracked portions, mainly during the erection phase. This element, nicknamed the 'bezel', is a stainless steel T-shape placed at both disc edges with the flange parallel to the disc surface. Cast-in-place urethane was provided between the disc and the glass. Tube steel spacers outside the disc perimeter connected the bezels.

Erection sequence

Clearly the bay supporting the disc could not be demolished until the disc was remounted, so to allow demolition of the existing Glass Center to proceed and the new structures to be built, the bay supporting the disc was saved and a construction joint around it created. The bay was then enclosed and thermally isolated from the surroundings.

The disc faces were covered with cushions and plywood sheets for protection against shock. For confinement and bracing during erection, a grid of steel beams was attached to both disc faces and braced back to the main structure of the bay. This was called the 'grillage'.

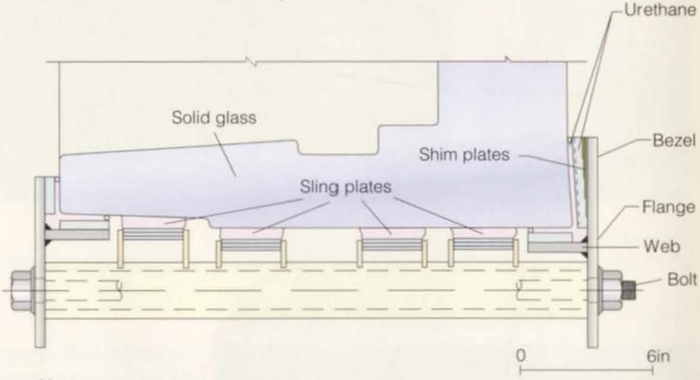
In the erection sequence, the main problem faced by the design team was how to build the concrete pier under the existing disc slab, install the new support structure on top of it, and then raise the disc to its final position. After exploring many alternatives, the adopted solution was to raise the whole structural bay by 6ft (1.83m) using hydraulic jacks. Thus the main erection steps became:

- Protect and confine the disc by installing the 'bezels' and the 'grillage'.
- Raise structural bay.
- Build concrete pier.
- Install new support structure.
- Install sling plates.
- Transfer disc load to new support structure.
- Demolish existing slab.
- Complete new slab around disc.

The load transfer was done with load cells at the top of the steel arms, one for each sling plate. This allowed the tensile force in each sling plate to be monitored at each load step and assured that all four slings were stressed in the final step.

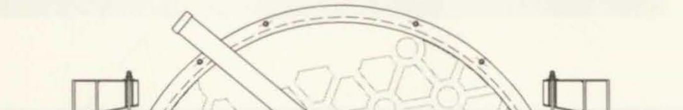
The construction documents issued by Arup and Watson & Henry Associates showed the erection sequence including detailed drawings for each step with a corresponding chart indicating description of the action, drawing reference, purpose, material comments and execution responsibility. This erection sequence was successfully followed by the contractor.

10. The 200in disc seen from the Optics Gallery.



11.
Section through rim of of 200in disc, showing support strategy.

12.
The disc still supported by the existing structure after being raised. The three vertical beams are part of the grillage. The new structure is installed below, ready for load transfer of the disc.



13. Elevation of Arup-designed mount for 200in disc.

Mechanical services

The original building was designed to be passively cooled via an evaporative cooling roof pond and a natural exhaust ventilation scheme. Within a year, however, failure of these systems to meet the occupants' needs forced the Glass Center to be upgraded to mechanical cooling through a multitude of separate renovation projects over the years. Adding mechanical services to a building designed to be passively cooled resulted in low finished ceiling heights, poor equipment placement, and a complicated maze of piping, ductwork, and conduits. Modernising the Glass Center's mechanical systems required substantial architectural modifications as well as innovative engineering solutions to place services through the building and provide a serviceable and efficient system - all while the building remained operational and open to the public.

Central plant

The existing building contained a number of small DX (Direct Expansion) or packaged air-conditioning systems serving localised spaces, while the main areas of the Glass Center were tempered using large air-handling units (AHUs) fitted with steam preheat coils, well water pre-cooling coils, and chilled water coils. The well water, supplied by a series of campus wells, provided supply water at a nearly constant 56°F (13.3°C). This water was first fed through the AHU pre-cooling coils, then used as condenser fluid to cool the three 90 tonne chillers, eliminating the need for cooling towers. Using well water like this gave overall energy savings for the Glass Center, but since several areas were served by packaged equipment, this was not the case throughout the building.

Determining the type and location of the mechanical equipment early on was important to the team, due to the architectural and economic impact the installation has on the project. The team agreed that the Glass Center would be best served by a central mechanical plant for the entire facility, eliminating the other many small self-contained systems. Due to the high energy efficiency of the existing chilled water and well water systems, the team decided to adopt these in the new scheme. However, hot water heating was used instead of the steam system in an attempt to avoid the distribution criteria associated with gravity steam systems.

The scatter of existing equipment throughout the building meant there was no existing mechanical space for any sizeable installation.

The team examined options within the building, in a shed next to it, in an underground bunker, and on the roof. The final solution drew on three of the investigated options: the large mechanical equipment was located in seven areas: a remote chiller room, one interior pump room, two interior air handling rooms, and three roof penthouses.

The chillers, chilled water pumps, well water pumps, and steam to hot water heat exchanger were put in what had been an outdoor courtyard under an overhang of the Glass Museum. The courtyard, already alongside the existing Museum mechanical room and loading dock, was enclosed with three new exterior walls, the existing Museum structure providing its fourth wall and roof. Aside from low construction cost, this location was chosen for easy access to the loading dock for servicing. The semi-remote location of the chillers also isolated a large noise source, and space was not reduced with the addition of the mechanical room.

The heating hot water pumps, electrical switchgear, sprinkler valving, and plumbing equipment were on the ground floor in a back-of-house space of the Glass Center. This area, formerly occupied by the old chillers, had a low ceiling height, making it difficult for new use. Keeping it as services space allowed the existing chillers to remain operational while the new ones were installed.

The main AHUs are in two interior mechanical rooms, and three roof penthouses. This combination and distribution of services rooms gave the required balance between optimising distribution runs, centralising equipment, and minimising impact on useable space.

Due to the limited ceiling heights from existing slab elevations, and new intermediate and double-height spaces created by the new layout, routing for distribution piping was accomplished with the aid of two services tunnels and a service corridor installed to link the interior mechanical rooms. The chiller room and back-of-house mechanical room are separated by a small outdoor space and a low-height occupied area. To maximise ceiling height, the first tunnel - 6ft (1.8m) wide by 4ft (1.2m) deep - was installed between the two spaces for the HVAC piping. The second tunnel links the back-of-house mechanical room at the south end of the building with the north mechanical room. The tunnel allowed the pipes to traverse the double-height space without compromising the exposed structural elements.

Energy issues

The design team was faced with a need to balance two opposing objectives. The first was a desire to create a building that portrayed the idea of glass - as was deserved by one of the world's largest producers of glass products. The second was having to meet the requirements of the New York State Energy Code for a building located in a region with a winter design temperature of -4°F (-20°C).

The architects expressed the idea of glass through the use of glazed stairs, glazed flooring, and extensive glass façades and clerestories. Overall, the building has large east and west-facing façades, and east and north-facing clerestories. The desire to maximise the transparency of the building entrance façade led to the use of large, clear, single-glazed glass panes.

The NY State Energy Code can be satisfied in either of two ways. First, the construction can meet the Code's prescriptive requirements. It specifies building interior and exterior design conditions, as well as the thermal and solar performance of exterior building elements, while limiting the quantity of glazing permitted on each exposure. The performance method, on the other hand, states that any building design with the same volume, area, hours of operation, and occupancy as a building which meets the prescriptive method of the Code, but uses less energy then that building, also meets the Code. The refurbished building does not meet the Code's prescriptive requirements but, by implementing various energy-saving methods, the design team was able to install glazed areas larger than those normally allowed by Code while meeting its performance requirements.

Energy-saving measures included using well water for pre-cooling in the AHUs and, as a condenser medium in the chillers, CO_2 sensors in the AHUs, occupancy sensors, high performance glazing, and air-side economisers. To reduce the building's energy load, the west façade was constructed using *Viracon* insulated low 'e' glazing, while the east façade used cantilevered roof overhangs.

The nearly constant temperature well water source is used for the pre-cooling coils in each air handler. The well water coils are designed to allow a maximum well water temperature rise of 12°F, from 56°F (13.3°C) to 68°F (20°C). The water then passes through the two 150 tonne chiller condenser bundles before being discharged into an immersion well at a maximum 80°F (26.7°C). Adapting this technique throughout both the existing building and additions required 600gpm (gallons per minute) of well water, nearly double the capacity used in limited locations of the original design. Energy calculations run using the US Department of Energy energy analysis program DOE2 show that the use of well water reduces chiller capacity by nearly 80% a year.

By also eliminating the need for cooling towers, the well water scheme provides significant energy savings over traditional plant schemes. Ventilation air, to improve indoor air quality, accounts for nearly 20% of the cooling load on the mechanical systems. The Glass Center - largely galleries, theatres, lobbies, and café - experiences significant fluctuations in occupancy levels as events, displays, exhibits, and meal crowds move throughout the building. The AHU ventilation rates are designed for the maximum numbers in each space; however, these occupancy rates may only be required for limited times during the day, or only during specific functions.

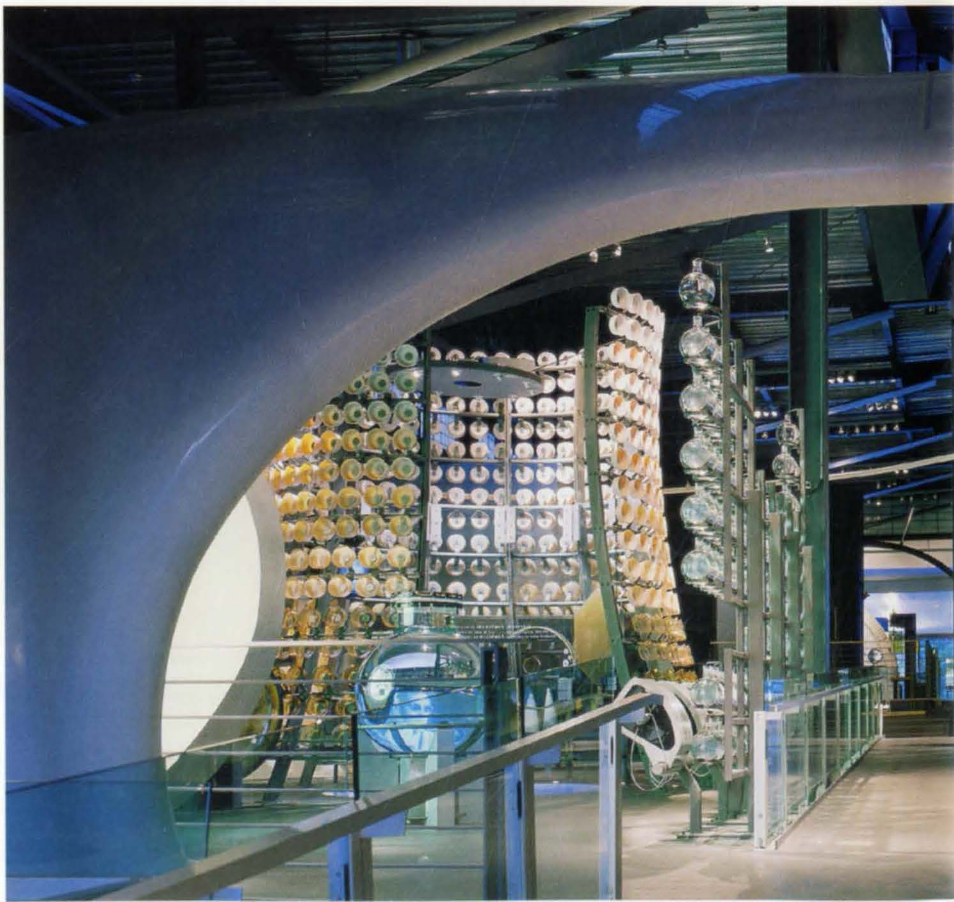
Reduction of the ventilation rates below the $15ft^3$ $(0.42m^3)$ - $20ft^3$ $(0.57m^3)$ per minute per person at design occupancy levels is done automatically by the Building Management System (BMS), which uses CO_2 sensors to compare the quality of the return air at each air handling system with the outdoor air quality. Since CO_2 levels rise with increased occupancy, comparison of the indoor and outdoor CO_2 levels permits the BMS to adjust the ventilation rates below minimum values when the occupancy level drops.

Theatre air distribution and noise criteria

Perhaps the greatest challenge for Phase 1 was the theatrical requirements. The former gymnasium-type space had to be transformed into an acoustically balanced theatre for 800, with a performance stage, NC25, and the ability to continue hosting local events like the annual gingerbread house contest or the jewellery show.

Meeting the NC25 criteria required three significant changes to the system. The first, and most obvious, was for the AHUs mounted on either side of the stage to relocate to a proper mechanical space. Secondly, the AHUs should be selected to minimise noise generation. Thirdly, the distribution ductwork should provide adequate absorption to eliminate fan noise before delivering air to the space. The AHUs were put in a mechanical penthouse on the roof of the Glass Center, but unfortunately the building geometry forced half of this to reside over the theatre proper. To help reduce mechanical noise inside, the part of the mechanical room above was used for duct distribution and coil pull, while the air handlers were located on the opposite side of the room, above the Innovation Center.

14.
Innovation Center gallery level as viewed from the West Bridge.



The theatre AHUs use large-diameter, low RPM, independently-isolated plug fans in a blow-through configuration to reduce sound levels that may be transmitted through the ductwork and into the theatre. Units are double-wall design, the inner being of perforated panels to help absorb sound.

Fan and air noise through the ductwork was eliminated by using low velocity ductwork, extended duct lengths, sound lining, and an active noise-cancellation system. Air velocities were limited to 1200ft (366m) per minute to eliminate regenerated air noise at elbows and volume dampers. Acoustical sound lining was used on all theatre ductwork to absorb air and fan noise. The idea was also to extend the duct runs before they entered the theatre to allow the greatest distance possible for the sound to be absorbed, or to break out of the duct. With the AHUs only 15ft (4.6m) from the theatre roof, an architectural solution was sought, and the team designed a 4ft (1.2m) high mechanical plenum above the existing theatre roof, adjacent to the penthouse, for ductwork distribution. This eliminated the need to distribute ductwork in the theatre, provided a means to incorporate longer duct runs, and isolated the theatre from external noise like rain. The active noise cancellation system works on the principle that sound can be eliminated by a sound equal in frequency, but with an opposite phase. The system consists of a duct-mounted speaker and two microphones, one mounted upstream and one downstream of the speaker, and a wall-mounted controller. The first microphone delivers the sound to the controller, which analyses it and instructs the speaker to produce the same sound with the opposite phase. The second microphone picks up any residual noise, or error, and allows the controller to correct itself. During sound testing the theatre, the NC rating with mechanical systems and lights fully operational was measured as between NC20 - NC25, well within the desired limits.

Fire zones

The design team's desire to improve visitor flow through the Glass Center by large, open, interconnected spaces did not accord with local building and fire codes, which restrict the size of fire zones in public buildings. However, by improving fire protection systems throughout the building beyond code requirements, a variance was obtained. Concessions included extending the sprinkler system throughout the building and upgrading it from light to ordinary hazard, providing complete smoke detection coverage, and maintaining a 24-hour fire watch patrol within the building.

Orientation Center air distribution

The Orientation Center's two-storey 'glass box' structure has a mezzanine area in the centre of the second level that connects the Orientation Theater and Innovation Center Glassway. The area north of the mezzanine on the second level is the entry lobby for the Glass Center; it has a clear height of about 24ft (7.3m) and is clad with a clear single-glazed façade.

This area was treated as transient space, making temperature variations of less concern and allowing the single-glazed façade to be used, thus increasing the transparency and lightness of the building. However, with a winter design temperature of -4°F (-20°C), heating was still a concern. Double-tier finned tube radiation was recessed into the floor along the façade perimeter, with linear diffusers also installed at high level for space heating and cooling.

This two-pronged approach maintained a clean, obstruction-free view through the façade. The south end of the Orientation Center was conditioned in much the same way, but since this area housed the café and theatre double-glazed low 'e' glass was used to maintain better control on indoor conditions.

The Innovation Center

The Vessels Gallery, Optics Gallery, and Windows Gallery are intended to look as if they are floating within the Innovation Center, disconnected from the main building.

Distribution of services to these spaces was therefore limited. The solution was to offset the façade, lighting, and ventilation load of the entire space via two main AHUs utilising duct distribution systems along the perimeter of the space, and supplement this with local fan coil units mounted on the undersides of the galleries to maintain comfort conditions in the occupied areas above.

Electrical services

The building has a new 13.2kV service from Corning's MV campus network, and a new unit substation was installed in it with a 13.2kV/480V dry type transformer. Primary distribution to mechanical loads was carried out at 480V with secondary distribution to receptacle and lighting loads at 208V. In addition a dedicated 300kVA 480V/208V K13 transformer was installed for the auditorium. The K-type transformer was used to minimise any distortions that the mechanical drives return to the main distribution system, preventing noise from filtering through to either the theatrical lighting or the sound system.

For the auditorium, three dimming systems were employed: stage lighting, concert lighting, and house lighting. All lighting is controlled from the projection booth in the auditorium. A series of branch circuit transfer switches was employed in the house dimmer system to obtain the required egress lighting levels in case of power failure.

Emergency power for the building's life safety functions comes from a 75kW/90kva natural gas generator outside the building. A second natural gas generator was installed in Phase 2 to power a set of storm drainage pumps, required because the landscape and architectural geometry required an exterior plaza area below the invert level of the storm water drainage system.

Conclusion

This very challenging project demanded close interaction between all Arup engineering disciplines, the architects, and the owner. Phase 3 was completed in April 1999, just in time for the grand opening ceremony in the new auditorium. The construction cost remained within budget and the owner is very pleased with the renovated building.

Credits

Owner:
Corning Incorporated, Corning, New York

Architects:
Smith-Miller & Hawkinson
Ralph Appelbaum & Associates (Exhibit design)
Foresight Design (Retail design)

Engineer:
Arup USA Leo Argiris, Louis Arzano, John Beckwith-Smith, Eugene Chow, Caroline Fitzgerald, Gregory Giammalvo, Charlie Gillen, Chrystalla Kartambi, Igor Kitagorsky, Sam Lee, John Miller, James Murphy, Ricardo Pittella, Ashok Raiji, Joel Ramos, Victoria Rom, Carleddy Sanon, Anatoliy Shleyger, Tom Smith, Nigel Tonks, Adam Trojanowski, Nellie Varvak, Margarita Venguelova

Lighting consultant:
Claude Engle Lighting Design

Curtainwall consultant:
R A Heintges Architects

Tension structure consultant:
TriPyramid,

Waterproofing consultant:
Associated Construction Consultants

Landscaping consultant:
Quennell Rothschild Associates

Preservation consultant (200in disc):
Watson & Henry Associates

General contractor:
Welliver McGuire (Phase 1)
Ciminelli Construction (Phases 2 and 3)
International Chimney (200in disc)

Illustrations:
2, 11: Emine Tolga
1, 3, 5-7, 14: Paul Warchol Photography
4, 8-10, 15: Scott Frances/Esto
12, 13: Arup USA

15 left:
Innovation Center gallery level
as viewed from the Orientation Center.

Managing the HIPP Programme

John Tsoukas

1.
The challenge facing the HIPP Programme: existing occupied self-made 'humpies' in indigenous Australian desert community.

Introduction

The health of indigenous Australians has long been recognised as substantially inferior to that of the mainstream population, and their need for improved environmental health infrastructure remains substantial.

Inadequate living conditions are a major contributor to disease, whilst lack of adequate water supply and waste disposal systems, housing, and other factors exacerbate their generally poorer health conditions.

In mid-1994, the Aboriginal and Torres Strait Islander Commission (ATSIC) sought proposals from industry to manage a major infrastructure and housing programme on their behalf.

This initial A$60M capital works programme - Health Infrastructure Priority Projects (HIPP) - was established in mid-1994 as a new targeted national initiative to better the environmental health of indigenous peoples.

This was a significant innovation in services delivery by ATSIC, against a backdrop of appreciable public disquiet about the effectiveness and efficiency in use of funds allocated for the betterment of indigenous Australians.

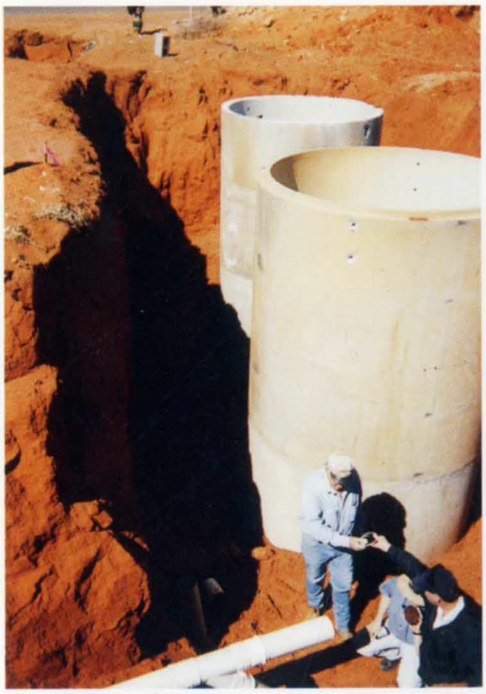
The initial A$60M funded a completely outsourced programme of consultation, planning, design, construction, inter-agency facilitation, and related social initiatives.

To achieve HIPP's objectives required both capital improvements and making developed assets more sustainable, a much broader task than simply building water supply systems or providing additional housing.

HIPP emphasised particularly strongly the physical development of infrastructure which impacted most on environmental conditions promoting improved health: water supply, sewerage/waste disposal, priority housing, power supply, (internal) community roadworks, stormwater drainage, and related community infrastructure, like landscaping for dust control.

Ove Arup & Partners Australia was commissioned In October 1994 to manage the programme which was organised country-wide from the Brisbane office.

2.
Remote desert community.



3.
Pump station construction in desert community.

Arup responsibilities

The firm's overall responsibility for running the programme included:

- evaluating and prioritising candidate communities for programme endorsement and funding
- developing individual project-by-project briefs for endorsed projects
- identifying prospective individual managers for the endorsed projects
- developing contractual agreements to regulate relationships between grantee communities (for the endorsed projects) and the respective project managers
- monitoring and administering the performance contract of project managers on behalf of grantees
- overviewing the technical appropriateness and sustainability of physical assets designed and constructed
- overall programme performance (planning, expenditure, time performance, reporting, interim evaluations)
- establishing and controlling trust accounts to make grant payments to project managers, contractors, suppliers, and community-based construction teams.

Arup was also responsible for facilitating community-based employment and training initiatives, during construction.

The third key area of responsibility was to lobby government (at all levels) throughout Australia for support to HIPP in the form of supplementary funding, ongoing assistance for operation and maintenance of built facilities, assistance with technical functions, etc. As well, the programme manager was charged with encouraging government health agencies to develop a framework for progressively evaluating health improvements achieved after HIPP projects were completed in beneficiary communities.

Finally, the project extended to planning continued support and maintenance of infrastructure provided under grants.

Arup's role as programme manager thus covered many areas, both technical and non-technical; it was a particularly challenging brief.

Programme principles

Some fundamental principles underpinned the way the HIPP programme manager was established and how it would deliver:

- targeting key identified areas of poor health with a large-scale, focused, three-year capital works programme (health issues which could not be adequately addressed under pre-existing funding arrangements)
- the need to pilot best practice techniques in project delivery and management, in an area of endeavour where delivery and management had not hitherto been outstanding
- the need to balance legitimate indigenous self-determination with effective and efficient disbursement of public money
- the need to show that accountability and probity standards could be met while simultaneously achieving community understanding and acceptance of grant funding procedures
- the need for design and construction standards in indigenous communities to be much improved, so that the cycle of early replacement of facilities due to lack of ongoing utility and sustainability could be arrested
- a faith by government that private industry, and in particular consulting engineers, could successfully deliver such a programme by the outsourcing strategy.

Projects undertaken

30 projects, in all States and the Northern Territory, with an initial endorsed value of cA$58.4M, were approved over the period February - June 1995.

These were generally in remote areas, covering many locations, scopes, communities, agendas, populations, and environmental settings.

The HIPP approach and excellence

Outsourcing

The 1996 Australian Government Productivity Commission Report 'Stocktake of progress in microeconomic reform' asked three pertinent questions:

- Do governments still need to be closely involved in all activities?
- Can these be better provided by others?
- Are there better ways of providing the services demanded of government?

ATSIC decided to outsource delivery of major infrastructure programmes for several reasons. It promised improved efficiency and effectiveness. Both ATSIC and the programme manager could concentrate on their distinctive competencies. In addition, ATSIC could access the assets and expertise of the programme manager and project managers without having to directly invest in the professional resources required. At the same time, ATSIC would have more flexibility to manage change processes, and access to the programme manager's innovative improvement processes and techniques. In turn, the programme manager would bring a sharp, commercial attitude to fund management and disbursement, and deliver greater economies of scale by having major programmes aggregated and delivered nationally.

Five years on, the programme management approach has delivered on most if not all of these objectives.

Achievements of programme management

Arup developed and used a quantitative and considered methodology for project evaluation and needs prioritisation, as well as standard project management contract frameworks to regulate relationships between grantee organisations and project managers in the delivery process. These agreements embodied emerging principles (for these works anyway) of risk management, quality assurance, real and effective consultation, and grantee community discretion in approval processes, all set in the context of clearly documented contractual outcomes.

The firm also arranged and managed workshops for key industry players early in the programme to explain in detail the new approaches. It forged closer linkages in various states and territories between agencies with a similar interest in improving indigenous living standards; and wrote and distributed regular progress reports on HIPP projects to engender support and keep numerous interested people informed.

The value of these approaches was shown when ATSIC decided early in 1996 to proceed to Stage 2 of HIPP using the processes and approach tested in the original pilot programme. Some A$80M additional federal funding was committed to 28 more community-based environmental health projects, and Arup secured around A$37M of this Stage 2 work as programme manager during 1996.

In the same year (and again in 1999) ATSIC decided to proceed to the next stage of programme management for delivery of infrastructure, using approaches pioneered in the pilot programme. About A$219M of federally-funded, state-based programmes under its National Aboriginal Strategy Environmental Health Programme (NAS-EHP), was committed to similar outsourced programme management initiatives in mid-1996. In turn, Arup secured NAS-EHP programme management commissions in the Northern Territory, Queensland, and New South Wales to a total (1999) value of over A$320M. A further measure of the viability of Arup's original approaches in the trial programme was their adoption by all other subsequently contracted programme managers.

In October 1996 the Prime Minister announced another new initiative, the ATSIC Army Community Assistance Project (AACAP). Under this, the Army became responsible as project manager and construction contractor for delivering A$10M of indigenous environmental health infrastructure to communities throughout Australia, with Arup as programme manager. The delivery model used was the same as that pioneered under HIPP, and the success of this approach resulted in an additional A$40M to AACAP recently announced by government.

Performance measures

The programme included the standard project and programme performance requirements of cash flow, commitment, and expenditure levels against forecast budgets. Procedures were established to monitor and appraise these measures, but where the programme differed from conventional project management practices was in its perceived success in three related key areas:

- level and quality of community participation in employment and training
- degree of support committed by other government and statutory agencies
- ways of assessing real improvement levels in the environmental health of beneficiaries.

Audit results

As with most major public programmes, formal review of HIPP's performance by third parties was a crucial indicator of success. ATSIC's Office of Evaluation and Audit (OEA) carried out a year-long appraisal during 1998. Their report to the Federal Minister for Aboriginal Affairs in March 1999, strongly endorsed the programme philosophy and commented favourably on Arup's performance.

Later in 1998, the federal Australian National Audit Office (ANAO) made an independent, shorter evaluation, with more intense scrutiny of the delivery arrangements and of the respective roles of the parties. Their report also was supportive and favourable.

Throughout the programme, the independent financial audits of the trust account, carried out by KPMG Peat Marwick, confirmed that accountability, probity, and transparency in funds management was of a high order. An external quality systems audit of the programme by Lloyds Register Quality Assurance (LRQA), confirmed observance to the requirements of the standard *AS ISO 9001-1994.*

4.
Community workers on housing site in the Northern Territory.

Programme manager team

The Arup team, while led from Brisbane, was also represented in the Cairns, Darwin, Perth, and Sydney offices. Members were mostly senior experienced professionals, with a smaller number of younger engineers, from backgrounds in civil, structural, water/wastewater, and mechanical/electrical engineering.

To support the team in delivering housing, architectural firms were engaged in Cairns and in Darwin. To complement the Arup team, senior support and assistance on community consultation, agency facilitation and co-ordination, and health assessment appraisals, was obtained from a Brisbane-based consultancy.

Dedicated administrative support was also integral to overall success. Lastly, a team was assembled in the Brisbane office to manage the funds transfer and disbursement processes, in the operation of the programme's trust account.

At the height of HIPP, some 20 (mainly senior) people throughout these organisations worked on the programme full time - a significant amount of consultant effort.

Team members came from a wide variety of backgrounds, and included female engineers and consultation specialists - necessary for the real input of indigenous women in grantee communities to be drawn out and reflected in project-by-project processes and outcomes. Key skills were ability to communicate; high interpersonal skill levels; sound writing ability, knowledge of design and construction processes; contractual awareness; and an ability to assess and reconcile competing ends. Enjoyment of travel and temporary living in remote areas were also important. Team members thus needed to be broad-minded, articulate, interested in the work for its longer-term rewards, and committed - and all over a comparatively long period (up to five years for some on certain projects).

A key aspect of Arup's approach to the task was therefore to identify, train, and then retain staff with these values. They attended a formal cross-cultural awareness course, run by indigenous trainers, to raise awareness of the indigenous people's culturally-based responses to the programme. The team thus attempted to mix its predominantly technical skills base with the more intangible demands of the social and cultural environment in which it was now operating. Even more than for conventional professional technical assignments, the success of HIPP was firmly rooted in the competence, independence, and enthusiasm of team individuals.

Co-operation with industry professionals

To deliver 30 projects throughout Australia, Arup called on the resources of consulting engineers, architects, and other construction industry professionals; given the remote sites of some projects, small local firms as well as national practices were engaged as project managers. Also many construction contracting and supply organisations were involved, including numerous local and regional providers, which led to more money circulating in both grantee communities and in local / regional centres. Co-operation with industry professionals was facilitated by promoting a realistic level of fees for project manager effort.

The outcome of the initiative has been better co-operation between programme manager, project manager, and grantee community. The remuneration-setting process helped change the industry mindset that low fees - and their consequence in terms of consultant effort - were the norm in this area of endeavour.

Support from government

Employment and training

Sustainable outcomes in terms of infrastructure provided on the ground were enhanced by the large amount of community training and employment generated. The Federal employment / training agency and the equivalent agencies at State / Territory level were instrumental in providing funding to facilitate these outcomes.

Several projects achieved substantial accredited training outcomes for community people, with agency support and contributory funding.

5 and 6:
Sewerage pond in central desert community. Left, during construction and below, the completed pond.

The total number of person days of indigenous employment achieved during construction was approximately 13 000 to mid-1999. Formal training achieved to the same date amounted to approximately 14 000 person days, much of it in accredited training modules. Many traineeships and some apprenticeships in the building trades were the outcome.

Other agency support

Some A$8.3M of other federal, state / territory and local government agency support was generated by Arup in conjunction with HIPP. Support came in various forms, financial and otherwise.

Health monitoring

Arup's endeavours to identify a framework for ongoing health monitoring and evaluation in grantee communities also achieved some success. State agencies in Western Australia, New South Wales, the Northern Territories, and Queensland have taken up the challenges.

Programme manager as catalyst

During the sometimes lengthy negotiations undertaken by Arup to elicit agency support, it became apparent that a key role was that of catalyst to bring together parties of disparate views. In this way, the programme manager's 'honest broker' role contributed to several joint initiatives with government, building on the programme's successes.

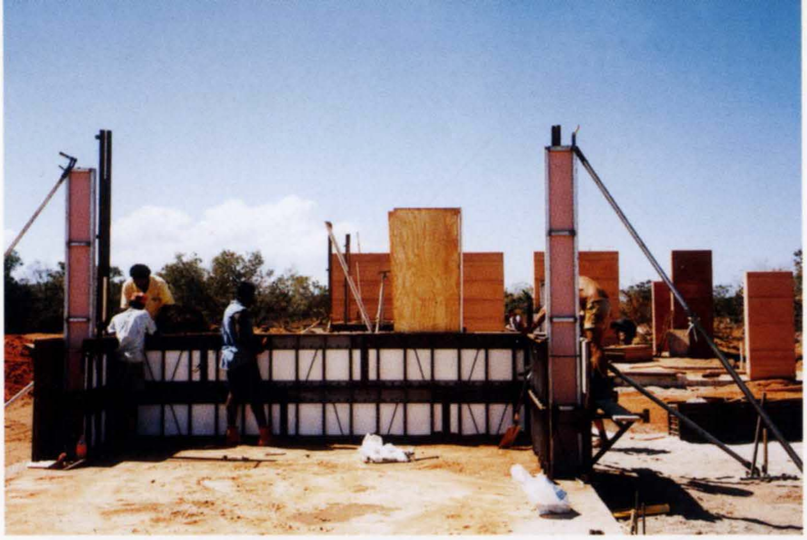
Attention to value adding

Throughout planning and delivery, Arup's approach was to strive for continuous improvement.

Many processes were developed, systematically documented, and implemented; refinements were made to processes and procedures which proved the value of this approach. Value adding occurred through:

- production of guideline notes, issue papers, workshop proceedings
- risk sharing approach in project management contracts
- use of contract documents by grantees for other projects of their own
- production and use of comprehensive checklists for key stages of the delivery processes
- development of procedures to satisfy both taxation matters and grant conditions for payment processes
- expanding final project reports to provide information for future works on the community
- post-construction appraisals
- suggestions to ATSIC on improving grant conditions for future programmes
- resolving technical standards and statutory approvals issues on environmental health in some jurisdictions.

Value adding was also demonstrated elsewhere - inter-agency co-operation, employment, training, sustainability, technical quality of constructed facilities, and lasting interpersonal relationships with many stakeholders.



7.
Rammed earth construction
by local workers from remote community.

8.
Completed housing in tropical Northern Territory.

9.
Typical new kitchen in housing for tropical Northern Territory community.

Conclusion

The infrastructure backlog to Australia's 300 000 indigenous people is estimated to be in excess of A$3bn, manifested by this community's significantly poor health. With this much need, it was impossible to satisfy all candidate communities with the initial A$60M of grants, and this differential was a compelling reason to rank needy communities to arrive at a distribution of scarce funds which would potentially make a significant impact.

Careful attention was paid to the HIPP delivery processes to strike an equitable balance between best practice techniques in project management, and legitimate rights of indigenous self-determination. Fortunately, general mainstream community aspirations tend to be positively predisposed to the sort of work undertaken:

- efficient and effective expenditure of government funds
- betterment of other people's livelihoods
- private industry assistance to government in discharging important public obligations
- the reconciliation issue.

The most fundamental help to beneficiary communities was in giving them the means to improve their physical and their lifestyle circumstances: training, employment, ongoing operational responsibilities, and greatly improved housing and infrastructure. This work demonstrates forcefully how engineers can materially assist - and across a broad spectrum of technical and non-technical endeavour. These endeavours can leave a long-term, tangible legacy of worth, which needs to be built upon.

The HIPP Programme has shown an innovative approach to achieving worthwhile community objectives, without losing sight of self-determination principles. It is a step change that has established a new way forward for the delivery of similar major publicly-funded projects by industry.

Credits

Client:
Aboriginal and Torres Strait
Islander Commission

HIPP programme manager:
Ove Arup & Partners Australia
Martin England, Richard Exley, Erica Ferrier,
Andrew Fieth, Karen Gordon,
Bill Haythornthwaite, Robert Hornsby,
Clive Humphries, Kisa Inivale, Robert Isaacs,
Alice Lim, Tanya Lochhead, Brad Pinches,
Brian Raine, Barry Retschlag, Andrea Ryan,
Sheldon Sherman, Andrew Stevens,
Paul Towers, John Tsoukas, Beth Woods

Illustrations:
The HIPP Programme

The HIPP Programme was awarded the 1999 Institution of Engineers Australia (Queensland Division) Engineering Excellence Award in the category of reports, procedures and systems, at a function in Brisbane on 3 July 1999.

Dundee Contemporary Arts Centre

Charles Moodie

Introduction

The Dundee Contemporary Arts Centre resulted from an architectural competition won by Richard Murphy Architects in 1996. The client was Dundee City Council, who are its present owners, and it is used by the City itself, the University of Dundee, and Dundee Printmakers. The major funders were the National Lottery and the European Regional Development Fund who between them provided some 75% of the funds. The balance came from the City Council, Scottish Enterprise Tayside, and the University of Dundee.

The design team of Richard Murphy Architects, Ove Arup & Partners for both structural and mechanical and electrical design, and Thomson Bethune as quantity surveyors, was appointed in July 1996. It was a funding condition that the contractor had to be appointed before the end of December 1996, so the design team had a £5.5M building to be designed, billed, tendered, and the contract awarded in five months.

To achieve this, only the building shell was fully billed and tendered, with provisional sums allowed for everything else. Tenders for the other packages were obtained progressively.

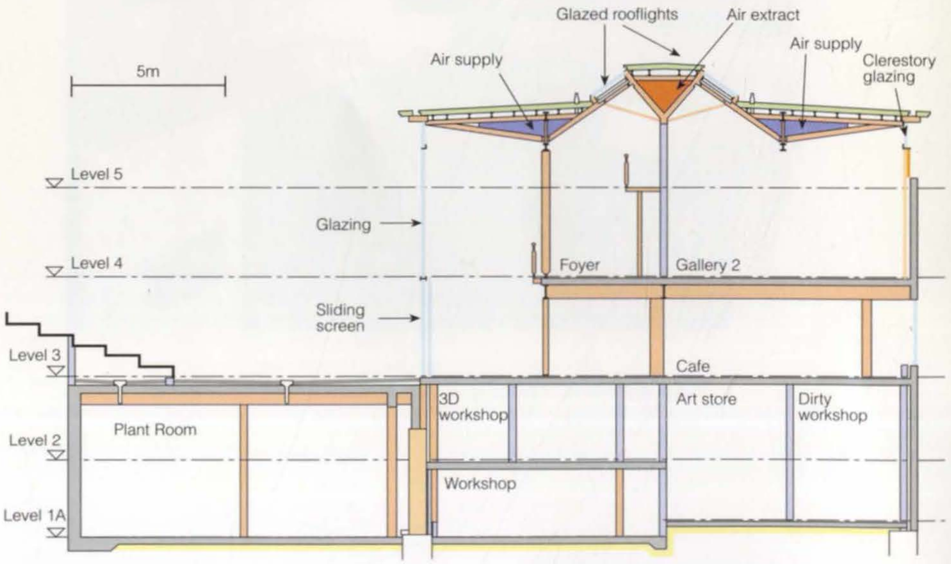
Architectural concept

The site is L-shaped in plan and falls 8m from front to back. The high end has a narrow frontage and this part was formerly occupied by a disused garage, sandwiched between the Roman Catholic Cathedral and a 19th century villa, now the Clydesdale Bank. The lower area of the site housed a three-storey, brick-clad, steel-framed warehouse. The architectural scheme required the garage to be demolished, but the warehouse was to be incorporated into the final building.

There are five floor levels in the building:

- 1: plantrooms, kitchens and University Research Centre facilities
- 2: more University Research Centre facilities, plus an artists' flat
- 3: two cinemas, café/bar, printmakers' workshop, plus external public terrace
- 4: the main entrance from the Nethergate, foyer, box office, shop, main galleries, activity room and administrative offices
- 5: more administrative offices, and a public meeting room.

1 top:
Dundee Contemporary Arts Centre
front entrance at night.



2.
Cross-section.

3.
Inside main entrance.

Using space and light underlies the architectural concept. To this end the building has many balconies, and sliding screens that can be positioned to change the volume of internal spaces. Sliding glazed doors between the 9m high café and the external terrace allow the latter to become part of the foyer and the café. The café is the hub of the building, in that each different function within is visible from it. The roof is a particularly notable feature of the design, in that it was intended to float above the walls and has continuous clerestory lighting below it. Its structure also incorporates air-conditioning plenums running the full length of the building, as well as rooflights running from the main entrance round to the galleries as a means of drawing the public through the scheme.

The site

The foundation design was done while the site was still occupied by the old garage, and was based on the results of previous borehole information and a desk study of historical maps. These showed that the site's southern boundary was the foreshore of the River Tay until the Perth-Dundee railway was built on reclaimed land in the mid-19th century. In 1972, Dundee Corporation sank boreholes on the line of a proposed sewer running north-south across the site; two lay within the site and recorded fill overlying dolerite. Another to the south of the site recorded fill overlying soft organic clayey silty sand, in turn above a layer of gravel overlying sandstone and dolerite. In 1991, five more boreholes were sunk over unoccupied areas of the site by open holing to rock. The information from all these allowed an interpolated plan of rockhead contours to be produced.

The proposed building's lowest floor level plan follows rockhead as plotted. It was decided to use piled foundations to rock for the new-build part - and, with the cathedral so close to the east, bored mini-piles instead of driven piles. The plantroom was founded directly on the rock.

Following demolition of the garage, the boundaries of the now cleared site were investigated to test assumptions made at design stage. A problem was discovered in that, whereas the cathedral building's lowest floor level corresponds with that of the plantroom, it had a small extension to the west, built on fill placed against the main part of the cathedral. The extension abutted the east boundary of the site and construction of the plantroom 6m below would completely undermine it without appropriate action.

Plantroom

An underpinning scheme was devised that would not only support the extension vertically, but serve as a temporary retaining wall so that the area of the plantroom could be excavated completely without restriction. This involved excavating pits 1.5m wide by 6m deep below the cathedral boundary wall, and constructing 1.5m wide reinforced concrete retaining wall sections in a 'hit-and-miss' sequence. Once the underpinning was complete and the plantroom area had been excavated, piling was carried out from staged platforms.

The plantroom - entirely of reinforced concrete, 6m high, and 35m x 11m in plan - is located behind the retained part of the existing building.

The plantroom rear is a 400mm thick retaining wall and its roof forms the terrace outside the café; the retaining wall is designed as a propped cantilever using the 300mm thick roof slab as the prop.
To resist the thrust from the retaining wall, 200mm thick reinforced concrete shear walls are placed at approximately 15m centres in the plantroom, perpendicular to the retaining wall, which is constructed in discrete panels 5.5m long with a water bar between each.

The plantroom is founded directly on rock.
At its west end, there is a reinforced concrete floor duct 1.6m by 2.3m deep extending into the existing building to contain the main ductwork for air-conditioning the galleries. This duct had to be cut into solid rock.

▶

4.
Entrance foyer.

Building services

Gordon Carrie Fred Robinson Alastair Bisset

Introduction

With two main art galleries, two cinemas, the café bar and recording studio, a darkroom, and the textile preparation rooms and screen printing areas, a wide range of uses had to be catered for. In addition, retaining part of the existing and original warehouse added further complications to the services design.

As the building is overlooked by others nearby, any roof-mounted equipment had to be well hidden with external louvres kept to a minimum, and in some cases substituted with a more discrete combined window and louvre detail.

Space requirements

The galleries are particularly important spaces and received characteristic attention to detail from the architects. The roof was raised above the line of the original warehouse and profiled to optimise natural daylight and facilitate services distribution.

Both the galleries are fully air-conditioned, with temperature and humidity controlled to suit international exhibitions and loans from other major galleries. The architects' vision for these gallery spaces required concealed services, so air is delivered and exhausted from the space through plenums running the full length of the galleries and formed from rigid foam panels rather than mild steel ductwork. Air diffusers are limited to single unobtrusive slots with the air flows carefully modelled during the design stage (with help from Arup Research & Development). In keeping with the minimalist visual approach, conventional smoke detection in the galleries was replaced with hidden beam detectors and located out of sight.

The brief for cinemas was for mechanical cooling, and noise levels not exceeding NR25. Space was at a premium here and ductwork was installed between the structured beams. Supply air diffusers are mounted flush with the underside of the structure. Air is extracted by way of a floor void with extract grilles under the seats.

Challenges of economy

Wherever possible, low-cost services solutions were adopted, such as natural ventilation and low pressure hot water radiators. These low cost areas offset the costs of the air-conditioned elements. Deeper plan areas and specialist processes such as textile printing, printmakers studio and dark rooms required mechanical ventilation.

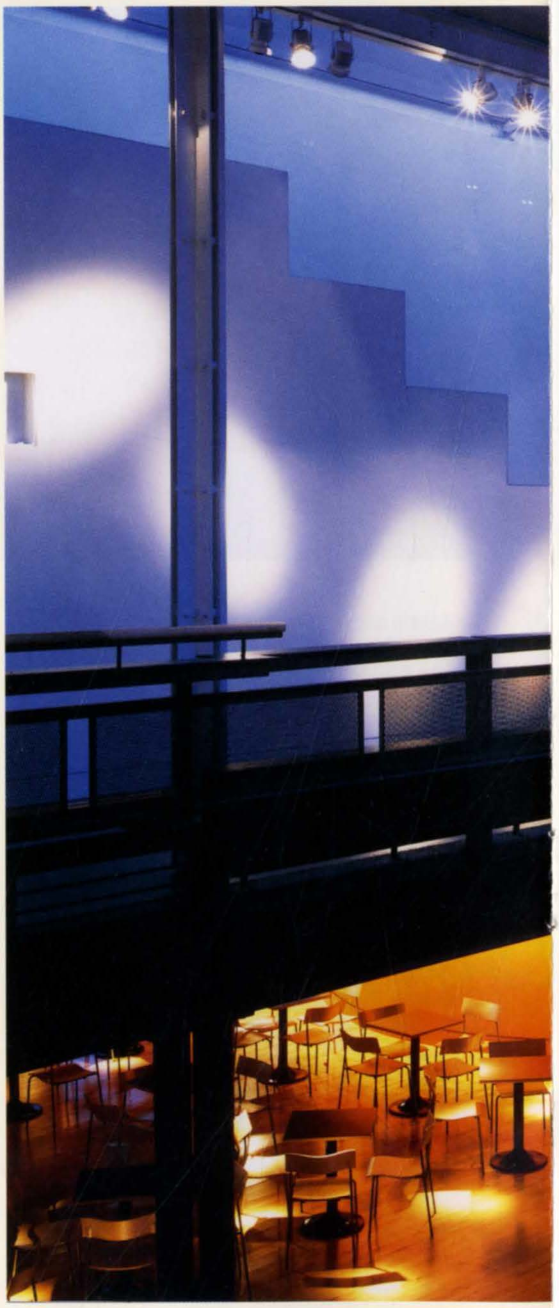
In some areas the exposed services had to be carefully co-ordinated. The café is typical, with electrical containment required to provide the necessary services routes. A visually acceptable solution was only possible with close collaboration between contractors and design team.

In the textile production area the fully-dimmable high-definition lighting was designed to achieve 1000lux. Similarly, in the textile printing and publishing areas, high-frequency dimmable fluorescent luminaires with colour 94 tubes were used to give accurate colour rendering.

The communications infrastructure was installed as a client fit-out item to an Arup specification. There is a direct IT link between a research room and the experimental studio, as well as a fibre optic link to the University and an IT network within the building.

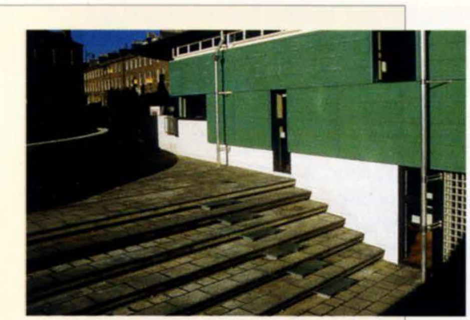
By virtue of the multiple building users the fire alarms, voice alarm and security installations have many individual zones. The security system included programmable card access and key pad entry systems so that personnel movement could be controlled.

6.
Gallery 1.



7.
Lighting establishes atmosphere to great effect.

5.
Café/bar:
The café is the hub of the building.



8.
Terrace steps. Air conditioning intake grills are incorporated in step risers.

9.
The condenser's location, behind the louvres.

Retained structure

The retained section of the existing building proved a dimensional nightmare. The front and rear walls are not parallel, and the internal column spacing is not precisely regular. The building appeared to have been extensively extended in the past, some steel sections embedded in the external walls indicating that a single-storey steel-framed building may originally have occupied the site. It seems that at a later date brickwork infilled the spaces between the steelwork. Further, a structural steel frame had been erected in the building, which was then extended to three storeys using the external walls as structural elements and brick piers built from ground floor to first floor to support the ends of the steel beams in the internal frame. The floors at first and second floor level were precast concrete planks.

The architectural scheme involved inserting a mezzanine floor between ground and original first floor level (now level 2). To get sufficient headroom, the existing ground floor had to be lowered by 0.6m. The existing steel columns did not extend below the original floor level, so they had to be extended to new foundations.

It was also found that the walls at the rear stopped just below floor level, but fortunately these walls are built on rock so underpinning was not required.

To keep the structural thickness of the mezzanine floor to a minimum, the floor structure used is precast concrete floor slabs set into the webs of structural steel beams, the latter supported mainly by blockwork walls and by a steelwork beam-and-column arrangement where there are no walls. At the upper floor levels, existing precast concrete floor units had to be removed to accommodate stairs, lifts, and large voids in the floors. It is a basic concept of the architectural design that anyone approaching a stair should be able to see where it starts and finishes, and therefore there are two-storey high openings where stairs extend over two storeys.

Another basic architectural concept was that all floor beams must have the same projection below the floor soffit and, as the transfer beams are larger than the other floor beams, the floor units were set into the webs of the transfer beams and supported on shelf angles.

As the roof was intended to 'float' above the clerestory glazing, conventional portal roof frames with large columns could not be used. Further, it was stipulated that the central rooflights would have minimal intrusion by the structure.

The roof therefore spans lengthwise along the building with as few columns as possible within the galleries; longitudinal steel trusses 1.1m deep are placed at the quarter and three-quarter points of the building cross-section.

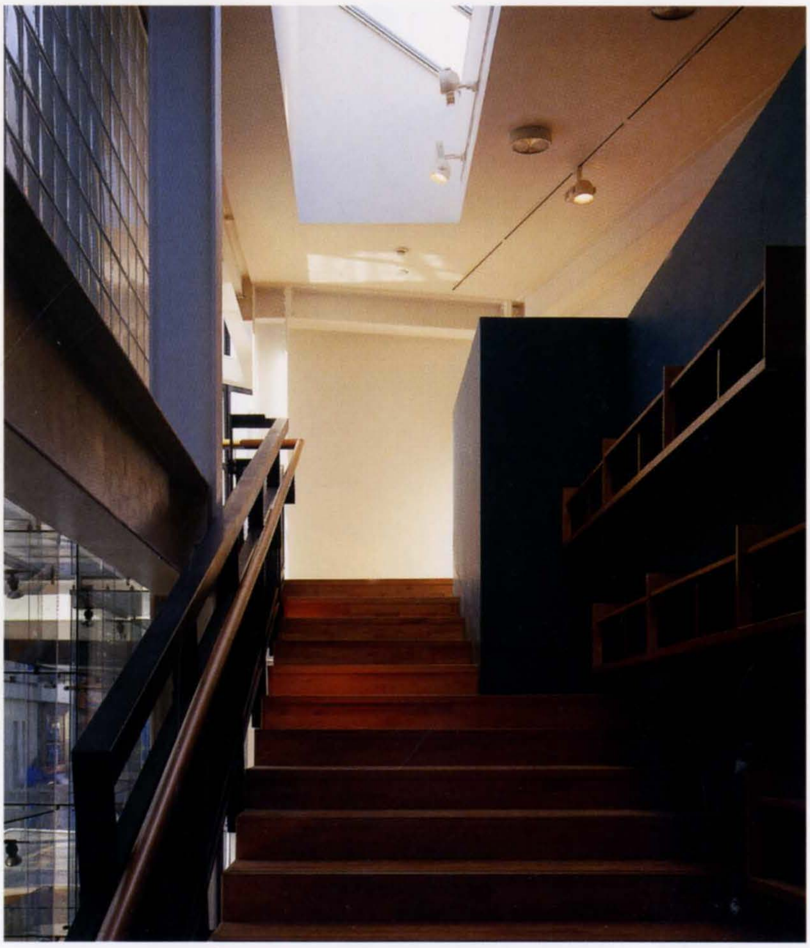
The column locations do not coincide with the original central support points, and transfer beams were installed at floor level in the galleries to take the loads to the sides and centre.

The trusses span 12m and support orthogonal triangular frames at 6m centres which are supported also by minimal columns at the front and rear walls. A central series of triangular frames at 6m centres is supported by the side frames, and in between the sets of frames are strips of rooflights.

The triangular frames are clad top and bottom to form longitudinal air-conditioning plenums. The bottom boom of the longitudinal trusses is formed of two channels back-to-back to form air outlets. Blockwork shear walls at the ends of the galleries cater for lateral wind forces. At the eaves, a projecting concealed gutter cantilevers from the roof edge using a 150mm square steel hollow section to resist torsion.

Externally, the walls of the existing building were mostly re-fenestrated, and large openings provided at the goods entrance and artists' flat. A passageway was created below the corner of the building near the Queens Hotel to enable access from south of the building to the Nethergate.

10.
View up two-storey stairwell.



On the north wall of the existing building a large, two-storey high window was created to light the printmakers' workshop and University areas at levels 1, 2, and 3. This window has a steel frame independent of another steel frame supporting the floor, the two arranged so that sliding screens can operate between them. A curved reinforced concrete retaining wall was constructed in the courtyard behind the window to create a daylight space.

During this part of the construction works, at times areas of the external brick wall were left unsupported due to removal of floors. To guard against accidental damage causing collapse of the wall, the existing roof trusses were left in position as long as possible and temporary lateral bracing was provided to the walls internally where floors were removed.

11.
Roof steelwork at valley.

The new building

The new-build section extends from the south boundary up to the Nethergate and occupies the area of the demolished section of the garage. At the lower levels, it is principally in reinforced concrete, with retaining walls at the rear of cinema 2 and at the rear of the plantroom extending to the cathedral boundary.

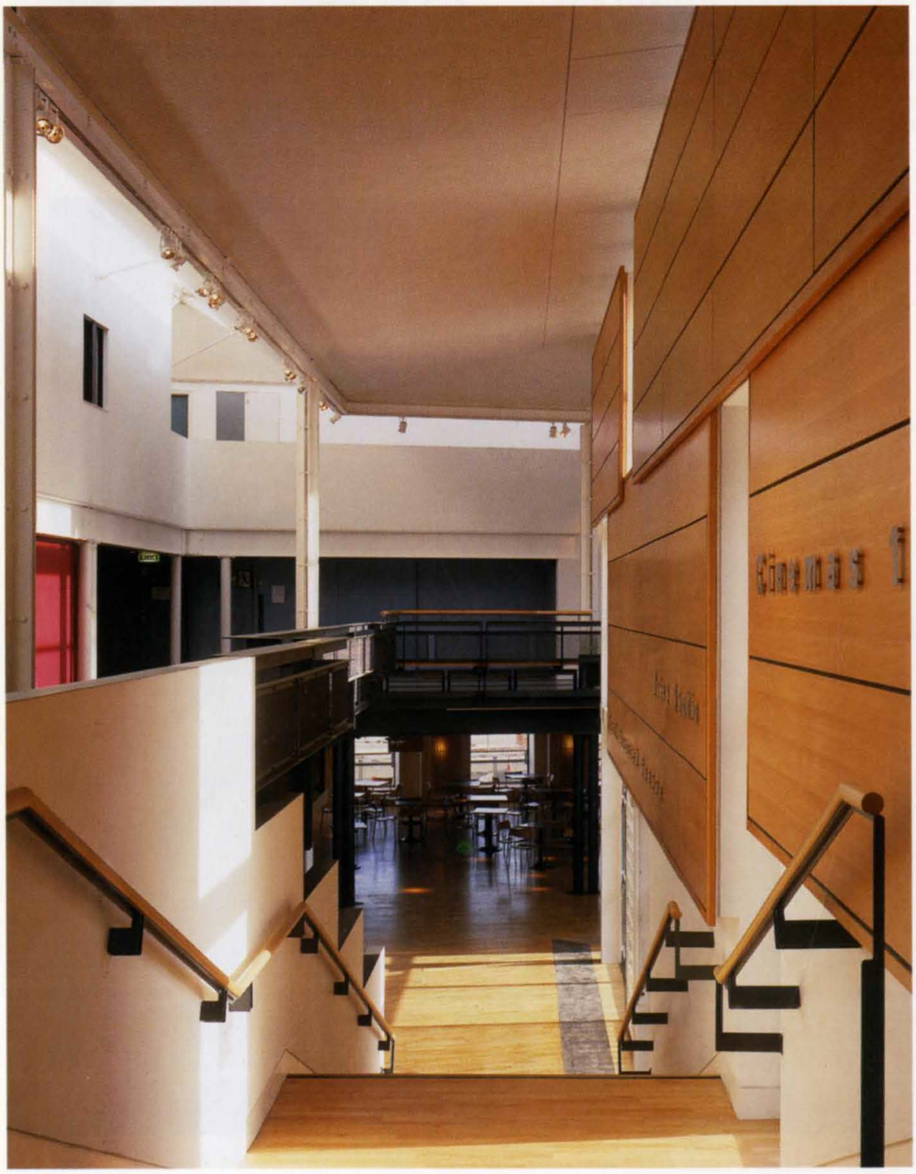
The fire escape from cinema 2 also runs underground before rising to exit at the Nethergate.

Over the two cinemas are heavily ribbed floor slabs of relatively long spans, carrying significant loads from the structure above. The ribs are spaced irregularly to suit air supply distribution ducts running between them. Below the sloping floor of the cinemas is a level floor slab, the volume between the two slabs being an air extract plenum.

Above level 4 the structure is a steel frame with precast concrete floor slabs, the roof steelwork construction over the galleries being carried around the corner of the terrace and continuing towards the Nethergate. Where it turns the corner, there are no columns on the line of the valley and the longitudinal trusses cantilever from each direction to the valley.

On the east side of this part of the building are offices with a balcony above, and the roof slopes quite steeply so as not to block light from the stained glass windows of the cathedral. Steel portal frames have been used here to provide a clear space over the office area and to give lateral wind stability to this part of the building.

12.
Stairs by cinemas to café, on level 3.



At the north end, fronting the Nethergate, is a two-storey section containing a shop. This area is curved on plan to the west and overhangs the wall below to the north. Steel portal frames have again been used here, with a reinforced concrete upper floor slab.

At the main entrance, a canopy projects past the northernmost supporting column. The canopy has no columns to the side and had to have minimal thickness along the west edge.

To achieve the desired effect, the steel structure consists of orthogonal cantilevers supporting secondary cantilevers.

Throughout the building, great attention was paid to the aesthetics of the structure where it is exposed.Columns supporting the roof are fabricated from four angles bolted together to form a cruciform cross-section. Steel beams had to seem not to pass through walls, so had plates welded to the webs to make the beams appear to terminate at the wall surface. Similarly, bases of columns terminate with either dummy base plates or a complete change of section. All downstanding steel beams had to have the same downstand and large beams are set into the slab above to achieve this. Where beams butt against each other, specially-shaped web plates are used.

Conclusion

The building was officially opened by the Rt Hon Donald Dewar, the Secretary of State for Scotland, on 19 March 1999 only a little over two and half years since the design team was appointed. Despite the many unforeseen obstacles that frequently occur when dealing with the conversion of old buildings, the final construction cost was £6M. After its first six months of operation the building has proved popular with users and visitors, and in December received the accolade of the Regeneration of Scotand Award from Scottish Enterprise and the Royal Institute of British Architects. The building is a valuable asset to the City of Dundee.

Credits

Client:
Dundee City Council

Architect:
Richard Murphy Architects

Structural, mechanical and electrical engineers:
Ove Arup & Partners Gordon Carrie, Annalisa Coutts, Alex Dekker, Steve Dickson, Allan Driscoll, Sandy Fraser, Alan Grant, Kevin Grant, Jim Hampson, Sai Ho, Peter Kearns, Steve Lindsay, Colin McCreath, John McDonald, Ian McGarrity, Alan Keith, Brian McLoney, Jaclyn McMillan, Charles Moodie, Harry Mulholland, Beth O'Donnell, Gavin Park, Scott Pritchard, Frank Reed, Mark Reed, David Robertson, Hazel Robertson, Fred Robinson, Ian Stenhouse, Willie Stevenson, Douglas Wylie, Robert Young

Quantity surveyor:
Thomson Bethune

Acousticians:
Sandy Brown Associates

Specialist lighting designers:
Jonathan Speirs & Associates

Main contractor:
Torith Ltd

Structural steel sub-contractors:
Jackson Steel Structures Ltd

Mechanical sub-contractors:
Jaydee Heating

Electrical sub-contractors:
D H Morris

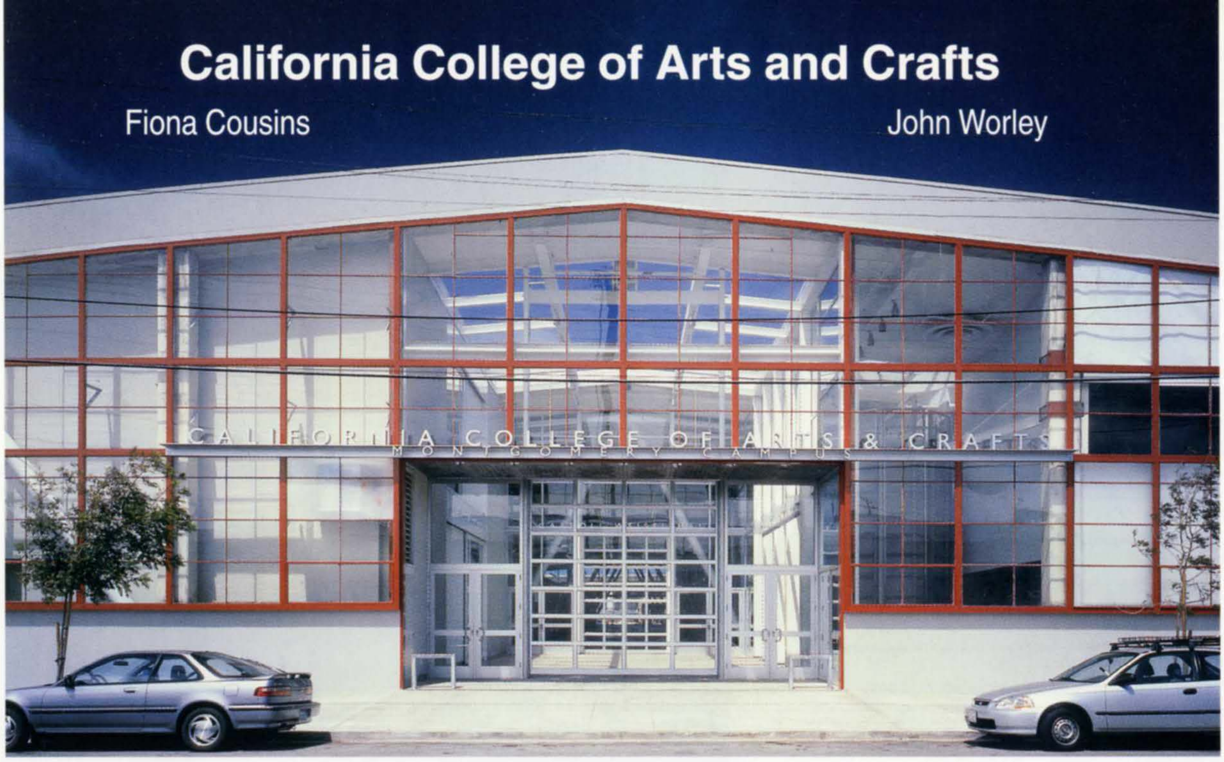
Communications sub-contractors:
Memorex Telex

Illustrations:
1, 7, 10, 12: Keith Hunter
2: Jennifer Gunn
3-6, 8, 9: David Churchill
11: Charles Moodie

California College of Arts and Crafts

Fiona Cousins

John Worley



1.
New main entrance to CCAC: the café is to the right and the Logan Galleries to the left.

Introduction

The California College of Arts & Crafts (CCAC) is a well-known and respected art college in the San Francisco Bay Area.

By the mid-1990s, it was running out of space due to the growing student body, and the existing facilities - in Oakland - also met neither the needs of a modern curriculum nor the College's own vision of what it should be achieving.

This vision, which included the unification of arts and crafts, relied in large part on the acquisition and development of a new facility in the South of Market area (SOMA) of San Francisco, an industrialised part of the city which has been evolving to house a number of multimedia and arts-related companies in former warehouse facilities. It was a logical place for CCAC to relocate to.

The College elected to purchase and transform an existing Greyhound bus maintenance garage into state-of-the-art facilities.

The building had been unused for about five years; some maintenance was required to the building envelope, but the existing structure was sound, although seismically poor. The decision to go for this building was made in part because of the flexibility the open, unencumbered structure would provide, as well as the over-riding commitment to a 'better world' solution. The building - originally designed by Skidmore, Owings & Merrill in 1954 - represented an opportunity for urban regeneration and sustainable design by retrofitting and recycling the existing structure.

Concept

The CCAC project was awarded to Arup's San Francisco office and architects Tanner Leddy Maytum Stacey of San Francisco through a design competition. The project progressed in two major phases: the seismic strengthening of the existing structure; and the build-out of the interior to accommodate the College's art programme, as well as space for a café, and several public galleries.

The College's wide range of artistic disciplines - traditional fine arts to fashion design, film and video, industrial design, architecture, and digital arts - are easily accommodated within the 150ft (45.7m) wide by 420ft (128m) long by 30ft (9.1m) tall space. The existing building was characterised by full-height glass window walls on three sides and a series of eight concrete arches that span over the space.

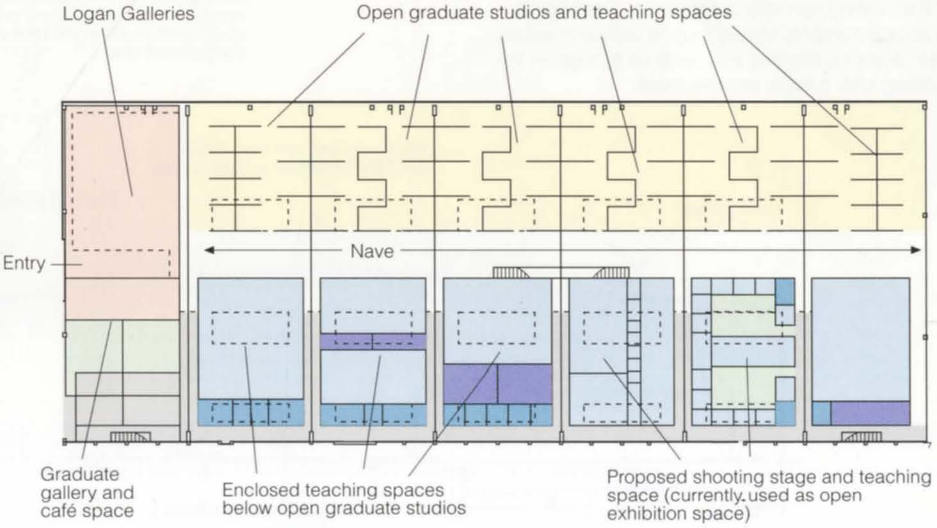
The College's programme was accommodated by splitting the building into seven equal bays, along the lines of the original roof arches, and dividing each of these bays in two with a wide corridor running down the centre of the arches.

The western bay became the entrance to the College, incorporating a café, an area of secure outdoor space, and several exhibit spaces including a fully climate-controlled gallery for public exhibitions. The southern halves of the remaining six bays are built out with one-storey structures to accommodate large classrooms on the ground floor and individual studios on the upper level. The northern halves of the bays were built out with movable lower partitions to accommodate graduate studios and to preserve the open feel of the space provided by the glazed walls and the high ceiling. The interior portion of the north half of the building was designed by faculty members Jensen & Macy.

Structural solution

The building is located in Seismic Zone 4, the most volatile of seismic locations, near the San Andreas Fault, which is capable of producing a Richter magnitude 8.5 earthquake. Exacerbating this was the fact that the original SOM-designed garage was sited on a 25ft (7.6m) layer of soft Bay mud, which in an earthquake will amplify any ground shaking and potentially cause more destruction. To withstand the lateral forces created from ground shaking, the building relied on the perimeter concrete beams, columns, and the concrete arches to act as moment frames.

These concrete elements were not provided with very much confinement reinforcement and therefore would tend to behave in a very non-ductile (brittle) manner when they reached their shear or bending capacity. Arup's analyses showed that these elements could experience earthquake forces much greater than their capacities.



2.
Plan of refurbished garage, showing principal College spaces.

Brittle failure of these critical structural elements could well have led to the building's collapse in a major seismic event, and so it had to be seismically retrofitted.

The team's goals for the seismic retrofit were as follows:

- Protect the life-safety of the occupants in the event of a major earthquake.
- Preserve the open volume of the existing garage space.
- Preserve the heroic appearance of the existing concrete arches spanning over the space.
- Create a simple and elegant earthquake-resisting system that could be viewed and understood by the occupants of the facility.
- Keep the construction cost of the retrofit to $1.1M.

To accomplish these goals, a lateral bracing system of exposed steel tubes was chosen to restrain the existing structure for horizontal seismic forces. For seismic load perpendicular to the arches, three new 30ft (9.1m) deep by 150ft (45.7m) long roof diaphragm trusses were added, horizontally spanning the width of the building. The end of each roof truss connects to a chevron brace frame at the building perimeter through a single node, clearly showing occupants how seismic loads will be resisted.

For seismic load parallel to the arches, chevron brace frames were installed that connect to the centre of each of the existing three-pinned arches. The connection between the arches and the new chevron brace frames only allows for horizontal forces to be transmitted so that the braced frames will not participate in resisting vertical forces from the arches. These brace frames are supported on steel transfer girders at grade level so as to span over the existing below-grade arch ties.

The transfer girders are supported on new steel piles that were drilled and grouted into the soil - a foundation system chosen for the following reasons:

(1) No soil from beneath the building (which is contaminated with hydrocarbons) needed to be extracted, thereby eliminating the cost of handling and disposal.

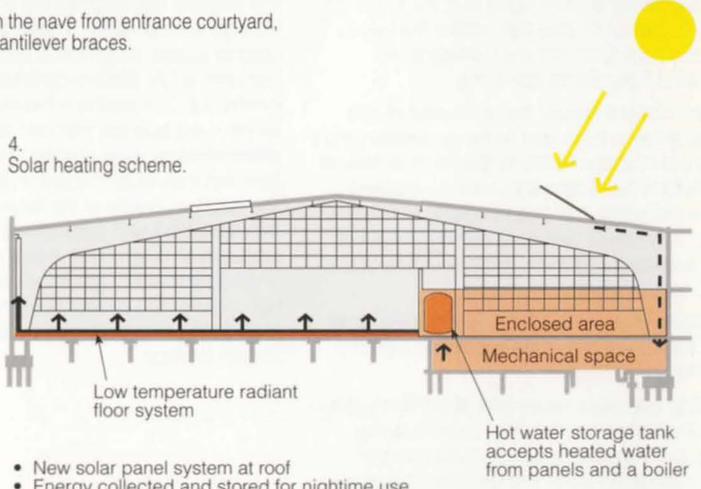
(2) It eliminated the potential damage that might have been caused by driving piles through the soft layer of soil.

(3) It could be installed within the clearances of the existing building.

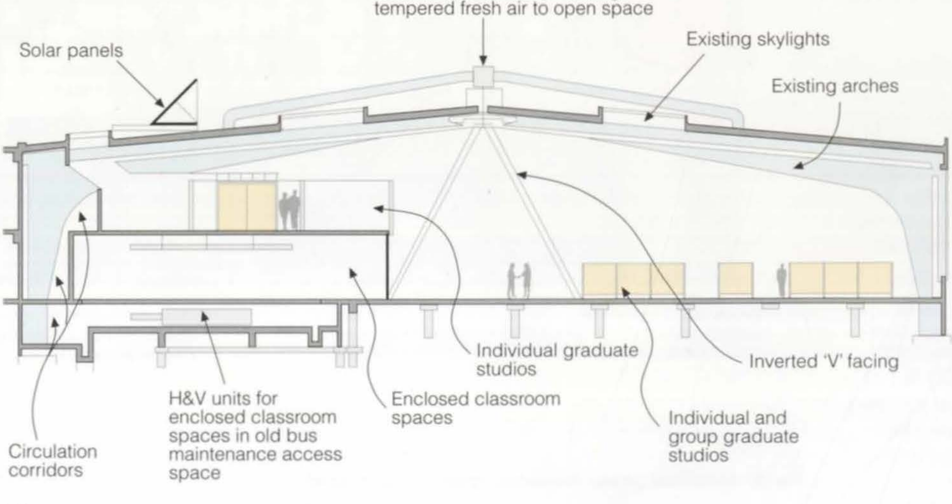
The new steel bracing system has been designed to possess the strength needed to endure a major earthquake. In addition, the system is designed to be very stiff so as to be compatible with the stiffness of the existing concrete construction. The original structural elements should thus be able to maintain their structural integrity and continue to support the building after a major seismic event.

3.
View down the nave from entrance courtyard, showing cantilever braces.

4.
Solar heating scheme.



- New solar panel system at roof
- Energy collected and stored for nightime use
- Back-up system for cloudy days. Back-up heating requirement is determined using temperature sensors at different levels in the tank and weather data from the previous day



5.
Cross-section through converted building.

6.
Solar panels and skylights on the roof.

Mechanical solution

In California, when a building is renovated, it is not permitted under current energy codes to heat or air-condition space that was not originally heated or cooled, unless the building envelope is upgraded to today's insulation standards or the energy is provided from renewable sources. During the design process it was determined that double-glazing the façade, to bring it into line with current codes, would be prohibitively expensive. Thus, the project provided an excellent opportunity to use a system based on renewable energy. This approach proved more cost-effective and could be financed by not upgrading other areas of the building. This system also fitted with CCAC's aspirations to a 'better world' solution.

Sustainable systems and materials were used wherever possible to reduce the overall environmental impact of the building. Its orientation, with most of the glass facing north, plus its location in the cool maritime climate of San Francisco, meant that it was possible to eliminate air-conditioning altogether. However, the large expanses of glass made it difficult to heat the building, especially at night when many of the students are working. Arup therefore designed an environmentally-friendly system which relies on the sun to heat hot water panels during the day. The hot water is stored in a large, insulated metal tank and is fed out to the radiant floor system during the cool hours to heat the building.

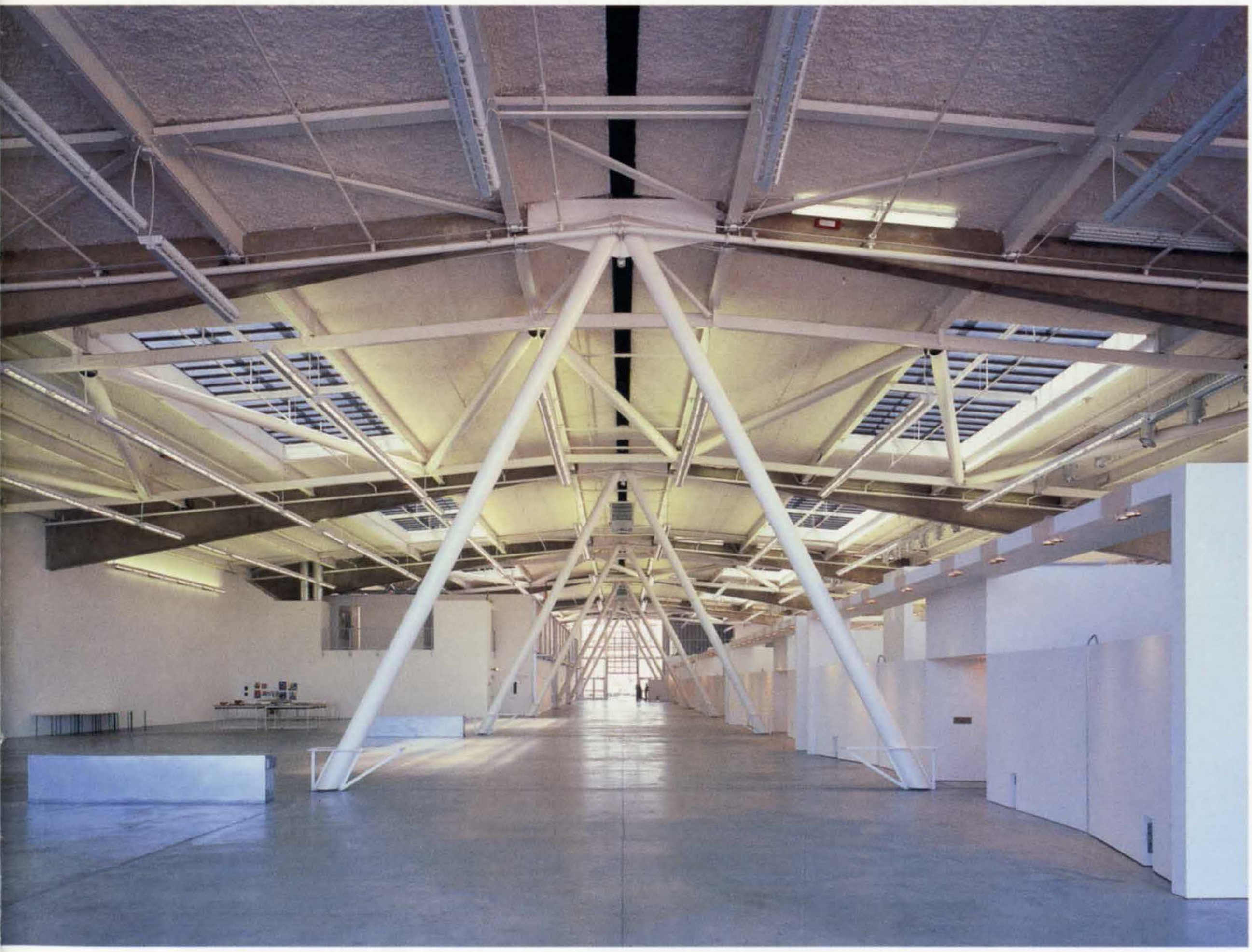
The radiant floor, which operates with water at temperatures of 80°-100°F (27°-38°C), is ideal for use with a solar system because:

- Its slow response time allows the space to stay warm during the night.
- Solar systems are most efficient at producing hot water at low temperatures

The enclosed classroom spaces are insulated, and heated and cooled, conventionally.

The solar storage tank can also receive heat from the boiler that provides heating to the classrooms when these rooms are not in use. Thus the boiler provides back-up heat at night, especially during cloudy weather.

Additional sustainable design features included the use of *Medite* panels to partition the space. *Medite* does not use formaldehydes in production. Arup also used an acoustic absorption material, sprayed onto the underside of the roof, which is derived from recycled cellulose.



7.
Interior view showing chevron braces and diaphragm trusses. Moveable partitions for graduate studios are to the right; enclosed classrooms and second floor graduate studios are to the left.

8.
General view of interior.

Conclusion

The building was completed in spring 1999 and was fully occupied by April. The graduate art students have moved into their studios on the second floor and have begun to inhabit them, introducing home comforts along with art materials and art. The 10ft (3m) high walls are always covered with works in progress, studies, and photographs. The first floor spaces consist of a mix of personal studios and teaching spaces, and are continuously occupied with students doing art work, setting up impromptu and formal exhibitions, and taking classes.

9.
Teaching area.

The open but personal studios, and colocation of architecture and art students, are beginning to assist in collaboration between students in the different disciplines.

The downstairs enclosed studios are classroom spaces: one dedicated to fashion, one to life drawing, and one to a reproduction service. The three remaining, as yet unbuilt, bays are occupied by exhibition space, but are planned to be filled with a video stage. The teaching work is complemented by the presence of the Logan Exhibit Gallery at the West end, where work by established artists is displayed to a public audience.

The building is a huge success. At the extravagant opening party, held for the fundraisers on 15 April 1999, performance art took place throughout the space. Acrobatic dancers took advantage of the expressed structure in their routine, thereby celebrating the heroic seismic solution.

The newly-completed building truly achieves CCAC's vision to interweave new programme space with the original heroic mid-century structure, to create a place where the unification of arts and crafts becomes a constructed reality. Its success was recently recognised by its receiving the California Preservation Award for Adaptive Reuse.

Credits

Client:
California College of Arts & Crafts

Architect:
Tanner Leddy Maytum Stacey

Consulting engineers:
Arup USA Peter Balint, Bianca Celestin, Fiona Cousins, Pompey Festejo, Anthony Fresquez, Michael Hoffman, Jack Howton, Jun Lautan, Alisdair McGregor, Kathleen Morelock, Mark Russin, John Worley

Illustrations:
1, 3, 7-9: Richard Barnes
2, 4: Tanner Leddy Maytum Stacey / Jennifer Gunn
5: Tanner Leddy Maytum Stacey / Emine Tolga
6: Fiona Cousins

The Mashantucket Pequot Museum and Research Center, Connecticut

Melbourne Garber   Liam O'Hanlon   Richmond So

Introduction

In 1993 Arup was contracted to provide structural engineering services for a new 308 000ft^2 (30 000m^2) museum and research facility for the Mashantucket Pequot Nation on their tribal reservation in Ledyard, eastern Connecticut. The goal was to create a major resource to study and promote American Indian heritage, scholarship, and cultural preservation, and to relate the story of the Pequots through an innovative and forward-looking design. The practice chosen to lead the design, Polshek & Partners, New York, are well-known museum architects. Incorporating the latest in archival and exhibit technology, the building developed into five distinct but interconnected structures stretched over a length of more than 800ft (240m).

Background

The Pequots have occupied a 250 square mile (65 000ha) area between the Thames and Pawcatuck Rivers in south-eastern Connecticut for many generations. The Mashantucket Pequots formed as a separate tribe following the 1637 Pequot War, which nearly annihilated them, at the Pequot fort in Mystic. In the years following the war, the Mashantucket Pequots were granted the right to return to Pequot country, and the Mashantucket Reservation was created in 1666. The ensuing years, right through to the 20th century, were marked by the migration of many tribe members and a reduction of the reservation, as sections of it were taken over by local and state authorities and sold to local settlers. The decimation of the tribe was eloquently expressed in *'Moby Dick'* when Melville's protagonist Ishmael first comments on the name of Captain Ahab's ship: '... Pequod, you will no doubt remember, was the name of a celebrated tribe of Massachusetts Indians; now extinct as the ancient Medes.'

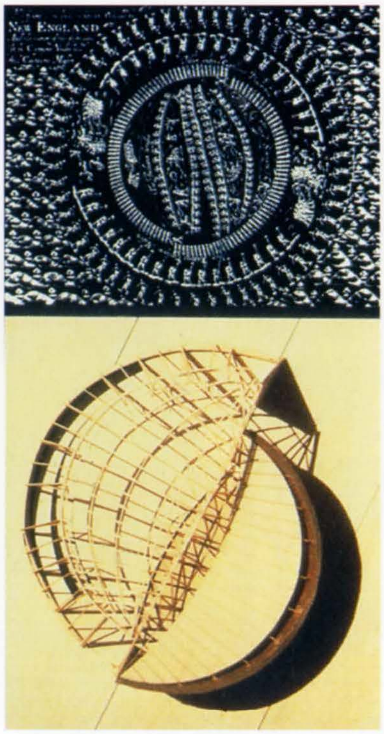
1 top:
The museum in its natural setting: l-r: Tower, Gathering Space, Museum (front), Bar Building (rear).

Though substantially reduced in number, the tribe survived intact on the reservation, and with the help of a local archaeologist and anthropologist it achieved Federal recognition in 1983. This entitled them to substantial protection against interference by local authorities, as well as significant economic subsidies. In the early years they used these to attempt small-scale economic development on the reservation, such as firewood harvesting and hydroponic farming. These ventures were marginally successful until the tribe decided to take advantage of its independent nation status to begin high stakes bingo in the late 1980s.

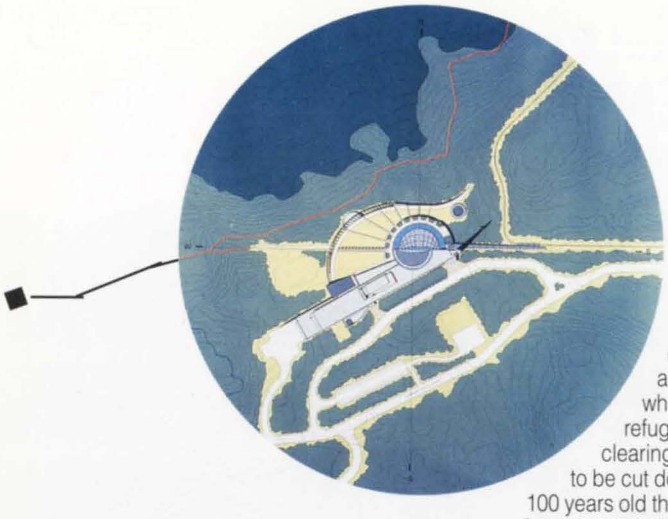
The operation was explosively successful, owing to the central location between Boston and New York - an area where more than 10% of the US population resides within convenient driving distance. The tribe is now operating the largest casino in the western hemisphere and one of the most successful gaming establishments in the country. It has provided the Pequots with a strong economic base and triggered the return to the reservation of many tribal members.

The creation and construction of the museum realises the dream and desire of a handful of tribal members 22 years ago to tell the story of the Pequots, and the building's architectural form was governed by their desire for it to merge with the natural form of the landscape (Fig 1). The building comprises five distinct elements:

- The Bar Building: a five-storey administrative and research wing containing executive offices, libraries, archives and archaeological research laboratories
- The Museum: a two-storey section with a landscaped, terraced roof and with much of the interior double height for exhibitions. It contains 'War Theaters', a performance auditorium, and exhibition space including a full-size replica of a 17th century Pequot village.
- The Gathering Space: a 75ft (23m) high glass hall; the main entry point and the building's architectural focus. Its form is based on the strategically offset semi-circles of the 1630s Pequot fort at Mystic (Fig 2).



2.
Pequot fort (above),
with model of Gathering Space (below).



3. Site plan.

- The Tower: a 210ft (64m) high observation tower serving to punctuate the architectural statement of the overall building. The Tower is semi-enclosed by stone and contains only an enclosed observation deck at the top, a stair, and an elevator.
- The Central Utility Plant (CUP): a remote one-storey building, underground on three sides. It contains chillers, boilers, generators, and other mechanical, electrical, and public health (MEP) equipment, and is connected to the main building by a tunnel (Fig 3).

4.
Counterfort retaining walls for Bar Building.

5.
Bar Building looking west from main entrance.

The site

The 10 acre (4ha) site traverses an original path leading to the remains of the Pequot fort destroyed in 1637. It is also located at the edge of the Cedar Swamp where some of the Pequots sought refuge during the Pequot War. While clearing the site required numerous trees to be cut down, a significant number over 100 years old that had historical and spiritual importance to the Pequots had to be protected. Due to the swamp's sensitive eco-system, all surface drainage and run-off for the building had to be re-routed to a filtering system before being discharged into the surrounding area around the museum. All re-routed ground water is gradually re-injected into the local sub-surface through intricate piping and drainage.

Foundations

Geotechnical recommendations indicated the need for pad footings to support the interior column loads. The initial report recommended a bearing pressure of 3 tonnes / ft^2 (290 kpa), generally to limit differential deflections and account for subsurface variations. A subsequent review by another geotechnical engineer recommended 6 tonnes / ft^2 (580 kpa) for the deeper footings in the Bar Building. This allowed many of the footings to reduce in size. The building form necessitated one and two-storey retaining walls on the south, east, and west sides. On the north side an architecturally exposed concrete wall was required to enclose the building.

The Bar Building required retaining walls on the south side varying from 18ft (5.5m) to 38ft (11.5m) high, while the walls to the east, west, and part of the north were 18ft (5.5m) high. Given the extent of basement walls required in the Bar Building and to minimise the wall thickness and an anticipated construction sequence, a counterfort wall arrangement was adopted for the south wall (Fig 4). Cantilever retaining walls were designed for the other walls in the Bar Building.

On the east and west sides of the Museum, 20ft (6m) high cantilever retaining walls were required; on the east side a 2-D model of the wall was analysed to investigate the behaviour of its semi-circular form, this resulted in a reduced thickness of the wall, taking advantage of its arch form. The architectural concrete walls forming the northern enclosure of the Museum were also designed as cantilevered walls, supporting the large loads of the Terrace roof above. The semi-circular wall that housed the fort of the Pequot village is 32ft (9.75m) high and the sinusoidal wall varied in height from 5ft - 38ft (1.5m - 11.5m).

The foundations for the Gathering Space and auditorium building required both pad footings and a combination of retaining walls. 'Reverse' counterfort walls were used for the semi-circular wall on the south side. At the south-east end of the building, due to site constraints and the requirement for the buttress foundations, a hybrid cantilever / 'reverse' counterfort wall was devised for the 40ft (12.2m) high wall. The buttress foundation consisted of two huge concrete cubes with approximately 12ft (3.7m) sides.

The Tower foundation is basically a 40ft x 40ft (12.2m x 12.2m) x 4ft (1.2m) thick reinforced pad footing, sized and designed to ensure that the eccentric loads of the Tower, due to lateral forces, always fell within the middle third of the footing. The schematic design for the Tower foundation included the use of rock anchors but these were eliminated during the detailed design.

The CUP Building is a wholly submerged building with ramped access from the south side. The walls were designed as cantilever retaining walls and the roof structure is designed to accommodate up to 6ft (1.8m) locally for landscaping and planting. The north wall was designed with a penetration for the tunnel link between the CUP Building and the main building for services.

Superstructure analysis and design

The size and configuration of the building and new seismic design requirements in the Connecticut State Building Code required the main building superstructure to be divided into the same four separate and independent sections. Expansion joints at pre-determined locations separate the 'independent' buildings although, due to its configuration, part of the Museum structure is tied to the Gathering Space structure.

Bar Building

This is a simple steel-framed building (Fig 5), tied to the retaining walls for the two lower floors and a standard beam / column construction above the third floor. Moment frames in both the east-west and north-south directions provide lateral stability. A full 3-D model was developed and analysed for lateral loads, including torsional seismic forces, and resulted in a maximum expansion joint of 8in (203mm).

Museum

The western half of the Museum is a two-storey structure with two two-storey high 60ft (18.3m) circular concrete walls forming the War Theaters and a single-storey wall on the west side. Steel framing on top and between these structures support the roof and floor structures. The west sidewall and the two-storey high concrete walls of the War Theaters resist the lateral forces for this building. The lateral load-resisting system was complicated by the stepped nature of the Museum roof slab, so seismic loads were carefully analysed in a 3-D model that included the round concrete structures required to provide stability. It was found that the asymmetrical but substantive circular forms of the War Theaters efficiently resisted the high roof loads comprised of assembly, soil, and snow loads.

Gathering Space

The geometry of the Gathering Space was developed by combining simple conical and cylindrical shapes, truncating them by angles off the horizontal, and then offsetting the two halves of the resulting circular base. The result is a 192ft (58.5m) centre-span three-dimensional truss stabilised by the roof beams it supports.

A combination of moment frames and braced frames for the southern half of the space, and moment frames and the concrete walls of the Museum to the north and east provided the stability for the Gathering Space glass structure. A full 3-D model was developed to analyse it because of its extremely complicated arrangement.

Because of the size and unique shape of the Gathering Space, a wind tunnel study was arranged, and the results used in the structural analysis to reduce the assumed loads derived from the Code (Fig 6). Qualitative studies of snow deposition were used to supplement minimal loads calculated according to the Code. This was particularly helpful in identifying additional areas subject to snow-drift. To achieve the architectural expression of exposed steel in the Gathering Space, Arup Fire was retained to conduct a fire study for submission to Code officials. The results indicated that the required two-hour rating was achieved, given the nature of the building and any conceivable fire loads. The results were accepted, thus eliminating the steelwork fireproofing and saving the client $750 000.

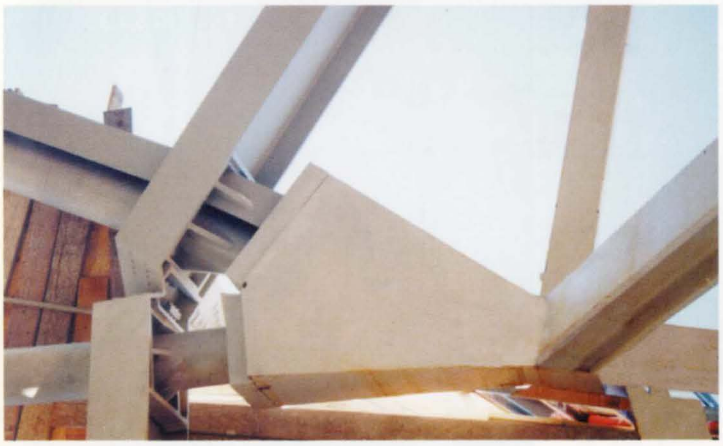
Design of the architecturally exposed roof connections was particularly challenging, due to the complex geometry and large forces from rigidly connected framing members. Combinations of bolted and welded connections were used to achieve a compromise between the architectural and constructability requirements. Heavy full penetration welds up to 2in (50mm) thick were generally limited to the fabricator's shop with fillet welds used on site.

To provide the Gathering Space's long clear spans, as well as lateral stability for the glass roof through diaphragm action, the roof-framing members typically carried both axial forces as well as bending moments in both principal axes with stress reversal.

At the end of the bifurcated arch, there were as many as nine members converging from different angles in one rigidly connected joint (Fig 7). Member sizes at these joints ranged from 18in (450mm) tubes, to 36in (900mm) deep wide flange beams, to 14in (350mm) deep wide flange beams with 2in thick (50mm) flanges. Axial forces in these members ranged from 100 - 600 kips (450 - 2700 kN) with bending moments varying between 100 - 500 kip-ft (135 - 675 kNm).

The amount of weld metal used for each of these 'bell' connections was estimated by the steel fabricator to be over 1000lb (450kg).

7 below:
'Bell' connection at top of Gathering Space.



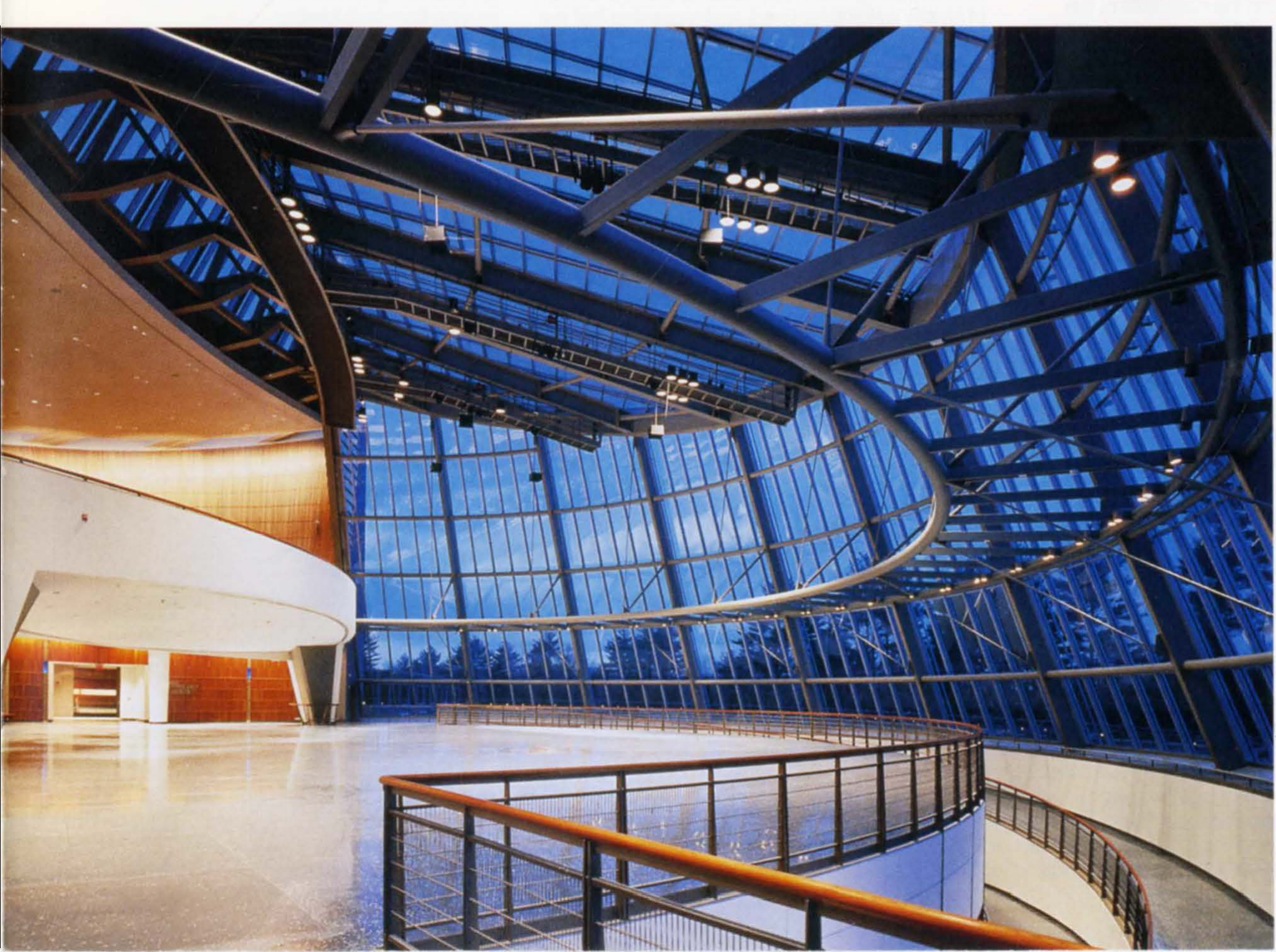
Tower

Braced frames in the east-west and north-west / south-east directions and moment frames in the north-south direction provide the lateral resisting system for the Tower. Here also a 3-D model for the analysis was created because of the structure's extreme aspect ratio of 15:1. Surprisingly, because of its braced lateral support system, the Tower was relatively stiff, with deflections well within acceptable limits. A separate aeroelastic model was investigated with the wind tunnel, and results indicated uncomfortable accelerations at the observation deck in wind speeds higher than about 20mph (32kph). The client, on being advised, limited access to the Tower when this occurred.

CUP Building and Tunnel

As the CUP Building was designed to be almost wholly below ground, except for the service yard area, the primary lateral load is thus earth pressure, resisted by the retaining walls. Its roof is a simple steel-framed structure designed to support the soil for landscape and snow loads. The ground slab is a conventional slab on grade designed to carry MEP equipment. Similarly, the tunnel structure was designed to resist lateral earth pressure and heavy vehicle loading above.

6 right.
Model for wind tunnel analysis.



A.
The Gathering Space at dusk.

Construction

Foundations

To meet the owner's requirements, the construction manager proposed a very ambitious construction schedule. The foundation contractor's bid was based on a 75% construction document set. Tree removal and site excavation began in June 1995; before foundation construction commenced, the site resembled a huge sandpit. Because of the deep excavation required along the southern end, a king-post system was utilised to retain the soil. Rock anchors grouted in to about 60ft (18.3m) were then used to stabilise the whole system (Fig 9).

Given the construction schedule and the complexity of the design, the client asked Arup to provide special inspections for both concrete and structural steel elements. As having a full-time resident engineer on site was not possible, a compromise of one day a week was agreed. The site was a 300 mile (480km) round trip from Arup's New York office and over 80 journeys were made during the construction.

9.
Waling structure for deep basements.

Foundation construction began in August 1995 within a month of the notice to proceed, generally progressing without major disruption. The fast-track nature of the project did result in several co-ordination problems with the MEP penetrations in the foundations, primarily the vertical elements. The foundation contractor was quite familiar with working on the reservation and a very good relationship was established. Of particular interest to the architect was the 'sinusoidal' architecturally exposed concrete wall on the north side of the Museum. The finished product is a testament to good workmanship (Fig 10). Ironically, the exposed face of the wall is adjacent to the woods and the swamp, which has a notice indicating that it is a lyme tick area and as such there is access restriction to the outside of the building here. Construction of the 38ft (11.6m) high counterfort retaining walls and the two 60ft x 38ft (18.3m x 11.6m) high circular War Theater walls during one of the worst winters in this area tested the contractor's ability to work in adverse weather conditions.

As is often the case, there was an inherent conflict between the foundation contractor's desire to pour as large an area as possible and the design team's requirement to limit pour sizes and maintain quality of the work, but a survey of the foundations from end to end revealed the entire building to be out by an outstanding 1/8in over 800ft (3mm in 240m).

Steelwork

The construction manager scheduled steel erection to commence at the Gathering Space, moving outwards towards the Museum and Bar Building. The design team had concerns about this sequence, given the complexity of the Gathering Space roof structure and the architect's requirements for architecturally exposed steel and connections.

The steel contractor was chosen in August 1995 and directed to scour the country for structural steel, there being a shortage in the construction industry at that time. Rather than give a hard cost for the fabrication and erection of the complex Gathering Space roof structure and Tower, the steel contractor gave an order of magnitude estimate as he felt the complexity of the structural form and its erection made it an intangible figure at the time of signing the contract. At a pre-construction meeting, the steel contractor expressed some concern about starting erection of the Gathering Space structure as he was uncomfortable with the amount of on-site welding required, and requested that the design team review the connections with a view to buildability.

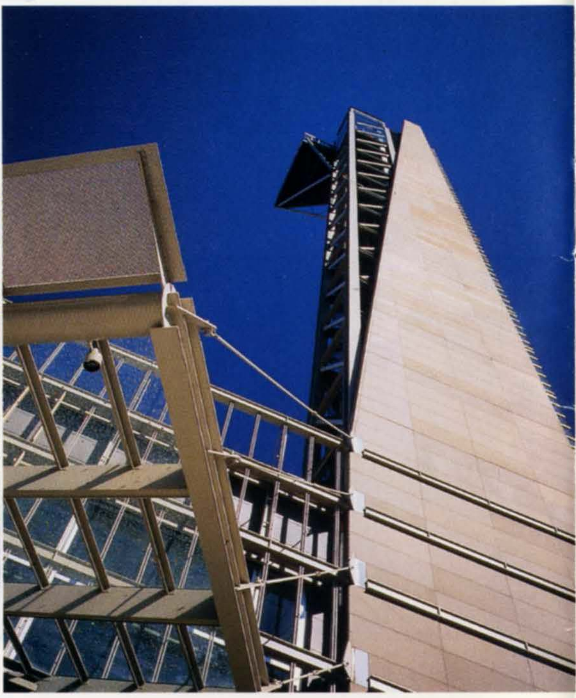
Soon after steel fabrication and erection started, it became apparent that the sequence of construction was becoming problematic and it was revised to start with the erection of the simpler Bar Building. In anticipation of the original erection schedule, an M250 crane was rented. This, the design team was informed, was the largest crane east of the Mississippi River and was delivered to site using 15-20 flat-roll trucks. After assembly and during testing of the crane, the top boom buckled and two other cranes were required to stabilise it. This of course had some impact on the erection schedule. Steel erection commenced in February 1996 with the Bar Building, proceeded with the lower floors of the Gathering Space, and then the Museum, moving from east to west.

For the design team the shop drawing process was an enormous task, as Arup's New York office had never taken on a job of this size to construction. Between October 1995 and June 1996 over 3000 steel shop drawings were reviewed, the office receiving over 150 drawings a week at its peak. Prior to the contractor recommencing steel erection, the construction manager developed a rigorous quality control regime for the architecturally exposed structural steel that was eventually copyrighted and fully described in *Modern Steel Construction*[1].

10.
Architectural wall of Museum.

12.
Temporary formwork for Gathering Space roof structure.

13.
Observation Tower.



11.
Construction manager's model of Gathering Space structure.

Due to the complex geometry, the usual tolerance requirements specified by the American Institute of Steel Construction Code were deemed not applicable. As a compromise for buildability, Arup reanalysed the Gathering Space structure and determined that tolerances 10% below AISC standards were structurally acceptable. This meant, however, that the team had to examine each joint to determine the maximum allowable tolerance in terms of the structural forces and architectural requirements. The erection of the Gathering Space was monitored vigorously to ensure the structure would meet the project tolerance requirements. To monitor the progress of erecting and surveying the Gathering Space structure, the construction manager built a 1/8in (1:200) scale model, and each member of the model was highlighted when it was erected (Fig 11). Arup was intimately involved with the rigorous survey regime that determined locations before and after welding for more than 500 points. Even though tolerances were exceeded at several locations during construction, the design team was able to backcheck the design with the given information to verify that the roof structure was not overstressed.

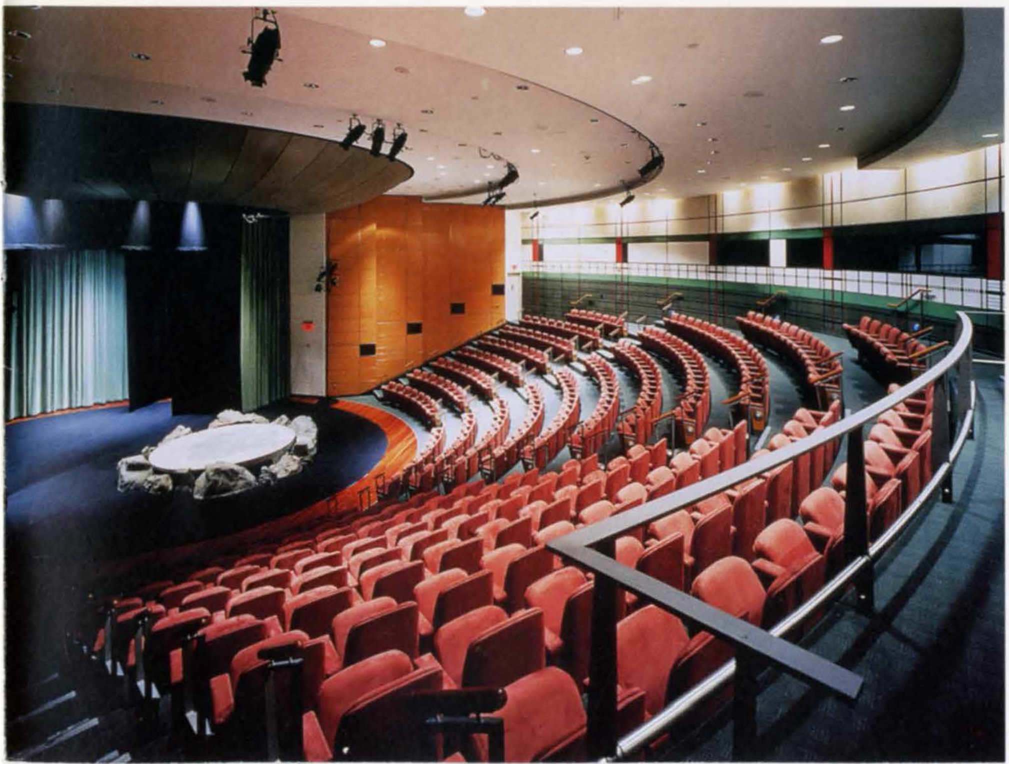
In one of the most impressive results, surveys before and after depropping the falsework for the 192 ft. (58.5m) roof arch determined that the depropped structure was within 1/16in (1.5mm) of calculated deflections (Fig 12).

Erection of the Tower progressed without difficulty and involved much welding of the braced frames, which were erected in floor-to-floor frames (Fig 13). Construction of the CUP Building was far simpler than the main building, with the structural steel being erected in a single day.

Conclusion

The Museum officially opened on 10 August 1998 in a ceremony that included traditional Native American rituals and congratulatory messages, both from the President of the United States and from other tribal nations. In 1998 the project won the AISC/AIA National Award for Innovation in Steel Design. It also received a National Insurance award for being one of the safest construction projects. The Museum has been received very positively in the eastern Connecticut region and is gaining recognition in museum circles for its state-of-the-art interactive displays and the quality of the exhibits.

14.
Gathering Space roof ridge structure.



15.
Performance theatre.

Reference

(1) PAVARINI, G F. Quality assurance for steel projects. *Modern Steel Construction*, 37 (12), pp50-57, December 1997.

Credits

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