MIX VOLUME NINE DECEMBER 2001

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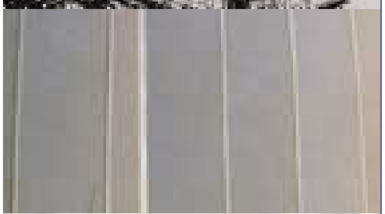

TIPS

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CEMENT & CONCRETE ASSOCIATION OF AUSTRALIA

Leading Knowledge-Sharing Information

NON-ORTHOGONAL PRECAST CONCRETE

DEVELOPMENTS BY JOHN HOLLAND IN WESTE

Curvilinear concrete forms have been used throughout history. Today's construction practises often favour using precast concrete to achieve curved configurations. At the Health Sciences Building, Joondalup Campus of Edith Cowan University (ECU) in Western Australia, by architects Jones Coulter and Young, curved coloured precast concrete is a dominant feature.

Some panels are curved to represent a three-dimensional 'sail' assembled in groups of four. These were produced using curved steel moulds by laying the side shutters at an angle across the main mould to produce the desired double-curves. Regular changes in curvature demanded two moulds and the re-setting of the side shutter several times.

The natural catenary of the suspended reinforcement fitted the shape comfortably. The reinforcing materials employed were simplified to a centrally placed mesh with perimeter and re-entrant bars, which all needed to be suspended so as not to leave support chair marks on the architecturally sensitive face of the panels. Two larger twenty-five-tonne feature panels had full reinforcing cages built in the mould.

CEMENT & CONCRETE ASSOCIATION OF AUSTRALIA

EDITOR: LORINA NERVEGNA
email: lorina@ccaa.com.au

C&CAA OFFICES:

SYDNEY
Locked Bag 2010
ST LEONARDS NSW 1590
Telephone: 02 9437 9711 Facsimile: 02 9437 9470

BRISBANE
348 Edward Street
BRISBANE QLD 4000
Telephone: 07 3831 3288 Facsimile: 07 3839 6005

MELBOURNE
1 Hobson Street
SOUTH YARRA VIC 3141
Telephone: 03 9825 0200 Facsimile: 03 9825 0222

PERTH
PO Box 43
WEST PERTH WA 6872
Telephone: 08 9214 3914 Facsimile: 08 9214 3998

ADELAIDE
Greenhill Executive Suites
213 Greenhill Road
EASTWOOD SA 5063
Telephone: 08 8274 3758 Facsimile: 08 8373 7210

LIBRARY
Locked Bag 2010
ST LEONARDS NSW 1590
Telephone: 02 9903 7720 Facsimile: 02 9437 9473
Email: info@ccaa.com.au

WEBSITE
www.concrete.net.au

PHOTOGRAPHY
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The complex logistics of handling and transporting the panels were overcome by way of a curved bolt-on strong-back with a turning mechanism built into it so panels could be taken out of the mould on-the-flat, turned ninety-degrees in mid-air and then stored, handled and transported on edge. The assemblage of these panels was challenging as the elevations and relationship to adjoining panels (yet to be erected) was all done some nine-metres above ground.

Generally precast is quick to erect and site personnel see the time-efficient end of operations. But what goes up in one day can take up to ten days to prepare, produce and finish.

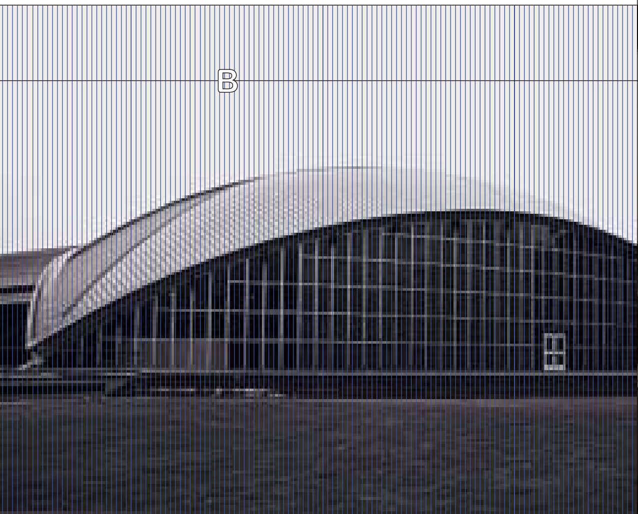
Repetition is not always achieved in an architecturally intensive building program such as at ECU, where each panel had its own requirements and peculiarities. Approximately 350 panels were produced in conjunction with some 200 shop drawings. Documention required the co-ordination of the architectural, structural, electrical and hydraulic services for each panel type. Details of cast-in items such as grooves and edges were checked diligently where they changed from panel to panel.

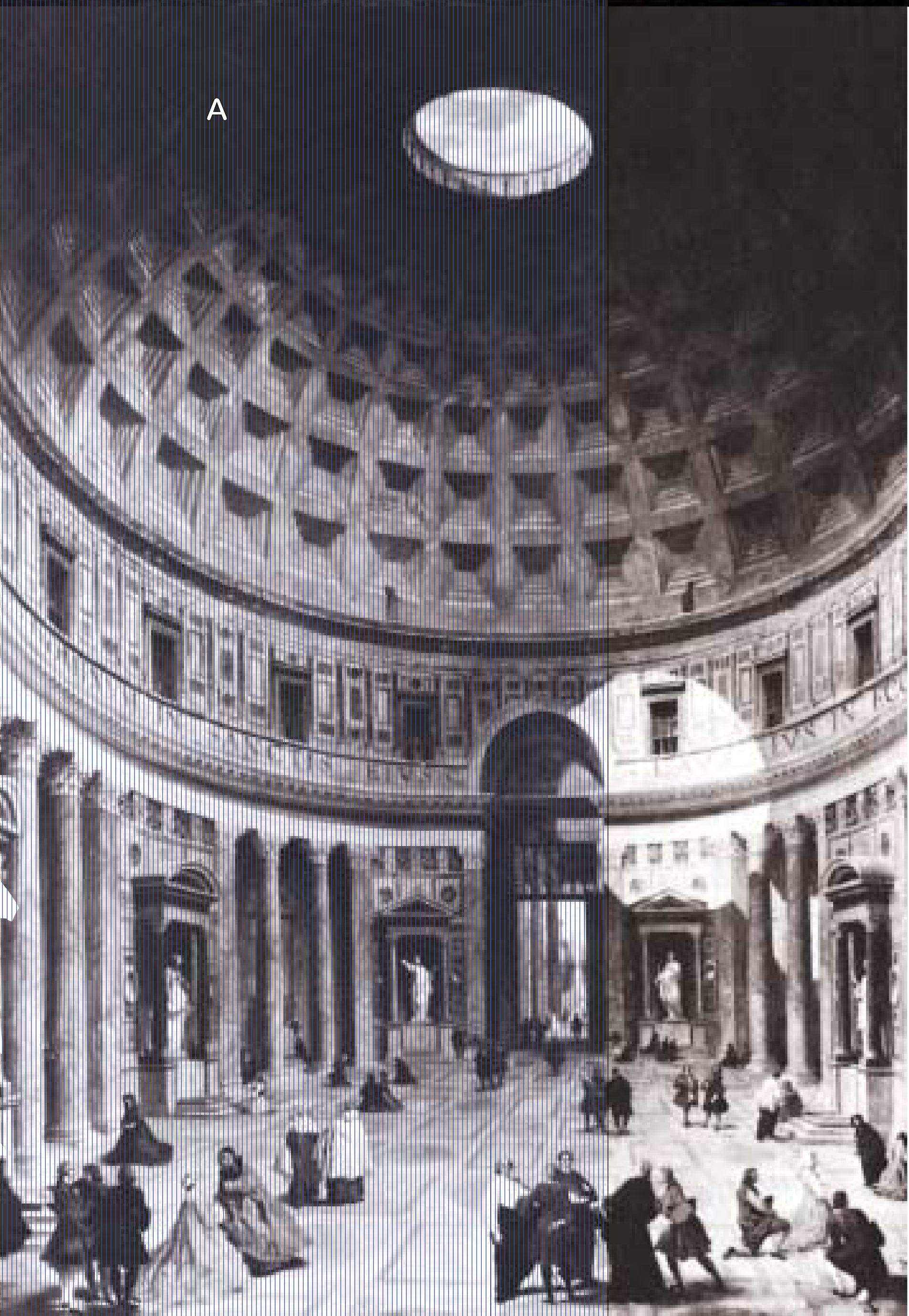
Attentive project administration and careful monitoring during all stages of documentation and construction greatly assists the sequence of events where this degree of complexity forms part of any project.

PHOTOGRAPHY: *Patrick Bingham-Hall*
ACKNOWLEDGEMENTS: *Tom Jackson, John Holland PRECAST*
Elisabetta Guj, Jones Coulter Young

PURE AND APPLIED SOLID GEOMETRIC FORM-M

CONCRETE CORPORATE BRANDING

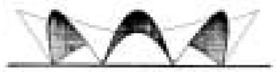




Non-orthogonal forms in architecture are not limited to any movement, historical period or ideological type. They appear in all permutations throughout history. However, the introduction of curvilinear form making in the built environment has often been seconded for expressing a connectivity with primal elements: a link with our natural history and environment; a morphological interpretation of, and relatedness to, our beginnings. The geodesic dome by Sir Buckminster Fuller is an example.

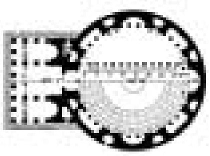
Yet in architecture, the dome as with all archetypal elements resists appropriation to any style or movement and is a recurring feature from ancient times, despite attitudes to the natural environment. For example, the modern movement gave rise to a post-industrial machine age that embraced repetition, easily achieved through production-line orthogonal forms. The foci was not on the natural environment, though this movement also saw the execution of some of the most sublime curvilinear structures of the twentieth century.

Circles, ellipses, parabolas, hyperbolas and their three-dimensional extrapolations and derivatives manifest in spheres, ovoids, and the torus, pose particular challenges to the building program. Our constructed environment is, for the sake of expediency, composed of predominantly orthogonal elements. Deviating from this usually results in costly adjustments within the average building program. Concrete is often the most accessible means of achieving non-rectilinear forms due to its integral ability to translate complex geometry into built form. It has been employed since ancient times to achieve shapes and features that have survived to demonstrate its plastic potential for sculpting and assemblage. Here we shall confine our discussion for the moment and narrow the field of vision to disentangle a brief homage to the dome and some related derivatives of pure geometry.



The Pantheon in Rome (AD124) presents an enduring example of the dome as archetype. The insitu concrete hemispherical dome or cupola spanning 42 metres, indicates the tenacity of the architect, thought to be Hadrian, and displays the determination of expressing the grandeur of the Roman Empire in built form. The Romans had developed pozzolanic

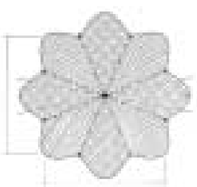
A



cement using a mix of volcanic ash (pozzuolana, or from Pozzuoli) and lime to create a concrete mix durable and strong enough for dome and arch construction. As a manufactured material it was readily transportable throughout the empire and thus became a suitable medium with which to mark the march of Roman domination leaving countless landmarks in its wake. Concrete could be viewed here as an early instrument of corporate branding and the Pantheon survives as a remnant example.

The dome has been used throughout history in ecclesiastical, public and private architecture. However, the use of the dome in the period referred to as the mid-Twentieth Century International Geometric Determinist Style may be viewed as a cavalier era, displaying a certain confidence which befits its place in the post-war period. Significant examples include the shell structures of Feilix Candela, Pier Luigi Nervi and Oscar Niemeyer.

D



These designs explored less formal solutions, which resulted in freer outcomes. Ferrocement technology was more often than not the building method employed for expressing solid geometry, along with advances in the research and development of site-cast or insitu concrete.

The ten-year period between the early 1950s and 60s, in particular, saw numerous examples of this style appearing sans frontières around the globe, with roughly equal representation in the first and developing worlds. An almost domino effect can be observed with the dome viewed as a prototype. In 1954, Eero Saarinen's Kresge Auditorium at the Massachusetts Institute of Technology in Boston was constructed (although the Kresge is in fact a segment of a dome), and in 1956 the dome appeared in Rome with Pier Luigi Nervi's Palazzetto dello Sport.

C

In 1959, the Shine Dome (formerly Becker House) by Roy Grounds was completed in Canberra, and the Palazzo dello Sport (Nervi again) was completed in the same year.

G

Within months, the right-side-up/wrong-side-up domes of the Palacio de Congresso Nacional in Brasilia by Oscar Niemeyer was under construction. Here the domes are set side by side with one being inverted in precarious balance. Niemeyer picked up on the use of the dome form and reworked it in a simple way. Using repetition and juxtaposition the overall composition, completed with a modern high-rise block at the rear is perhaps one of the most subtle and thought provoking of all. The proliferation of the concrete dome during this time can be viewed as a modern metaphor of early Roman concrete corporate branding, with its vantage being founded in industrious, optimistic post-war thought.

A HADRIAN 124AD
Pantheon, Rome
[History of Rome, Michael Grant]
Pantheon Plan [A History of Architecture, Sir Bannister Fletcher]

B EERO SAARINEN 1954
Kresge Auditorium, MIT Boston
[Professor Mary Ann Sullivan, Bluffton College, Ohio]

C PIER LUIGI NERVI 1956-57
Pallazzetto Dello Sport, Rome
[Paolo Desideri, Pier Luigi Nervi Jr, and Guiseppe Positano, Zanichelli Press, 1979]

D FELIX CANDELA 1958
+ JOAQUIN ALVAREZ ORDONEZ
Les Chalupas Restaurant, Xochimillo, Mexico
[Candela and Calatrava—*Two Generations of Engineering Architecture* reprinted from World Architecture, Issue 13 British Cement Association]

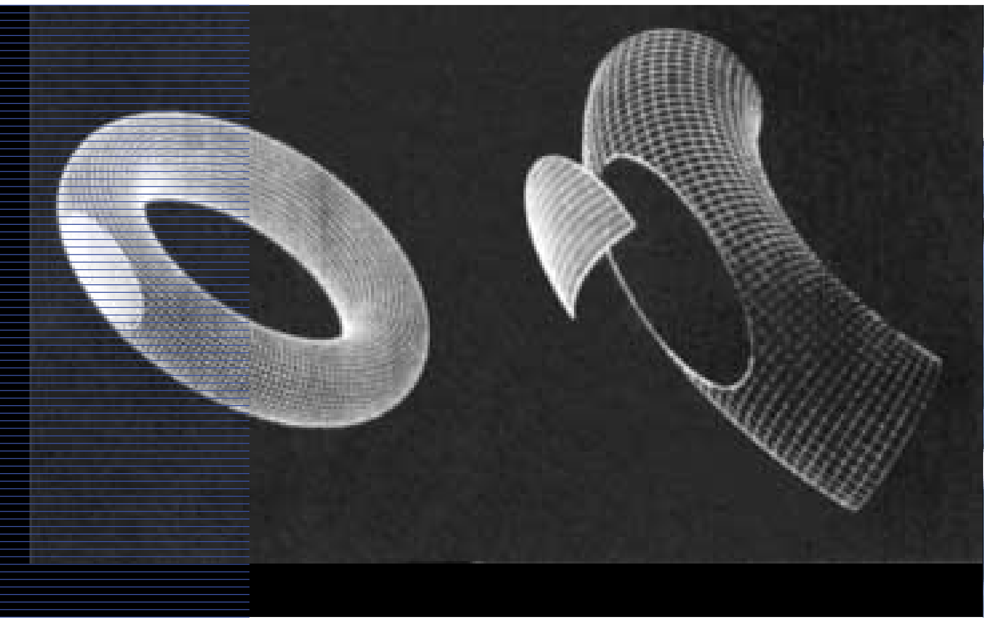
E OSCAR NIEMEYER 1959
Palacio de Congresso Nacional
Brasilia
[Lorina Nervegna]

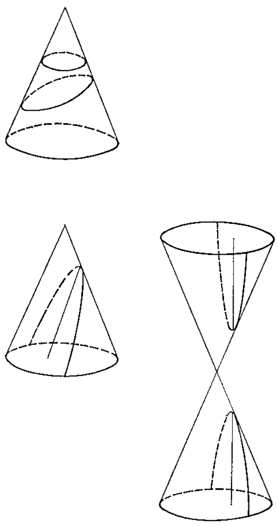
F ROY GROUNDS 1959
+ GROUNDS ROMBERG BOYD
Australian Academy of Science
Canberra

G PIER LUIGI NERVI 1958-59
Palazzo dello Sport, Rome
[Aesthetics and Technology in Building, The Charles Eliot Norton Lectures, 1961-1962 Pier Luigi Nervi, Harvard Uni Press 1965]

Thanks to Clare Newton, University of Melbourne

US AIR MUSEUM, DUXFORD, CAMBRIDGESHIRE





As with Jørn Utzon's Sydney Opera House, Eero Saarinen's Kresge Auditorium—and his later much debated (due to an uncertain future) TWA terminal at JFK International Airport in New York—the segmentation of spheres, ovoids and the torus present challenges to the building program.

The recent American Air Museum in the UK (1996) by Foster and Partners is an example of the segmentation of pure geometry, and in this case, the doughnut-shaped torus. Located at the western end of the Imperial Air Museum at Duxford in Cambridgeshire, the American Air Museum was built at a cost of 7.2 million pounds.

One of the most challenging aspects of the brief was to house a significant collection of aircraft dating from World War I to the Gulf War. Included in this collection is the largest B-52 bomber ever built, the 'Strato Fortress', with a 61 metre wingspan and 16 metre high tail fin. These dimensions set the building envelope and led to a structurally efficient design solution to contain the enormous

PROJECT: American Air Museum, Duxford, Cambridgeshire
ARCHITECT: Foster and Partners
STRUCTURAL CONSULTANT: Ove Arup & Partners
PHOTOGRAPHY: Nigel Young/Foster and Partners
ACKNOWLEDGEMENTS: Elizabeth Walker/Foster and Partners and Clare Newton/University of Melbourne
TORUS GEOMETRY: David Bennetts, *Exploring Geometry*

exhibits and, in some cases, suspend their considerable bulk from the ceiling. The 6,400-square-metre facility was completed in fifteen months (December 1996).

The execution of the design was facilitated with electronic (CAD) assistance and involved the detailing of the vaulted roof based on toroidal geometry. The roof/ceiling shell was pieced together using six different concrete panel types which measured approximately 12x4 metres in size. This low unit type facilitated repetition of the manufacturing and site assembling processes, and the subsequent lowering of overall costs. The partially submerged building has an overall vault span of 90 metres and a building length of 100 metres.

The shell roof structure is constructed from interconnecting precast panels comprising two layers or shells of concrete separated by an insulated core which is 900-mm deep. Each shell's thickness is 100 mm and reinforced with two layers comprising mesh of 8-mm-diameter bars at 150-mm centres. The shells are connected by an inverted reinforced precast T-beam, cast in sections which are ten metres in length and two metres wide.

Originally, white concrete was specified with limestone aggregate but budgetary constraints resulted in a conventional grey mix. To achieve the highest quality surface finish, a superplasticiser was added to the mix to ensure high early release strength for the moulds. When the entire on-site shell and beam assemblage over false work was completed, the joints were stitched or sealed with insitu concrete, producing a monolithic structure.

The life-cycle costing of a concrete structure versus alternative industry standards early in the design process also favoured the materials selection and design. This was due in part to low on-going capital maintenance, minimal additional mechanical services, and thus low running costs. This precast shell structure was chosen due to the high passive thermal performance and excellent condensation control of the insulated system.

SCIENCE AND HEALTH BUILDING, EDITH COWAN U

The design for the Science and Health Building, Joondalup Campus at the Edith Cowan University (ECU) by Jones Coulter Young of Perth, was the result of an intensive value management assessment undertaken during the design process. The results included the selection of a limestone-coloured concrete skin as the external finish requiring no painting or ongoing maintenance.

The limestone colour was consistent with other off-form concrete elements such as beams and columns of the existing surrounding campus buildings. The concrete supplier, Pioneer, made several colour test samples prior to arriving at the final mix selection. All panels were lightly sandblasted to remove sheen off the face giving a slightly matt effect. They were then sealed with an anti-graffiti and waterproofing agent in the precast yard. The concrete mix incorporated a blend of naturally occurring granite (as quarried) and cream coloured cement. No additional oxides for colouring were used. The mix was plasticised to improve workability, surface finish and curing time demands. Colour consistency was a high priority, especially due to the panels being fabricated over a seven-month period from mid-summer (dry and hot) to late winter (wet and cold).

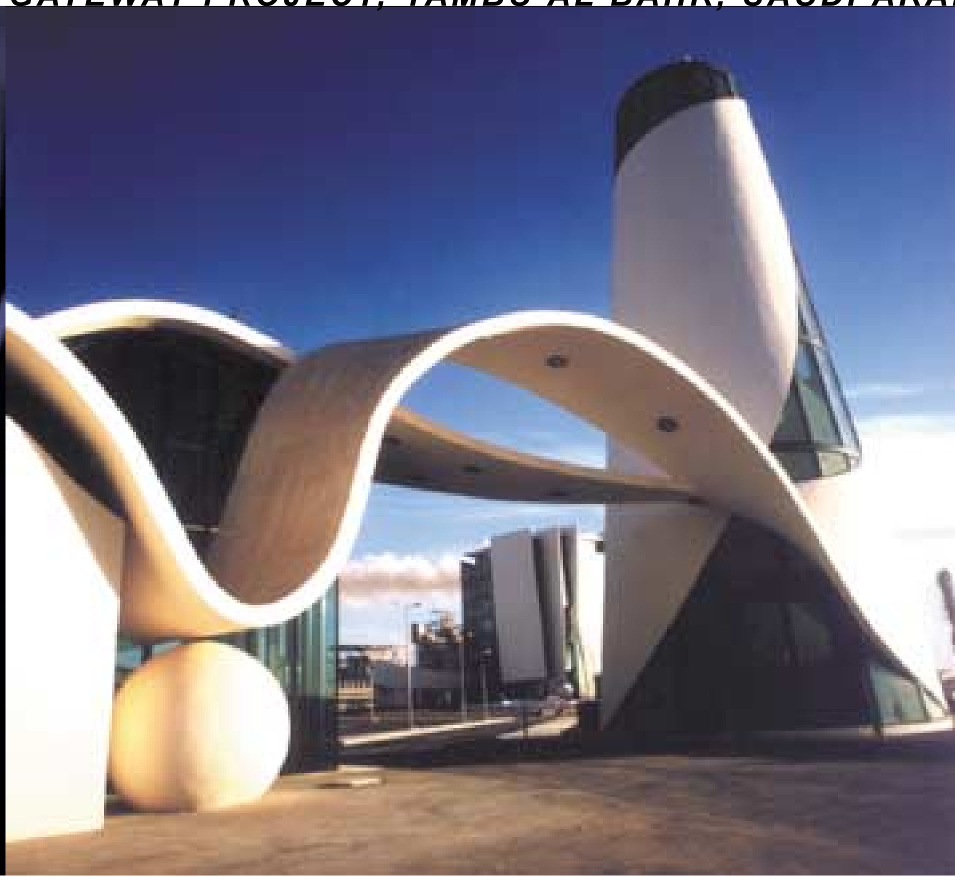
The three-storey concrete-framed structure with precast concrete plank floor system has elements throughout selected for their cost effectiveness and speed of construction. All the curved precast panels (except for two 40-tonne panels) were designed to weigh a maximum of ten-tonnes for ease of transporting to the site. Assembling the modular system was a relatively straightforward exercise, as the building was designed as a kit of parts with all precast and self-coloured elements manufactured and sealed off-site. The west wings have amorphous precast concrete elements, while the north and south facing blocks incorporate concrete sunshades or brise soleil to assist in passive thermal control.

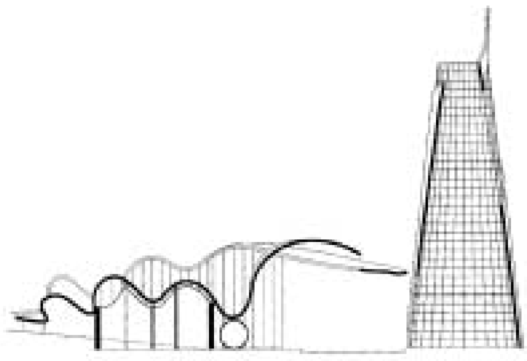
At ECU, Jones Coulter Young have released an oblique and unusual vision into a generally tame and conventional campus context. The richness of the forms are in the fresh assembly of shapes and openings, which are moulded Plasticine-like in an overall engaging composition. A significant prerequisite of the design brief was for the building to incorporate ecologically sustainable features. That it has done so and been awarded the RAIA 2001 Chapter Award for institutional work, demonstates the multivalent qualities that contemporary work is increasingly adopting.

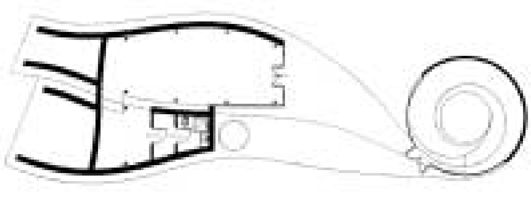
NIVERSITY, WESTERN AUSTRALIA

PROJECT: Science and Health Building, Joondalup Campus, Edith Cowan University, Western Australia
ARCHITECT: Jones Coulter Young
STRUCTURAL CONSULTANT: Ove Arup & Partners
BUILDER: Cooper & Oxley
PRECAST CONTRACTOR: John Holland Pre-cast
ENVIRONMENTAL CONSULTANT: Gabriels Environment Design
PHOTOGRAPHY: Patrick Bingham-Hall
ACKNOWLEDGEMENTS: Elisabetta Guj, Paul Jones, Jones Coulter Young

GATEWAY PROJECT, YAMBU'AL BAHR, SAUDI ARA







The forms of billowing concrete ferrocement fabric in the Gateway Project, at the Yambu'al Bahr Cement Company, the largest cement plant in the Middle East, 80 kilometres north of Yambu along the Red Sea coast of Saudia Arabia, exemplifies a comprehensive palette of possibilities for moulding and sculpting concrete.

Designed by Franco Audrito, of Italian architectural firm Studio 65, the architects were the successful entrants in a limited competition. Ferrocement technology has been employed here, displaying the structurally efficient qualities of this particular albeit uncommon building technology. Its structural efficiency is in its ability to contain relatively thin elements in complex configurations with limited formwork. It pushes the limits for conceiving concrete possibilities and highlights its eccentric possibilities. The juxtaposition of a massive material portraying soft lightweight cloth flailing in a windblown landscape is a confronting visual form. The architects desire was to 'liberate' the concrete

PROJECT: The Gateway Project, Yambu'al Bahr, Yambu Cement Company, Saudia Arabia
ARCHITECT: Franco Audrito, Studio 65, Turin, Italy
STRUCTURAL CONSULTANT: Ermanno Piretta, Patrick Jennings
BUILDER: Ret-Ser, Saudia Arabia
FERROCEMENT CONSTRUCTION: Alphacrete Construction Linings UK Ltd, Manchester
PHOTOGRAPHY: Studio 65
BUILDING PLAN AND SECTION: *iiCC* (Lindustria Italiana del Cemento), Issue 755, June 2000

BIA

and project the entrance portal as a drape blowing in the wind under which all who enter the complex, including administration, executive and cement manufacture staff, are then able to pass.

This animated vision was made possible using ferrocement technology in an industrial climate that favoured a labour-intensive building program rarely seen these days outside of emerging economies. Costing analysis for conventional insitu proved to be prohibitive and the ferrocement technique was regarded as a relatively simple process not dependent upon skilled labour.

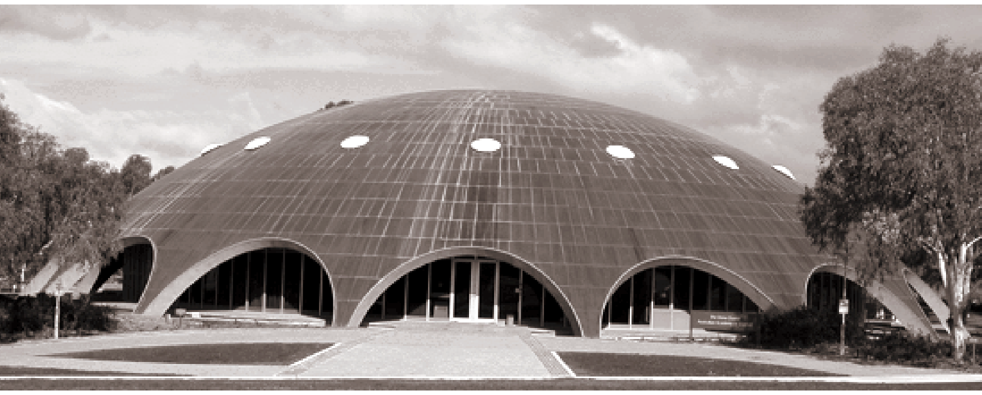
The entire ferrocement ribbon was constructed by firstly framing the shape of the skeleton. This was done by assembling a two-dimensional weave, made up of steel reinforcing bars and mesh of 5-10mm diameter, with girders along the edges and placed cross stiffening ribs. A polystyrene core (chosen for and characterised by its high thermal insulation coefficient) was placed and fixed in the small bays formed by the weave of the steel reinforcing bars to complete the skeleton. The concrete was then sprayed over and under the skeleton using a cement rich mix (sand to cement ratio of 2.5:1) with a concrete strength of about 25 MPa. A set-retardant additive was introduced into the mix to assist curing and, despite temperatures of 43°C, no cracking occurred during or after curing and setting.

During the 1950s and 60s, ferrocement technology was a popular method of executing pure curvilinear structures. The fluidity of form in the Yambu'al Bahr Gateway takes off from this legacy, suggesting possibilities for future experimentation.

Pure and applied solid geometric forms are a reprieve in a predominantly rectilinear and orthogonal built environment. Contextually, the inclusion of curvilinear forms could be read as providing a balance of external forces on the senses, informing our understanding of the built and natural environment with spaces and places not necessarily derived through expediency.

SIR ROY GROUNDS (1905-1981) AND THE SHINE

AUSTRALIAN ACADEMY OF SCIENCE, CANBERRA,



Having recently been nominated by the RAIA as one of seven Australian projects to be included on the World Register of Significant Twentieth Century Architecture, the Shine Dome (formerly Becker House) stands as a familiar sentinel in the Canberra landscape.

Partially obscured by mature eucalypts and appearing blurred as one travels past at high vehicular speeds, it is best experienced upon pedestrian approach where one's attention is captured through its taut simplicity and imposing scale. However, it is only with a tour through the building that it systematically unfolds as a thorough and resolute undertaking by a focused and meticulous designer.

Almost all the original fit-out and custom-made furniture remain, from chairs, tables, lecterns, light fittings, sideboards all contributing to the consistency of the overall design integrity, much of the furniture design being done by D.F.W. (Fred) Ward and interior design consulting by Betty Grounds, Sir Roy Grounds's wife. Becker House was awarded the Sulman Medal for the year it was completed (1959 RAIA NSW Chapter), the Canberra Medallion two years later (1961 RAIA ACT Chapter) and the 2000 RAIA (ACT Chapter) twenty-five year award. It was Sir Roy Grounds's first major public commission and is said to have remained his favourite building. This becomes clear as one delves into the history of the project which, in addition to all of the above, has Australian Government heritage listing on the Register of the National Estate.

The Kresge Auditorium by Eero Saarinen (1954) at the Massachusetts Institute of Technology is reported to have influenced the design for a limited competition held in 1956, to house the Academy of Science by Grounds Romberg and Boyd, Grounds having recently returned from a sabbatical in Boston. Consistent with the structure of the architectural practice at the time, it was in fact a Grounds design and the project was designed and supervised during construction by Grounds alone. Anecdotes abound over the project and its place in history as a landmark building that exceeded the architectural program through the combination of a number of favourable forces and is recalled with luminous admiration in interviews with key members of the building committee of the time. These forces included a formidable client, headed by no less than Sir Mark Oliphant, a prominent site in the national capital, innovative and ground-breaking building technology, an architectural project completed one month early and on budget, and a design described as 'pure genius' by Oscar Bayne ARIBA FRAIA, the architect presenting the entrants to the building committee at the time.

Bayne was credited with being the catalyst for the selection of the winning scheme, appearing as it did, as if it had landed from another world, displayed alongside a collection of projects that reportedly paled in comparison. This, it must be remembered, was during a visionary scientific era prior to manned space travel and in the time of Sputnik. The winning design captured this spirit, as architecture can, in an inexorable manner such that the seemingly moderate and sober council members of the Academy, unanimously accepted it.

The Australian Academy of Science was at the time establishing itself in the post-war international scientific community. It had no home or headquarters and pertinent to recent discussions of corporate branding, Becker House helped create a corporate consciousness, becoming in time inseparable from its association with the institution that commissioned it.

The dome is in fact a slightly flattened dome, a segment of a semi-sphere, which was at the time the first freestanding concrete reinforced dome formed for a public building in Australia and at a diameter of 46.3 metres, larger than the dome at St Paul's in London or St Peter's in Rome. It was a major engineering feat, untested, and there were doubts by some whether the scheme could be built at all. The design relies on the support of the structure being distributed evenly on sixteen equally spaced inclined parabolic arched piers at the base of the building envelope. The footings consist of the water-filled concrete moat, which acts as a continuous beam along with reinforced concrete pad footings under the base of each arch.

W.L. Irwin and Associates of Melbourne, executed the complex engineering computations for resolving the stresses caused by the forty-five-ton concrete dome perched on sixteen slender supports. A one-in-forty fibreglass and resin scale model was built prior to construction to test the structure and even then there were doubts. It is a reflection of the dogged

E DOME

1959

PROJECT: Australian Academy of Science, Canberra
ARCHITECT: Roy Grounds, Grounds Romberg Boyd
STRUCTURAL CONSULTANT: WL Irwin and Associates
BUILDER: Civil and Civic Constructions
ACKNOWLEDGEMENTS: Clare Newton/University of Melbourne
Victoria Grounds, Nerida Dunn and Jack Deeble

determination of the entire project team that the building was built at all.

Civil and Civic was selected as the builder at a cost of eight pounds per square foot and at a total project budget (including furniture, equipment, landscaping and professional fees) of two-hundred-and-sixty-thousand pounds. After excavation and sub-floor works, the construction process involved setting out the arched pier timber formwork inside and out, one at a time pouring concrete into one pier before setting out the adjacent pier. This process had a turnaround time of three days and so the systematic setting-out, formwork construction and placing of concrete became a repetitive process, albeit complex due to the arches sloping inwards and having to be set out at the correct curvature. When the concrete for all sixteen arches had been placed, the remainder of the dome was placed in virtually one pour.

The dome at the top of the arches is at a point where its slope is becoming quite flat which assisted the final placing of the concrete. The removal of the timber formwork after curing is recalled in an interview with Mr Jack Deeble, the Executive Secretary of the Academy at the time as well as the Secretary of the building committee:

"... *during the whole of this dome construction period there was a forest of steel supports resting on the floor slabs inside the building, supporting the dome. When it came time to take those away, the concrete having set, it was known that the dome would deflect. So a system was worked out so that the supports were taken away from the centre of the dome, gradually working outwards. I was with Roy up on the slab on the second floor when the group of supports in the centre of the dome were taken away, and Roy dashed out to some supports that were about two-thirds of the way out from the centre of the dome, and he said, 'If the calculations are right, this should be loose.' And he seized a support and it came away in his hand. The dome bulged; as the centre was released, it dropped and there was a bulge in the dome, which made the supports at that point come loose. And it all worked.*"

Incredibly, the dome deflected less than one centimetre as it took its own weight for the first time. Overall, the dome shell has a thickness ranging from 75mm at the top to nearly 600mm at the base. Civil and Civic Constructions took fifteen months to complete the building works (one month early) and then with aplomb, presented a one-thousand-pound cheque as a donation to the Academy during the opening ceremony.

With many concrete features and finishes expressed internally in addition to the structure itself, one may be forgiven for thinking that the building was commissioned as a concrete building prototype. However, the extensive exposed and polished concrete finishes used internally can be attributed to the low maintenance requirements stipulated in the design brief. This is also obvious due to expanses of face brickwork walling throughout the interior with records stating that Grounds specified struck mortar joints, thus avoiding dust traps as he continually pressed for a maintenance-free building.

Upon entering the building the first concrete element encountered is the exposed shallow barrel-vaulted ceiling being the underside of the first floor slab. The internal stairs are formed from site-cast concrete, elongated and cantilevered semi-circular treads that appear to float in mid air. In the auditorium, the ceiling is for the most part exposed off-form concrete. The kitchen features dark grey polished terrazzo floors, under-bench shelving and splash backs with contrasting exposed (white quartz) aggregate. The building displays a confidence in the design, specification and construction of these concrete elements rarely found in such a comprehensive assemblage.

Recently, the Academy has undergone renovations and mechanical services upgrading made possible with funding from the Council of Centenary of Federation and private sources. A generous donation towards the recent works made by Professor John Shine, explains the name change from Becker House to Shine Dome. As many works on historic buildings attest, this is often a period when forgotten pieces to a filed-away puzzle emerge to facilitate the conservation and renovation process.

It is with much dedication and respect for the architect and project team that the recent works have been completed despite the challenge of incorporating contemporary facilities for a building predating them. The Academy continues to be one of our most respected learned institutions deserving of one of our most enduring architectural icons.

To view the UIA submission, visit www.raia.com.au for links to the report prepared by Eric Martin and Associates.

To view the Australian Government heritage listing, visit www.environment.gov.au

To view the transcript of the interview with Mr Jack Deeble, visit the web site of the Australian Academy of Science www.science.org.au/dome

BLACK AND WHITE CONCRETE

Achieving brilliant white or pitch-black concrete is traditionally the most sought after architectural concrete finish. This specification guide follows on from the previous issue (see MIX EIGHT) where Class 1 and 2 concrete surfaces were discussed. Even though black and white are not colours as such they should be specified as requiring a Class 1C or 2C finish depending on the function of the element and extent of the area. Because of the difficulty in achieving colour control over large areas, the stringent requirements of Class 1C finishes are generally reserved for small elements that can be placed from a single batch (truckload) of concrete. For black and white concrete, the colour control (denoted by the 'C' suffix) comes from careful selection of the concrete materials and mineral oxide pigments

For a list available concrete standards and related publications visit www.standards.com.au or www.concrete.net.au

AUSTRALIAN STANDARDS

Although not a definitive list, at the very least these notes should be read in conjunction with the following Australian Standards.

AS 1379-1997 Specification and supply of concrete
AS 1379 Supp 1-1997 Specification and supply of concrete—Commentary (Supplement)
AS 3600-2001 Concrete structures
AS 3600 Supp 1-2001 Concrete structures—Commentary (Supplement)
AS 3610-1995 Formwork for concrete
AS 3610 Supp 1-1995 Blowhole and colour evaluation charts (Supplement)
AS 3619 Supp 2-1996—Formwork for concrete—Commentary (Supplement)

GENERAL

Achieving a high quality end-product, which matches client and architect expectations, is possible with well-researched specifications during contract documentation in addition to attentive supervision during the supply and placing of the concrete. In particular, special attention should be paid to Class 1C concrete in contrast to ordinary ready mixed concrete. Strict adherence to quality assurance is essential in order to achieve consistency in all aspects of the work. Even with Class 1C concrete some colour variations are permitted and the most effective way of limiting these is to achieve as consistent a concrete as possible and specifying a range of acceptable options. Cement type, aggregates, batching and mixing regime, curing method and time, form release oils, temperature and humidity, formwork materials and stripping time can all affect the colour tone and must be closely controlled.

WHITE CONCRETE

There are many different shades of 'white' with the variation often only becoming evident by direct comparison of samples. Determine the degree of whiteness required and compare different samples from pigment suppliers to assess the whiteness possible with off-white and white cements, pigments and surface hardeners. Consider whether vertical and horizontal surfaces are to have the same colour, as the methods available to obtain the colour for each may vary.

White concrete is usually achieved by specifying white or off-white cement, white sands and pale aggregates (quartz if the budget allows). The addition of a white mineral oxide pigment will further brighten the colour, but only 5% by weight of cement is normally added (refer pigments below). For a whiter finish, a white colour hardener which has a pigment to cement ratio of about 10 to 15% can be applied to the surface. Again the surface hardener will give a whiter finish when applied over white or off-white concrete than when applied over grey concrete. Note that adding white pigment to grey cement does not produce a white finish.

BLACK CONCRETE

Black concrete is achieved by introducing black oxide pigments to the cement matrix and is not dependent on the colour of the aggregate. However, the use of dark aggregates will produce a more intense colour, and if the surface is subject to wearing, a light coloured aggregate may affect the final visual 'reading' of the intensity of the tone if worn or polished sufficiently to expose the aggregate. The saturation point of black pigment is about 6% by weight of cement. While very little difference in the colour intensity can be seen with increasing pigment dosage past 6%, for 'black' finishes, a pigment loading of 8% is recommended. Keep the water content of black concrete as low as possible to reduce possible problems with efflorescence. Using a blended cement will also help in this regard.

CEMENTS White and off-white cements are both Portland cements, but white cement costs some four times that of off-white, being an imported product. Grey cement can be either a Portland or blended cement. For white concrete on horizontal surfaces it may be more economical to use off-white cement with a white pigment or even a white surface hardener, and for vertical surfaces, off-white with a white pigment added. For black concrete, the use of a blended cement will reduce the possibility of efflorescence affecting the surface colour.

WATER TO CEMENT RATIO The water to cement ratio is a measure of the amount of water in a concrete mix. A consistent and fixed water to cement ratio must be maintained for all batches to ensure a uniform visual finish, as the amount of water available will cause colour variations. This is crucial to giving a consistent finish for a large expanse of walling for example. High water contents will typically result in a lighter colour, possibly due to efflorescence or dissolved salts being brought to the surface by the water as it bleeds or evaporates from the surface. For white concrete, water content is therefore not as critical, but for black concrete, low water contents are recommended. Thus, a superplasticiser should be used to reduce the water content for black concrete mixes.

AGGREGATES For colour control, both fine (sand) and coarse (crushed stone) aggregates need to be consistent, as variations will affect the colour. For large projects aggregates should be stockpiled, and when batching the moisture content should be checked for each batch to ensure a uniform water cement ratio.

PIGMENTS Introducing mineral oxide pigments is generally the most effective method of introducing a long-term desired colour, or in the case of black and white concrete, tonal finish. Optimum pigment content should be 8% by weight of cement (ie Portland cement or a blend of Portland cement and fly-ash/slag). Using a higher pigment concentration (than the usual 5%) will assist in producing a uniform finish. This will give consistent colour and an intensity of colour that will tend to mask variations between batches of concrete. Using pigments sparingly is the most common reason for inconsistent final finishes. The introduced pigment, generally in a powdered form, does not dissolve in the mix but remains suspended in the mix, and becomes permanently bound into the cement matrix of the concrete. Contrary to popular belief, mineral oxide pigments do not fade over time; long-term discolouration is generally due to weathering and environmental pollution permeating the concrete matrix. The use of white pigments will produce whiter finishes, even when used with white and off-white cements.

COMPACTION Crucial to achieving all high-quality architectural concrete finishes is adequate compaction of the concrete following its placement into the forms. This is usually done with mechanical vibration. The vibration removes entrapped air within the concrete in order to achieve the correct density and concrete strength. In terms of finishes, the number and size of blowholes and the occurrence of honeycombing are reduced.

FINISHING For horizontal work where the surface is to be steel-trowelled or burnished, care should be taken to avoid discolouration or 'burn' marks from the trowel. This only applies to machine-trowelled surfaces and results in dark staining of the surface. Not considered a problem for black concrete, the trowelling of white concrete should be done with care.

CURING Variations in the curing time and method can cause colour variations. Outside temperature fluctuations can also affect curing rates and hence the final colour or visual finish. In short, curing rates must be consistent to achieve uniformity in the final end-product.

PROTECTIVE SEALANTS It should be reiterated here that concrete, like stone, is a porous material that when left unsealed will invariably be subject to environmental pollution and weathering dependant upon site conditions. Various sealants are available and their suitability should be discussed with the manufacturer.

FORM RELEASE AGENTS The release agents used on the formwork should be neutral and non-staining and should not be changed during the work as this may affect the colour.

TEST PANELS As the formwork standard only deals with variations in the colour of 'grey' concrete, a means of determining the required colour and acceptable tonal range for coloured work must be agreed with the contractor. The usual method is to produce a test panel to approve the colour. The production and placement techniques for the actual work must be the same as that for the test panel. The agreement of a tonal range is more difficult. A number of test panels from different batches could be made, with the colour variations between samples agreed, or a limit set on the acceptable variation.

CONTRACTORS AND SUPERVISION Specify that the formwork and concrete contractor are experienced in this class of work and that the site supervisor is also suitably qualified with relevant experience. Class I and 2 finishes, particularly with colour control require communication between all parties so that each understands what is required and how to achieve it. The best way to ensure a uniform colour is by keeping the entire process—from manufacture of the concrete to curing—as consistent as possible.

CURVED PRECAST CONCRETE

TIPS

KEY POINTS TO CONSIDER

Precast concrete has a wide variety of uses. It often needs to be curved for architectural, structural or functional reasons. Pipes, tanks and manholes are the best examples of curved products and are either spun wet or dry-cast in moulds. Although curved components are quite common throughout the construction industry, there are few areas of concern for the designer about their manufacture.

UNITS

structural Structural units such as bridge beams and columns are often curved in section for structural reasons. Such products are usually poured in steel moulds and require good compaction. For instance, the curvature of the web of a beam will increase the risk of blowholes—especially where the curvature tends to prevent entrapped air from moving to the surface. Care must be taken to ensure thorough compaction after placing the concrete.

It is very seldom that these aspects of curvatures present an architectural problem. If there is concern however, the advice of experienced precasters should always be sought and similar projects inspected.

architectural Curvature is often requested for architectural reasons in building cladding and other applied surfaces. Specifying large radius curves on architectural facade units, is cost intensive. A visually similar result may be achieved with a series of straight broken elements assembled in a curved footprint where budget constraints do not allow for a true curve.

MANUFACTURE Curving a unit is generally more expensive than using straight elements and should be allowed for in the budget. Large radius curves, say greater than 2 metres, generally will not present special problems in achieving selected finishes. Moulds incorporating curves must be constructed so that reinforcing can be placed and concrete poured without difficulty. With moulds curved vertically there is always a higher risk of air being trapped and large blowholes being formed along the height of the unit. Pouring into curved mould configurations may increase the risk of segregation, which will affect exposed aggregate finishes.

It is common to have circular column cladding made in two halves. Experienced precasters will be able to limit segregation and blowholes in such units to within acceptable tolerances.

Specialist manufacturers, suitably equipped, can manufacture circular sections using a spinning process. This will ensure a very dense finish and assist in eliminating segregation.

FINISHES

paint For a painted finish to be acceptable, a high quality mould is required. In Australia most moulds are steel, although timber, concrete and fibreglass are also used. High-build paints are preferred but any airholes that will not be effectively hidden by the paint should be filled.

off-form Off-form finishes to Class 2 of AS3610 are difficult to achieve under ordinary conditions. Introducing curvature may add another degree of difficulty. Samples should be prepared or similar building examples should be inspected where there is any doubt.

sand-blasted It is common to have curved sandblasted units. Matching the colour of the matrix to the coarse aggregate usually provides a forgiving finish, allowing even small radius curves to be successfully manufactured.

etched Etched finishes are susceptible to segregation and trails left by escaping air which may be accentuated on curved units. Test samples should be assessed prior to finalising the finishes selection.

polished Polishing curved units are an additional cost that must be allowed for. Units with a convex face, such as circular columns, can be polished by rotating them under a polishing machine. Some curves can be polished by hand which will incur an additional labour rate. Generally, concave curved units cannot be machine-polished as a rigid flat polishing head is used.

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