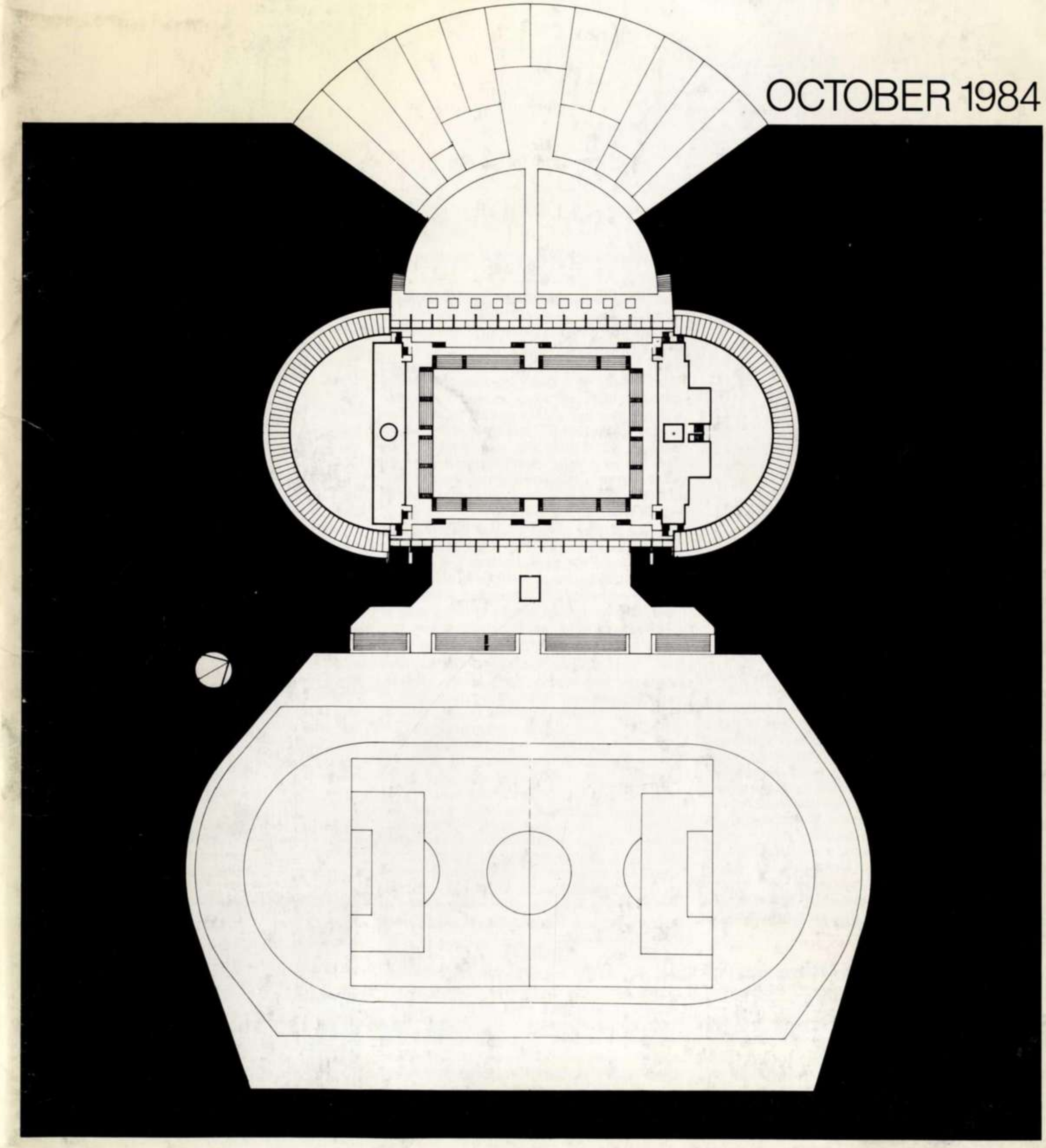
THE ARUP JOURNAL

OCTOBER 1984



THE ARUP JOURNAL

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Back cover: Stuttgart Art Gallery (Photo: Peter Walser)

The Festival Hall International Garden Festival Liverpool '84

Arup Associates Group 4

An Introduction by Richard Frewer

Background

With the 16p commemorative postage stamp and the royal opening in May it would have been difficult to avoid knowing of the first International Garden Festival Liverpool '84. It has acted as a focus for political mud-slinging for the last 18 months, and most of the journalists who have written of it during its construction have been determined that it was a political stunt which they appeared to hope would be a literal and proverbial wash-out. In the event, whatever you think of the way it has been conceived, the Festival has given a great deal of pleasure to 2 million people to date and has given Liverpool some much needed positive advertising. 3 million visitors were anticipated in the original plan; it now looks as though this target will be passed.

Urban renewal

The Festival was never planned to be an end in itself; it is the second stage of a reclamation of this land for mixed use – a park, a sports centre, an area for industry and for housing, and with a new road connecting these to the renovated dock area.

The first stage was the reclamation of 105ha of derelict land, originally used as a marshalling yard and fuel store, but for the past 20 years as an enormous domestic rubbish dump. It represents one of the largest exercises in urban land reclamation ever carried out.

The Liverpool City Council which changed from Liberal to Labour control at the vital moment last year, has moved from total support through total opposition, and now to the position of requesting that the whole site, not just a third of it, should be left as a park because the locals have found it such a revelation. However, the Council still claim that the intended conversion of the Hall is a waste of resources.

The originators of the Garden Festival idea found a champion in the Merseyside Development Corporation who are charged with the revitalization of the river on both the Birkenhead and Liverpool sides. The idea was born well before the summer of the Toxteth riots, so any connection between the two is purely a coincidence.

The first British Garden Festival was originally intended to be a solely national event; it was only through the hard work of Lord Aberconway and his deputy Martin Slocock and against a background of considerable opposition from the Europeans, that it gained international status. Whilst at the British Day at 'The Floriade', the Dutch International Festival in 1982, I was told by the Dutch Commissioner that it was impossible to do such a thing in two years. They had taken eight. Clearly in two years the Liverpool site is a very different site to the Dutch example, which was much more mature. However, Liverpool delivered on time and it is there for all to see, and now in August, halfway through the Festival it is looking very lush.

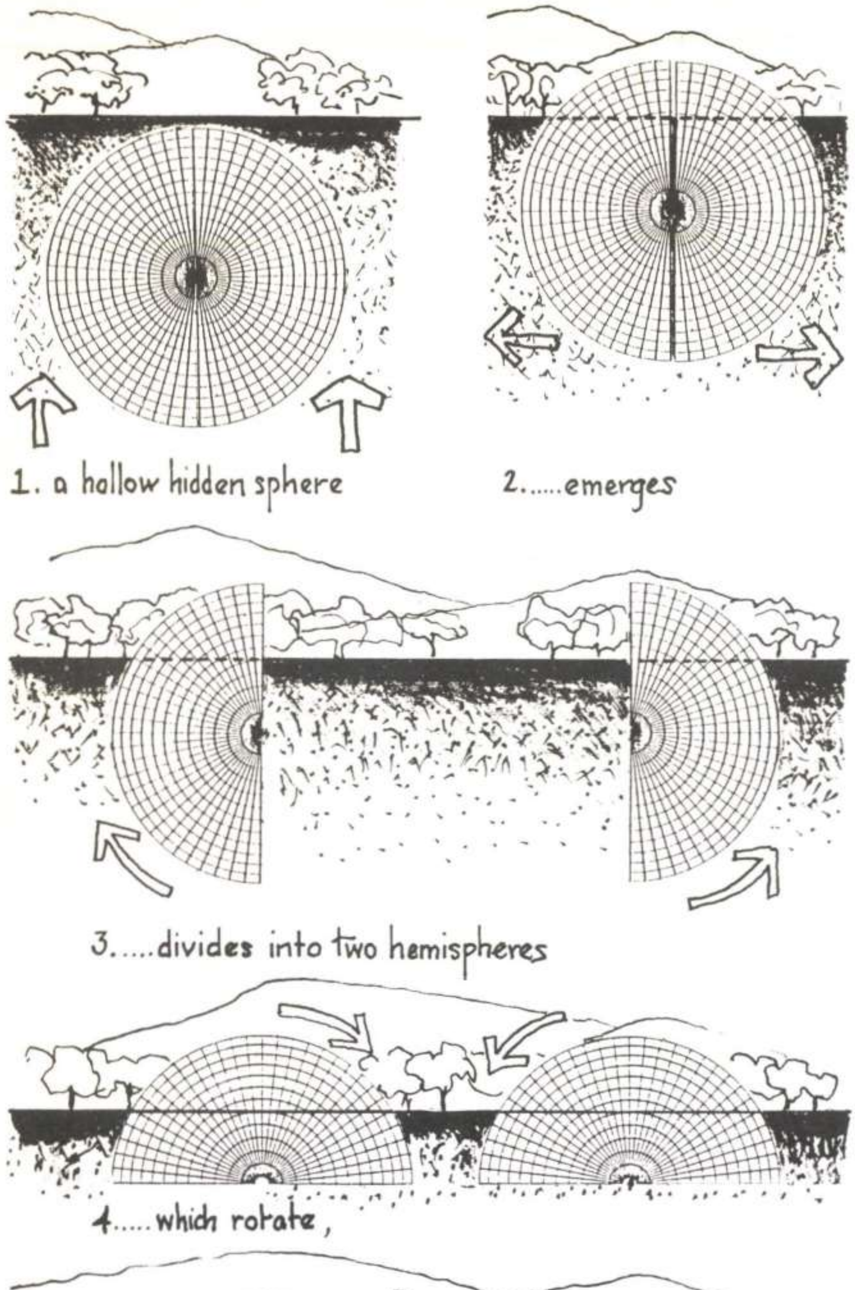
A feasibility study for a Garden Festival was carried out in the autumn of 1981, and from it arose the suggestion of two national design competitions. Remember, it was at the time of Heseltine's initiatives. These competitions were for a festival hall to be converted into a major sports complex, and a landscape competition, this latter being won by Derek Lovejoy & Partners, for a water feature illustrating the river from its source to the sea.

By this time a site reclamation team was set up to relandscape the site and to cap and drain the methane from the rubbish-filled site. The main land forms had been fixed, and a design co-ordination team had been appointed. This background was all part of the competition conditions.

The competition

There were three major national architectural competitions instigated at this time. The building by the Thames to replace the 'Green Giant' proposal, the National Gallery extension and the Liverpool Garden Festival Hall. The Green Giant replacement has still to appear, the National Gallery has recently been through a Public Enquiry and only the Festival Hall has been realized.

This says as much about the method of competition as about the clients' and their chosen architects. The National Gallery competition was open to any developers and their architects; the Green Giant site competition was similarly organized. Merseyside Development Corporation invited architects to submit their credentials, not only of their competence in design, but also their ability to deliver on time. Obviously this was a vital consideration when the opening date of 2 May 1984 had already been fixed. From this long list, six firms were chosen to submit designs – Nicholas Grimshaw & Partners, Terry Farrell Partnership, Faulkner-Brown Hendy Watkinson Stonor, Brock Carmichael, Austin-Smith Lord and Arup Associates.



The form emerges

The brief for the Hall

The very idea of the Festival Hall in Liverpool was tied from the beginning to its use after the Festival as a sports complex. The Liberal chairman of the City Council at the time, Sir Trevor Jones, had a brief written for a sports hall to be compatible with the overall size of the hall. The brief for both uses was put together in a very short period and not surprisingly there were a number of serious inconsistencies.

The sports brief asked for a building to accommodate three sports halls, six squash courts, a leisure pool, a practice hall, projectile hall and all the ancillary space. It was also to include seating for 4,000 people for exhibition match purposes, and a changing suite for the outside sports track and arena. The Festival Hall was by comparison a simple brief for three exhibition halls, each of which could be used separately or together in any combination. At least one of these spaces had to be glazed sufficiently to act as a conservatory.

Competitors only had some eight weeks in which to produce their design, and by the time a team had been assembled and Easter had cut across it, the period of design was very limited.

The priorities of the design

From our first look at the conditions and the site, the priorities of the design appeared plain.

The design of the 105ha of festival site was to be a conglomeration of small-scale garden elements, none of which was formulated at the time. They needed something of scale to hold them together, and it appeared that the bulk of the building would be similar in scale to the land forms, and could perhaps complement them in a single statement. As some of the land forms were to be higher than the building it would be looked down upon and so its roof was of prime importance. The organizers asked for the limited money in Phase 1 to be spent in such a way that it went as far as possible towards providing permanent enclosure for the sports complex.

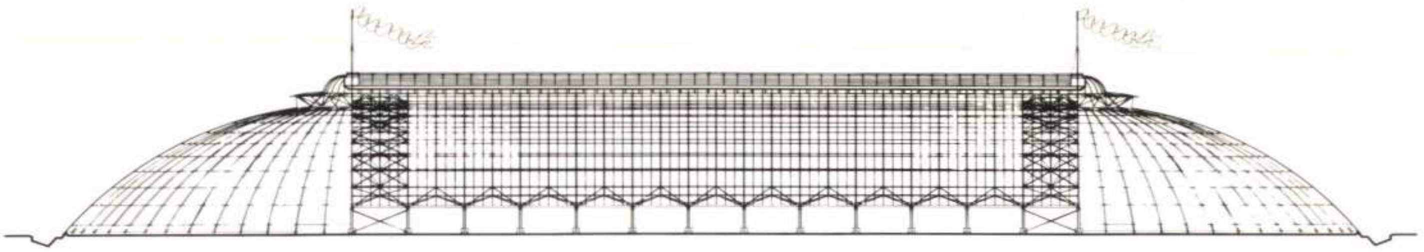
Although everyone now judges the building in its present use, the real problems of the brief related to satisfying the needs of the sports complex.

The options

There were two ways of tackling this design. One was to design a specific building to satisfy the sports complex, omitting parts for the festival phase. The other approach, the one that Arup Associates took, was to design a 'loose fit' building. That is to say, to design an envelope or enclosure which could take a great deal of variation within the brief. As I have said before, the sports and festival brief did not appear to agree so we had to be ready either to decrease the size of the sports area or increase the area of the Festival Hall without invalidating the concept. Speed was of the essence, and having previously won competitions we were very aware that the one certainty in the scenario was that there would be enormous pressure first to stop the building from going ahead, second to change the site, third to overturn the brief and, in consequence, the concept.

With these thoughts in mind we needed an idea which was strong in its identity, but which gave our potential client the maximum freedom. This may appear a cynical view, but the realization of any building is equally about understanding the nature and requirements of one's client as it is about design.

It would be useful to be able to discuss the design process which was followed to reach the solution. But in the end conceptual design is not a purely sequential pro-



cess and all we can do is to describe the intentions and priorities held at the time and the way they were met by the idea. Design is created by developing attitudes to different and ever changing areas of concern. These concerns can be touched upon but they are in themselves only signposts. A hypothesis, as in any 'scientific' pursuit is proposed and tested. It either holds truth or not. It is a delicate balance of the rational and the intuitive with the one informing the other within the light of previous experience. The Festival Hall design problem was a particularly clear example of architecture and engineering being of equal importance within the hypothesis.

The areas of concern were all illustrated in the report which accompanied our competition entry. There are copies of this which can be read in the Arup Associates' library.

These concerns are summarized here:

- Could the building be converted into a sports hall of variable brief?
- Cost of the project was strictly limited, how could the money best be used?
- Would the running and maintenance costs be low?
- If the cost was to be low, could each element be exploited in a number of different ways?
- As the client's priorities were not clear, could the way in which the money might be spent in first phase be left flexible?
- Could the building itself be a heat source or heat sink?
- Could the level of natural light within the building be changed?
- Could the building be demountable?
- Had the idea an inevitability and rightness in plan, structure and form?

Some would contend that the qualities of a building should be understood by the designer completely at its inception. I believe that this is an extremely limited view. What we understand is but the tip of the iceberg – there is much more in the subconscious and this we must learn to rely upon. This is fully accepted and celebrated in the performing arts, but in architecture, an applied art, 'Art' is often justified out of existence. Let us respect and draw upon our dreams. Charles Darwin put it well, 'Our failure to understand nature is not a failure of logic but rather a failure of the imagination'. Architecture that balances logic and imagination is most vulnerable – it is that balance for which we strive.

The building's identity

This was summarized in the introduction to our competition report. It expressed our concerns then and can now be read against the finished building.

The essence of a festival building

A festival is a celebration and consequently its main building must reflect this mood. The festival building, like a theatre, is a shell within which the widest possible range of festive events can be mounted. The design of a garden festival building should be perfectly balanced with the scale of its surroundings.

The architectural idea

The architectural form must be designed with a simplicity and immediacy which everyone can understand – but it must hold great richness. Like a poem, the total shape is enjoyed and then each part holds many meanings.

Intellectual clarity

A building of absolute simplicity and visual clarity is required to tie together all the separate small-scale elements within the festival park. The festival needs a very strong statement. At the same time, the festival hall must act as a backdrop to the fascination of studying plants at the smallest scale and should feel welcoming to the thousands of visitors. This clarity must, in the fully developed design, have a consistency, when viewed 'from 40,000 feet' or at the closest range.

Primary geometric forms

The use of simple geometric forms in harmony with the surrounding landscape give the strength necessary. These forms are highly evocative, and are universally understood.

Technology as a means not an end

Ease of construction, economy of means, programme, low maintenance and running costs are all important considerations, but this is not a technological celebration, this is a garden celebration. The building must take its major character from the gardens and the exhibition.

The form has many metaphors – it is rich with association. Those spoken of include a grounded air ship, a submarine, emerging spheres, a glistening raindrop, the Kew Palm House, the Crystal Palace, a great beetle, a land form.

We have been asked on occasions to show people around the building. Our answer is that it is a single space, so can be seen at a glance and needs little explanation, but it should be experienced. Still pictures of such a building cannot do it justice. It is a building that does not dominate its site. It appears and disappears, and acts as a quiet backdrop to the exhibits which surround it.

The planning solution and its realization

The enclosure was to have within it an arena which would act like a buckle, dividing the three exhibition spaces and giving control of each space separately.

In the event, because the sports brief was left undecided by the City Council, it could not be included. Consequently the umbrella alone was left.

At the time of submission of the building the materials for the enclosure were left as a series of options ranging from glass and polycarbonate to teflon and polythene in the central section, and metal covered ends which would be detailed according to performance and price.

The final decision depended upon our client's final requirements...

An innovation was proposed which was not realized; this was the inclusion of a solar roof over the vault within the polycarbonate double skin. This technique has been employed by Arup Associates in solar panels. It has been patented as a window technique, but has never been used on this scale.

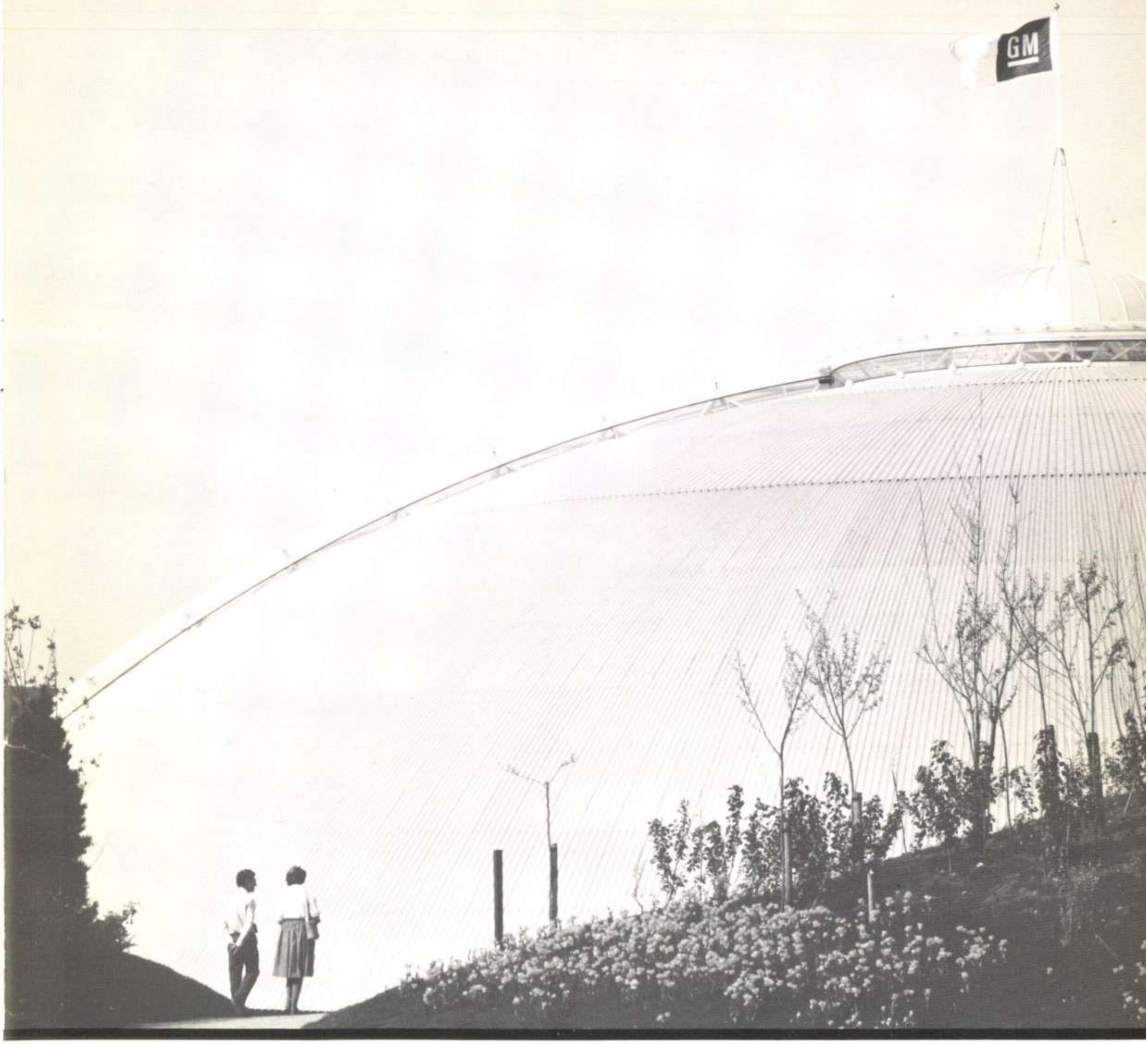
The idea was to circulate a fluid of high heat capacity and variable opacity through the ribs of a twin wall extruded polycarbonate sheet. These sheets would then be plumbed to a series of pumps and heat storage tanks and the heat used within the building or recirculated to increase the insulation value of the building. The variable opacity or even changes of colour can then control the lighting properties of the space, greatly increasing the range of possible uses. The company McKee Solaronics, who patented this method, have now been linked to Dunlops and are continuing to develop these ideas.

Future possibilities

The method was not used in the end, but provision has been made within the strength of the structure to allow for its later addition. The problem of hydrostatic pressure within polycarbonate is still to be totally solved but this is an idea, perhaps five years too early, which will have exciting applications for large-span structures such as these in years to come.

The form is approached

Design of the structure



Site

The festival gardens cover an area of 105ha and are sited on the Dingle Municipal tip, an area sandwiched between Toxteth and the Mersey. Domestic refuse has been deposited over the past 20 years in thicknesses varying from 4 to 10m.

The building is positioned within an area that was originally a railway marshalling yard serving the nearby docks and wharves. The area had been built up into a platform of hardcore, and partly covered by a mass concrete slab and eventually overlain by about 4m of domestic refuse. As part of the civil engineering operations (controlled by MDC) refuse within and around the general building area was removed and reinstated to finished ground level using compacted river dredged sand from the Mersey.

Brief

The final brief called for a building that could accommodate two quite different functions; primarily it should form the focal point of the festival and provide a weather-tight enclosure for a great variety of events and activities. Subsequently the building enclosure should be capable of being economically and easily converted into a sports and leisure centre. Facilities included divide broadly into three main categories, thus:

(1) A leisure pool with wave machine, beach, refreshments area

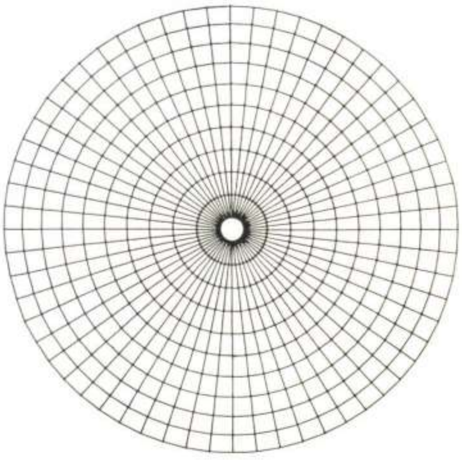
(2) A multi-purpose sports hall with provision for exhibition matches requiring variable seating for up to 3,000 spectators

(3) Various smaller scale 'club' activities, including squash, gymnasium, projectile hall, etc., plus refreshments and administration offices.

Each of the above have differing spatial, environmental and organizational requirements.

This second stage was fairly loosely defined however, and a degree of flexibility was required in the general planning, although it was requested that the fabric of the building should be permanent and suitable for Stage 2.

Photographs in this article are by Judy Cass, John Mills and members of Arups



Enclosure

Study of the brief generated the following design criteria relating to the building enclosure:

(a) To form one enclosure which would both unite and yet define and express the three principal activity areas of pool, hall and club

(b) To provide an 8,000m² column-free space, and so give flexibility for both the festival and sports complex

(c) To form a minimal external surface requiring little maintenance, being durable and technically efficient in many ways

(d) To form a natural relationship to the landscape which would give pleasure within the festival park.

(e) To possess an identity reflecting the spirit of the festival and Liverpool's architectural heritage.

Structural form

The structural form is a direct and specific response to the foregoing. The arrangement of structural elements changed little from the original competition entry, and were derived principally from the following:

(1) A compatible geometry to unite domes and vault

(2) The need for dome and vault to have different cladding suggested that the domes connect via the lower layer of the double layer vault, thus expressing the transition externally and preserving the clarity of the structure within

(3) A convenient and regular structural grid for the attachment of external and internal cladding. A 3m structural module was chosen permitting relatively slender longitudinal members

(4) Evenly distributed building dead and live loads and the ability to absorb differential settlements

(5) Simplicity and clarity of design, fabrication, construction and perception.

Primary elements

Vault

A two-layer barrel vault structure 78m long, comprising braced arched frames of three pin configuration at 3m centres with upper and lower booms connected by longitudinal members. The lower layer connects the domes and supports services and acoustic-panels in selected areas and provides the path for the axial forces from the domes. The upper layer supports the external cladding.

The intermediate arch frames are connected by braced frames which, with the on grid frame, transfer their reactions to bipod frames at 6m centres. Roof cladding terminates at an eaves gutter which discharges into a rainwater pipe running above the inclined leg of the bipod frame.

Domes

The half dome at each end is of segmental, ribbed, single layer construction with circumferential rings at 3m centres connected via the longitudinal members in the lower layer of the vault.

Thus the continuity of the dome rings is maintained and the out-of-plane forces at the junction of dome and vault are resisted by the flexural and transverse stiffness of the three end arches combined with their three-dimensional bracing.

Foundations

Loads on the foundations were relatively small (a typical arch thrust being approximately 450kN D + L). Overturning moments were high due to the level of the springing point of the arch (approximately 4.7m above the underside of the footing). This was overcome by displacing the footing so that its centre of gravity approximately coincided with the line of thrust passing through the inclined bipod leg. The maximum allowable pressure at the underside of the footing was restricted to 150kN/m².

The vault bipod frame foundations were inverted tee reinforced concrete spread footings tied across the vault by mild steel bars (pretensioned) to resist the horizontal thrust from the arch.

The dome foundations were concrete ring beams forming two semi-circles on plan, connected longitudinally by mild steel pretensioned tie bars.

The diameter of the tie bars was sized on permissible strains (horizontal deflection) rather than stress.

Modelling and framing configuration

Following the definition of the conceptual design it was clear that in order to maintain the building's simple elegance the structure should be well-defined, simple and precise. It was important that the underside of the vault be a single unbroken line along its length and that the undersides of the connected domes be a continuation of this alignment. It was of equal importance that the joints be functional and aesthetically pleasing and that stability structures be simple statements of function. The structure divided naturally into three parts: the two dome sections connected by the vault.

The vault required only horizontal bracing in order to provide stability; the dome sections required horizontal and vertical support at their discontinuous vertical edges.

Studies were made into the economic spacing of the vault frames and whether a two or three pin configuration would prove more economical. These were carried out ignoring any interaction with the dome ends.

Studies were made, influenced by architectural considerations, for the moving of the central pin from the mid-point position between top and bottom booms to the centre line of the top boom. The initial studies of the dome discontinuity support showed that stability could not be achieved within the dome structure itself without massive and quite out of proportion members. It was therefore decided to make use of one of the dominant architectural features of the building, namely the oculus – the continuation of the ventilator structure.

The principle here was to introduce a semicircular (in plan), triangular (in section), braced girder which would cantilever from the last three vault frames and pick up the braced in plane ends of the dome ribs. It followed from this that these three end frames were treated as braced bays with in plane and out of plane bracings providing horizontal and vertical reactions respectively to the out of balance forces arising from the dome discontinuity.

The studies into vault frame spacing and configuration when combined with the ease of erection, cladding fixing and access into the building, etc., resulted in vault frames spaced at 3m and with alternate frames being supported off the adjacent lower pins with bifurcated braced frame. This gave a frame spacing at ground level of 6m.

The configuration chosen was of the three pin type with all three pins on the axis of the top boom.

The penalty paid for the choice of three pin was a small increase in the maximum bending moment of the order of 10%. This did not cause sufficient changes in member forces to give a change of section size.

When this was compared with the advantages to be gained in both off and on site fabrication plus ease of erection the choice became obvious. Combined with this was the understanding that configuration with the three pins would not be as sensitive to differential settlements of the foundations.

The location of the pins on the axis of the top boom was not so obvious a choice, the principal motive behind this decision being architectural rather than engineering. This resulted in an increase in the top boom thrust of 20% above the bottom boom and a section change due to the redistribution of the axial forces.

The selected cladding module of 3m x 1m led to the primary circumferential spacing of the Warren truss nodes. This gave 11 equal arc lengths of 3m on the centre line of the upper boom each side of the centre pin.

From this came the location of the longitudinal members connecting the arch trusses and the dome ends.

The upper longitudinal member acted principally as a purlin supporting the cladding whilst the lower member carried the residual longitudinal strut/tie forces not catered for by the end braced bay. This lower member also provided compression 'flange' stability during load reversals under the partial live loading condition.

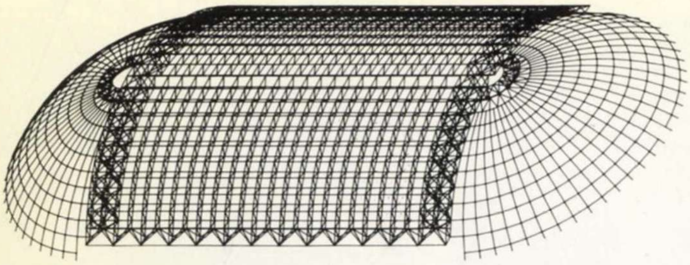
From an architectural point of view it was considered important that the springing point for the arch trusses be located high enough to provide a side wall to the hall. This problem was solved by sitting the arches 2.8m above ground level on a simple bipod frame with the inclined member of the bipod following the line of thrust through to the inverted tee footing, the resultant horizontal thrust being catered for by a 75mm diameter mild steel tie between opposite footings. Longitudinal stability to the pinned junction between arch truss and bipod was provided for by bracing in the plane of inclined lower boom.

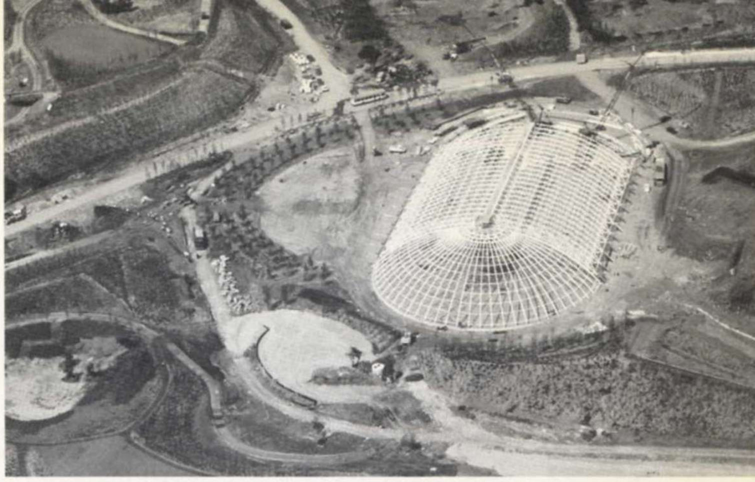
A joist section was chosen as the principal for the upper and lower booms. This gave the advantage of clarity of line whilst minimizing the bulk and making connection easy. The joist section can also be used as a runway for an access cradle.

From this latter potential use it was necessary to set the position of the lower longitudinal members above the bottom boom. These lower members ran continuously along the length of the building emerging at the dome ends to act as both strut and tie around the circumference of the dome. Due to the increase of dimension of the dome rib above that of the lower boom to the trusses, this circumferential strut/tie is discontinuous around the dome with a pinned connection to each dome rib.

The use of curved members for both the vault and dome induced significant secondary stresses in the arch and dome ribs and dome purlins. In the case of the dome purlin this tended to reduce flexural stresses due to dead and live loads.

Large-scale models were made in the office of all the main steel connections as the success of these was paramount in the clear detailing of the building.



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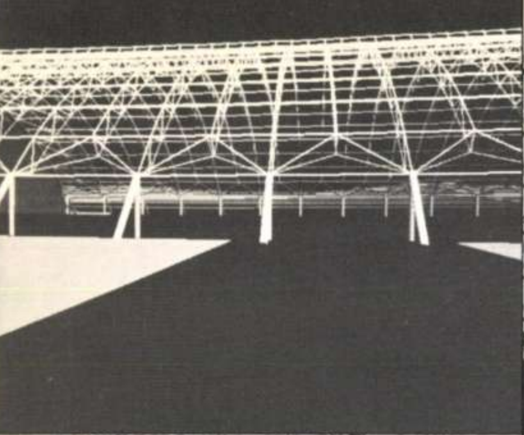
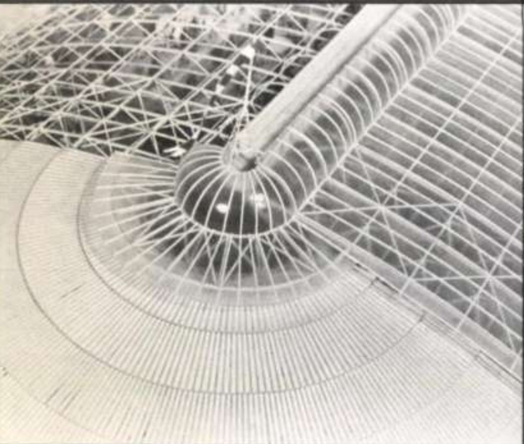
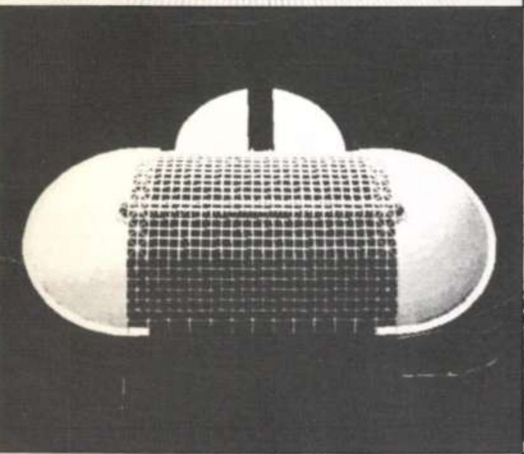
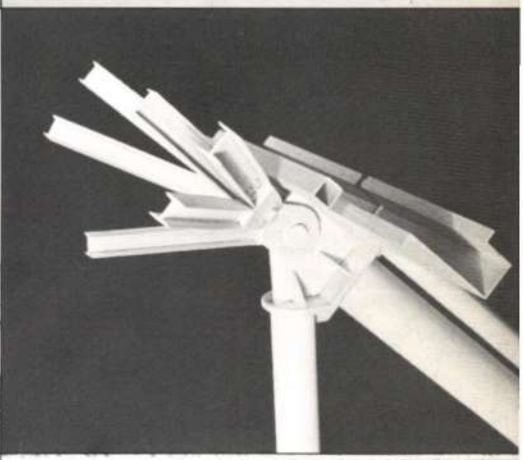
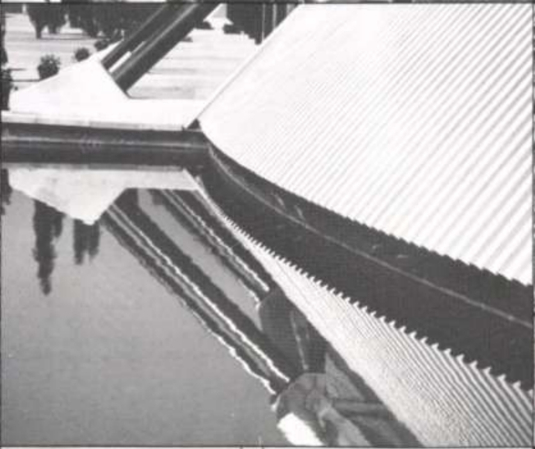
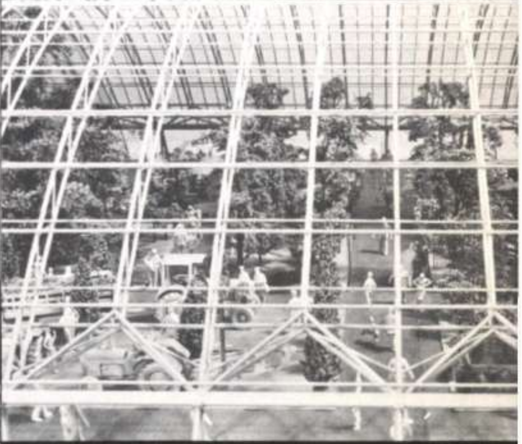
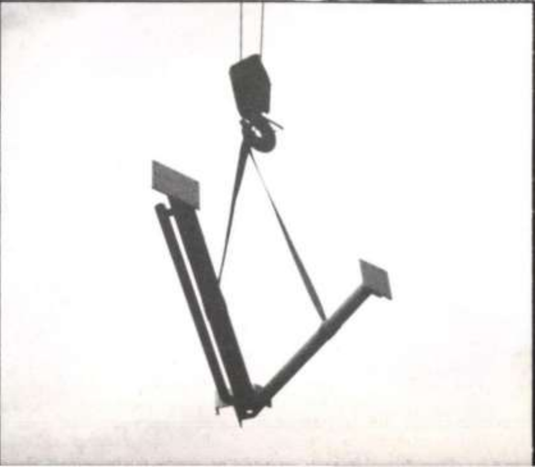






Credits

Client:
Merseyside Development Corporation

Architects:
Arup Associates in association with
Merseyside Development Corporation

Landscape architects:
Arup Associates in association with
the Garden Festival co-ordinators for
the site as a whole

Specialist consultants:
Ove Arup & Partners Geotechnics Group

Management contractor:
Norwest Holst Projects

Stuttgart Art Gallery

Architect: Stirling, Wilford and Associates

David Atling
Cecil Balmond
Tom Barker

Introduction

Stuttgart's Art Gallery opened this spring to much critical acclaim, and to celebrate the occasion a public reception was held for 7,000 people.

The building has been hailed as a breakthrough for the new architecture: an original design that acknowledges the past while creating its own new style. Certainly, if the enthusiasm of the public is anything to go by, the building can be judged a success.

The focus of the building complex is a large open circular space called the sculpture court, around which the various exhibition spaces are planned, opening onto terrace and foyer levels, and linked by a series of curving or zig-zag ramps. An imaginative feature of the scheme is the pedestrian route for the general public, which winds up and round the central court, connecting Konrad Adenauer Strasse at the front of the site with Urbanstrasse at the rear. The public on this route can look into the sculpture court and view the activity of the podium and terrace areas without visiting the gallery.

Local marble and sandstone are used extensively for the external cladding to the buildings. Contrasting with this traditional look are the twisting glass walls of the foyer, the steel lattice canopy structures and the angular lines of the elevations themselves; it is a striking mix of high tech with classical form.

Apart from the art gallery, there is a theatre, a music school and a library in the building complex. The total cost of the project is estimated at just over 82m. Deutsche Marks, approximately £22m. at current rates of exchange.

Background

In May 1977 James Stirling and Partners (now Stirling, Wilford and Associates) were one of 10 architectural practices invited by the authorities of Baden-Württemberg to compete for the extension to the Staatsgalerie, the State art museum in Stuttgart. The Staatsgalerie is a fine neo-classical building of about 1825 located on the edge of the city along Konrad Adenauer Strasse. It is regarded as one of the major landmarks of Stuttgart.

The architect's submission was made in early August 1977. By the end of the following month James Stirling was informed that he had won the competition; significantly no modifications were requested to the winning scheme.

Ove Arup and Partners were invited to design the structure and services for the project, as part of a Joint Venture, with Boll und Partner for structural engineering and Eser Dittman Nehring und Partner for the engineering services. It was agreed that Arups would lead the engineering design up to scheme stage and then transfer the lead to the German-based team for the production of the tender and working drawings.

The official title for the project, given in German was 'Erweiterung Staatsgalerie; Neubau Kammertheatre'. The client was the local government of Baden-Württemburg, the LAND.

The site

The site (fig. 1) which was largely waste land, is approximately 140m long × 90m wide, bounded by the old gallery to the north, by the dual carriageway to the west and minor roads to the south and east. The level difference from west to east, that is from front to back, is 15m.

Site investigation proved that the building would be founded on Keuper Marl with a safe bearing capacity of 40 – 50 tonnes/m^2.

Wells were set up on site to check ground water levels and initially these wells indicated that the major part of the site excavation would be above the water table. But the water in the wells continued to rise, not only in level but in temperature; we had discovered a hot spring! As a result the building was lifted slightly and special precautions were advised for water-tightness of the basement and for the routing and protection of subsoil drainage to avoid contamination of the hot springs.

Concept stage

The initial task for the design team was to work out a structural and services concept that would fit the tight planning of the various levels and yet not raise the building height above that of the existing gallery. Keeping the basement excavation to the minimum, and out of the water table preferably, was an added constraint to vertical storey heights.

For the structure, downstanding beams were avoided where possible. Floor slabs were designed to span directly onto columns or to be supported by walls serving as full storey-height beams. In Germany, reinforced concrete wall construction was priced more cheaply than column infill block

Fig. 1
Site plan

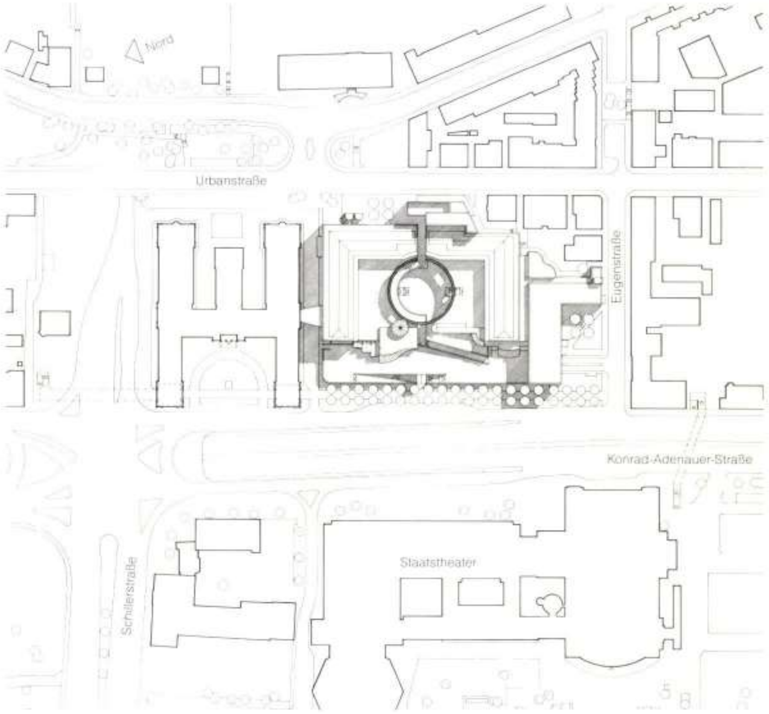
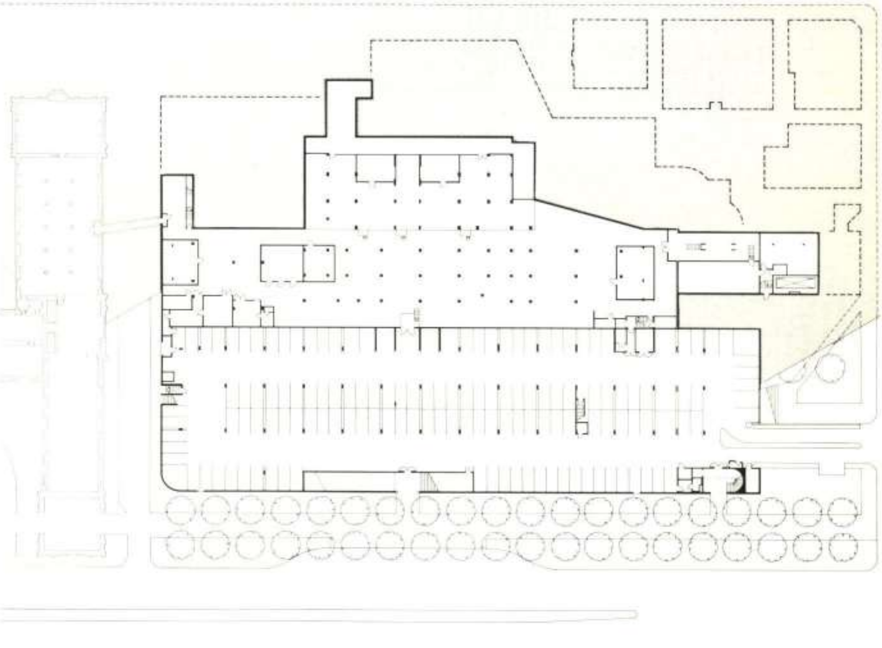


Fig. 2
Plan at car park
and plantroom level



construction, so the use of walls as beams became feasible. This was also compatible with the planning of the internal spaces.

Flat slabs supported by these storey-height wall beams kept the horizontal structural depths to a minimum.

The use of walls, however, restrained the structure to the extent that the conventional approach to expansion joints could not be adopted. The 102m × 90m gallery structure, being exposed externally to a temperature range of ±20°C and internally to an air conditioned environment, would normally have needed more than one break line in the structure, as early sketch proposals indicated. However calculations showed that the extra cost of reinforcement was about 4% for having no joints in the structure. It also meant that the possibility of water leaking through joints in the structure and damaging valuable paintings was thus eliminated. The theatre structure, 37m × 65m, was isolated from the gallery structure by an expansion joint.

The mechanical system chosen was an all-air system with low velocity distribution. The layout of the services was planned to avoid large ducts running horizontally which would have raised the height of the building. Consequently, the plantroom was stretched out along the whole length of the building with vertical service risers connected directly to strategic areas.

The plantroom is located adjacent to the car park. Excavation and retaining wall costs were reduced by pulling the car parking and plant space as far forward as possible. (Fig. 2).

Above this level are the main features spaces of the foyer, the temporary exhibition room, the large drum of the sculpture court, the lecture theatre, and the drama theatre foyer. The permanent exhibition spaces are on the uppermost level, opening onto terrace areas. At this level there is the theatre and rehearsal room. (Figs. 3 and 4).

It was initially intended to provide a fully glazed roof over the upper gallery areas to maximize natural light conditions for viewing the pictures. However subsequent energy considerations caused the area to be reduced and the roof void was made 2m deep with steel trusses spanning onto the gallery walls, with the ductwork hugging the walls to avoid reduction of daylight.

For maintenance of the ceilings and the daylight control louvres in the roof spaces, catwalks and permanent moveable trolleys were provided within the roof zone, integrated into the structure and services planning concept.

Fig. 3
Plan at entrance level and east-west section

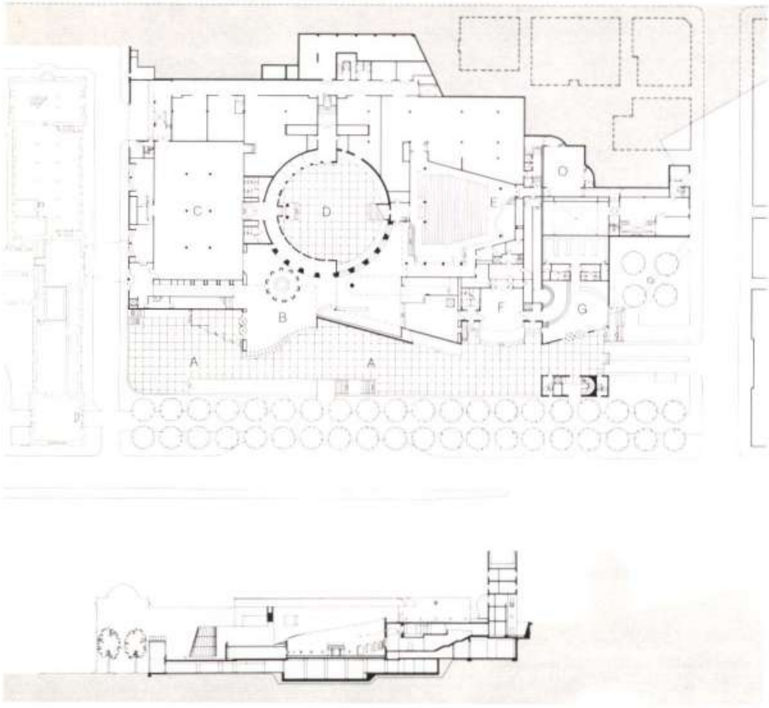
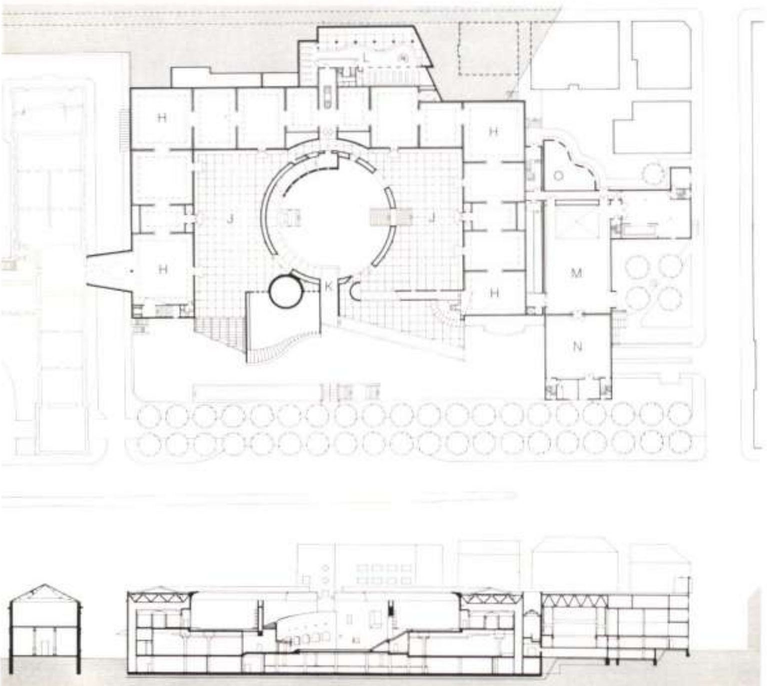


Fig. 4
Plan at Gallery level and north-west section



Design submission stages

The design team presented a report to the client in February 1978 incorporating these concepts, highlighting the total co-ordinated/integrated aspect of the adopted solutions.

At this stage, according to the German State regulations, the submission was classified as the Vu Bau submission stage and Parliamentary approval was obtained for the project.

Being a State project, from the Vu Bau stage the project had to progress through Building Regulation submission to the technical submission stage called Hu Bau. At this point a detailed technical cost plan was drawn up and the project became real with full go-ahead status for the tender.

In developing the concept design to Hu Bau stage the Joint Venture Boll-Arup-EDNP, worked closely together, getting to know each other's approach to engineering and understanding each other's country's regulations.

On the structural side the design had to satisfy a checking authority, the Prufe-engineer (equivalent to our District Surveyor). For the building services design, apart from the local authorities, the client's own State Construction Department had to approve the services installation plant and costs.

Meetings were held fortnightly with the client and the architect in either Stuttgart or London. Various galleries were visited, both in England and Germany, to reach a common understanding of the problems of gallery design.

Though most technical points were resolved quickly it became apparent that a full-size mock-up would be required to test the gallery roof and lighting concept. The client agreed to this and awarded a separate design contract to build a model room in the grounds of the existing gallery.

Various specialists in Stuttgart and Munich were consulted on aspects of building physics, acoustics, and materials to draw up the final brief for client approval.

In terms of our Joint Venture agreement, Ove Arup and Partners had to develop a set of 1:200 drawings, with larger scale details and a set of calculations proving the concept and taking the design to a point at which our German Partners would commence tender/working drawings. The Hu Bau submission was made in July 1978.

Thereafter the emphasis of the project moved to Stuttgart, with the architect opening an office on site. Throughout the course of the project the Joint Venture has continued its collaboration.

Lighting

The competition brief required maximum use of natural light for viewing exhibits. Initially the upper gallery rooms were planned with fully glazed roofs. As the design progressed, however, areas of glazing were

Fig. 5
Sculpture
Court

reduced to lower the air-conditioning load and attendant running costs, but still allowing viewing under natural light for 76% of normal opening hours.

For viewing water colours and oil paintings the illumination levels of 50 and 200 lux respectively were specified on the vertical surface 1.5m from the floors. With artificial lighting these levels are achieved by switching circuits in the upper gallery rooms and by dimming in the temporary exhibition space.

Natural light is controlled by adjustable motorized louvres mounted in the ceiling void. Initially these louvres were planned to operate automatically via individual room sensors. But in the end the client required them to be under manual control of the guide responsible for each room. The substantial nature of these louvres help them to act as anti-burglar devices and also as thermal insulation when fully closed during the winter hours of darkness. The louvres are located beneath the roof glazing and span onto the top booms of the structural trusses.

Table 1

1	2	3	4	5	6	7
Area designation	Air rate m^3/h	Temperature		Relative humidity		Noise level
		Winter	Summer	Winter	Summer	
Foyers	25,000	19 ± 3	26 ± 3	30-60	65-30	38 ± 2
Temp. exhibition	18,000	19 ± 1.5	23/26 ± 1.5	45/55 ± 5	45/55 ± 5	38 ± 2
Lecture theatre	19,500	22 ± 1.5	22/26 ± 1.5	40/55 ± 5	40/55 ± 5	33 ± 2
Galleries/Depot	108,000	19 ± 1.5	23/26 ± 1.5	55 ± 5	55 ± 5	38 ± 2
Roof void	108,000	15 ± 3	35 ± 5	20 ± 5	—	40 ± 2
Theatre	43,500	23 ± 1.5	23/26 ± 1.5	30/60	40/60	30 ± 2

Along the bottom boom of the trusses is a steel grillage to support the ceiling layer which is made up of glass, incorporating an ultra violet filter, which prevents harmful radiation entering the exhibition space. (Fig. 7).

Extensive tests were carried out with paintings hung in the model room for daylight and artificial light, using various glazing solutions for the roof and ceiling.

It was found that the sole use of float glass produced an unacceptable green hue to exhibits. This was overcome by incorporating *Albarino* glass into the system.

Albarino glass has been developed especially for use on solar cells and has very high transmission factors for all wavelengths of light. But expense limits the extent of its use. The final make up of the glazing system was:

At roof level a sandwich of:
5mm thick *Albarino*
1.5mm thick *Thermolux-Gespinst*
5mm thick *Albarino*

At ceiling level 1m × 1m triple-glazed panels of:
5mm thick *Kristal* glass
12mm thick air gap
5mm thick *Albarino*
12mm thick air gap
9mm thick laminated glass incorporating a 1mm thick U.V. filter

Fig. 6
Elevation from Konrad-Adenauer-Strasse

Lighting sources

Generally lighting sources within the development are fluorescent, though in the entrance and reception areas it was intended to use incandescent lamps to create a warm atmosphere.

During the design period new regulations came into force in Germany for lighting schemes in local authority buildings and these dictated the use of high efficiency fluorescent lamps. Though a waiver could probably have been obtained, the architect decided to comply with the regulations and new schemes were successfully developed to mount fluorescent lamps in recesses created in the fibrous plaster ceilings; this effect can be seen in Fig. 8 overleaf.

Building services

In conjunction with the client's technical experts the design parameters for the air conditioning systems serving the gallery rooms were designed to maintain temperatures at 23°C ± 1.5°C during summer; 19°C ± 1.5°C during winter, as shown in Table 1 on the facing page.

Spray washers, containing alkaline water, together with high efficiency filters, were incorporated in the air-handling plant serving the exhibition spaces in order to prevent sulphur dioxide present in the external air damaging the exhibits. In the absence of specific data for Stuttgart a SO_2 concentration level of $0.3 mg/m^3$ was considered. The systems also incorporated frost protection coils and pre-filters, all located at the fresh air intake plenum.

Fig. 7
Roof void above galleries

Fig. 8
Entrance hall

Fig. 10
Gallery lift

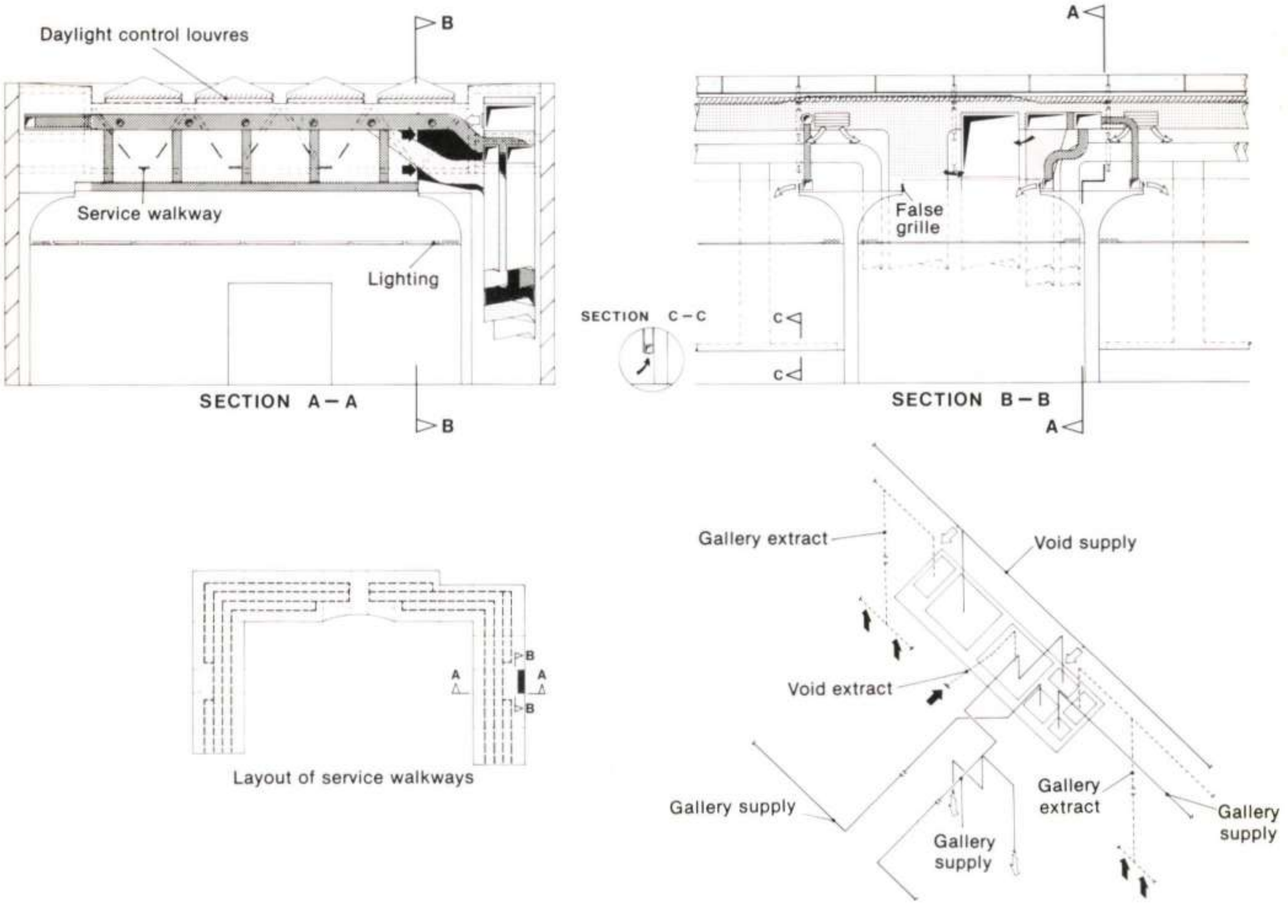


Fig. 9
Detail of services at Gallery level (Reproduced from the Vu Bau report)

Fig. 11
Gallery room from link bridge to old building

Fig. 12
Sculpture

Re-circulation of air is incorporated in all the systems except the kitchen/cafeteria and toilet extracts where the air is exhausted to atmosphere.

For the upper gallery rooms air is ducted from the basement air-handling plant to distribute along the edges of the 2.0m high ceiling void. The supply air is discharged at low velocity, at high level, around the perimeter of the rooms and extracted at skirting level via ducts within the wall linings, equalizing vapour pressure in front of and behind the paintings (Fig. 9).

Since the roof to the upper galleries is almost totally glazed, the ceiling void above the galleries is treated as a buffer zone, with its own dedicated air-conditioning systems. This reduces the air conditioning load in the galleries, permitting solar heat reclaim via the roof, which in turn is used to preheat the building's fresh air supplies.

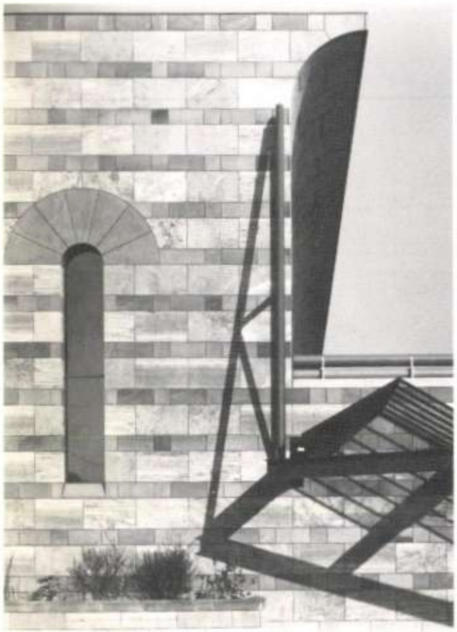


Fig. 13
Detail of entrance canopy

In the theatre areas a 100% recirculation of return air is incorporated to facilitate a rapid heating or cooling of the space. The supply and extract systems were acomodated at high level, above the metal grid ceilings and in the wall linings of the theatre. Supply is through banks of nozzles set in the wall linings and extract is through holes in the concrete ceiling.

A medium pressure district heating main that runs in the road at the rear of the site has been extended to provide the primary heat source to heat exchangers in the basement plantroom. Large chilled water storage tanks are located in the basement plantroom to minimize peak demands on energy.

Electrical energy is obtained at 10 kV from the supply authority and this is transformed down to 380V in the ground level substation at the rear of the development.

Structure

From the outset the main problem to contend with on the structural design of the gallery was the large span of the roofs of the lecture theatre and changing exhibition rooms. The span was approximately 21m and the available depth for structure and services was in the order of 1.2m. The upper galleries and terrace areas had to be carried by these slabs and various grid solutions were tried, from the straight, deep rectangular coffer grid to other configurations that reflected the distribution of bending and twisting moments in the structure more accurately.

As expected, computer analysis gave high torsion stresses in the grillages. But in collaboration with our German colleagues we agreed that the high torsion stresses would not really arise in the actual structure to the extent indicated by theoretical analysis and we put forward a solution to the client of a composite steel/concrete grillage, with slots cut out in the steel webs to allow for the distribution of services. Everyone was relieved that the major problem of span had been solved and that the overall height of the building would remain unchanged; that is, everyone except the quantity surveyor – the cost of the grid solution was prohibitive.

The alternative to the clear span was to introduce columns into these rooms and use a straightforward flat slab solution which would give significant cost savings. The architect was not unhappy with this proposal as the columns introduced a more intimate sense of scale into the large spaces. A further consequence of this decision was that

Fig. 14
Typical Gallery room

the walls of the upper galleries could be located on plan with more freedom, and minimizing the slab depth with the use of large columns heads also improved the available roof void depth at the higher levels allowing for better access and better integration of the structure and services.

During early concept stage the other matter for debate on the structure was whether an expansion joint was desirable or not. Wherever a joint line could be drawn the details became extremely contorted. The tight 'layering' of the various levels did not lend itself to independent structural units; the walls located along all external sides of the building removed any 'give' in the structure at the edges normally free for expansion and contraction, therefore it had to be a 90m × 100m structure without joints. For a while prestress was considered but it was agreed then to abandon a sophisticated treatment of the expansion problem problem and to deal with it by simple crack control procedures, based on the even distribution of strains induced by temperature and shrinkage.

There are clauses in the relevant German Code that enables these calculations to be done quite easily to the Prufe-engineer's satisfaction.

In the detail development of the structural design a series of finite element analyses was carried out on the wall/beam elements. Underneath all bearing points, where a large heavily loaded section framed into a more slender support member, local elastic stress distributions were calculated to satisfy the Prufe-engineer.

For final calculations, consistent with German practice, all foundation loads were marked on a drawing and the long-term settlement of each point was calculated and shown on the drawing.

As a damp-proof membrane was used under the ground-bearing slabs resistance to sliding had to be proven to the Prufe-engineer's satisfaction. A slip circle analysis was done to check earth stability under the stepped cross section of the building.

The retaining wall at the back of the site was designed with steel king posts at 2.4m centres tied back by ground anchors. In between the king posts a gunite skin reinforced with mesh was constructed. Earth pressure at rest coefficients was agreed with the Prufe-engineer for the design of the retaining wall.

To satisfy the Prufe-engineer the structure was also checked out for seismic action – a low base shear of 2% was adopted for this calculation.

Concrete grade was 25 N/mm^2 generally. The reinforcement came to a total of 2000 tonnes. The structural steel weight for the gallery roofs was 42 kg/m^2.

German practice

The scope and duties of an architect or structural engineer in Germany are described in great detail in a document called the HOAI. There are nine work stages from initial concept to final account and percentage fee breakdowns are given against these stages. The work itself has five classifications from simple to complex, with the top category carrying maximum points. The gallery project just missed the top grade according to this classification.

On the services side there is no such document and the fee negotiations are not that straightforward. A similar system had not been formalized for the design of the building services but the basis of fee calculation was similar. However, the fact that the different systems within the total services contract attracted varying degrees of difficulty ratings resulted in the fee calcuations being often more complicated than the design of the building itself.

Imposed loads given by the client were as follows:

Gallery floors Sculpture terrace Entrance podium	500 kilo ponds unit force/m^2
Lecture theatre Studio theatre	(100 kp/m^2 = 1 kN/m^2)
Changing exhibition gallery Sculpture garden General store rooms Ramps for delivery trucks	750 kp/m^2
Sculpture store	1000 kp/m^2

All other loads plus wind and snow loads were in accordance with German Standard DIN 1055

Typical structural dimensions are as follows:

Car park ground-bearing slab	200 mm
Plantroom basement raft slab	400 mm
Changing exhibition floor: flat slab spanning 9 m × 8 m	400 mm
Lecture theatre floor slab: 10m spans	400 mm
Structural walls in general	250 mm
Concrete drum surrounding sculpture court	1.26m thick with void formers

Any special calculations out of the ordinary attracts extra fees. On the gallery project, special duties such as Building Physics (study of gallery walls and roof), reinforcement measures for no expansion joint, ground water problems in connection with the hot springs, all attracted more fees.

As one would expect, there is a great degree of thoroughness in German practice. On this project despite available results from the bore holes, the Government geologist had to confirm officially the water table before foundation design commenced. No one embarks on final calculations without final information. Therefore when revisions are necessary there seems to be a genuine case for extra fee claims.

On site the work force was well disciplined and of a very high quality. Typically the contractor provided small hut shelters on site to enable drawings to be read, sheltered from the elements.

Work on site began in 1978 and the job was completed in May 1984. The Client's own State Building Construction Department, the Staathochbauamt, acted as Project Manager on all phases of the project.

Not unexpectedly James Stirling's innovative design caused some critical debate, mainly amongst the local architectural fraternity when he won the competition. Now, seven years later, the ingenuity of the design not only received much acclaim from the critics, but is so obviously expressed by the public's enjoyment of the building.

For those of us in the Ove Arup and Partners' team who were fortunate enough to work on the project, the last six years have been an exciting and rewarding period.

Fig. 15 left
Theatre entrance ramp

Fig. 16 top right
Sculpture terrace looking west

Fig. 17 right
Entrance viewed from roof
of existing Gallery

Photos:
7/12/14/15: Ove Arup & Partners
5/6/8/10/13: Peter Walser
11/16/17: Waltraud Krase

Credits
Client:
'LAND' Baden Württemberg
Architect:
Stirling, Wilford and Partners
Quantity surveyor:
Davis Belfield and Everest
and
'LAND' Baden Württemberg
Consulting engineers:
Boll/Arup/EDNP
Main contractors:
Dykerhoff & Widman
Fahrion and Barasel

Tolmers Square, 250 Euston Road

Architects:
Renton Howard Wood Levin Partnership.

Michael Courtney

INTRODUCTION

General

The design of a building can be such that no single discipline is dominant but all the diverse and sometimes conflicting requirements are integrated into a single, unique and satisfactory construction.

This idea was followed in the design and construction of an office building in the context of the development concept for an area, and the architectural expression, the byelaws, the financial considerations, the services design and the intended use were interrelated with the structural design to produce the final form of the building.

History of the site

In the last two decades Tolmers Square has been one of the most controversial and complicated development areas in London. It is of historical interest as it is believed that the Manor of Tottenhall mentioned in the Domesday book was situated in the vicinity. In the 17th and 18th centuries Tottenham Court Fair gained a low and shady reputation and in the 19th century the area was developed by speculators as low quality housing for the new lower middle class.

The building of the railways at Euston, Kings Cross and St. Pancras displaced thousands, causing severe overcrowding in adjacent areas, including Tolmers Square, and creating a poverty stricken area. By the mid-20th century the area was extremely depressed and squalid.

Fierce political and sociological arguments raged over proposals for development until in 1973 it was designated a Comprehensive Development Area.

Camden Council appointed the Renton Howard Wood Levin Partnership as master plan advisers to study existing buildings and sites in the area, to define buildings or groups of buildings which could be left, rehabilitated or only demolished, and to develop a comprehensive policy and plan for the area in order to regenerate its vitality and life.

The development plan was accepted. The initial stages concerned infill housing on empty sites and rehabilitation of housing and small business units leading up to recent larger housing developments and an office building on the south west corner (Fig. 1).

Geology

To give a basis for advice on ground and foundation problems and possible solutions, records were studied and an initial site investigation was undertaken.

The area is underlain at a depth of 3.5m to 6.5m by London Clay extending down approximately 60m to the Woolwich and Reading Beds. Over the south west section there is a terrace of Taplow sandy gravel 3m to 5m thick but this tapers out so that to the north east the overlying fill is directly on the London Clay at a depth of approximately 3.5m. The ground water table is perched just above the London Clay.

The ground conditions are complicated by varying ground levels and previous constructions including a foundry, reservoir and shallow wells, and the existing terrace houses. Old foundations are generally spread bricks in the fill.

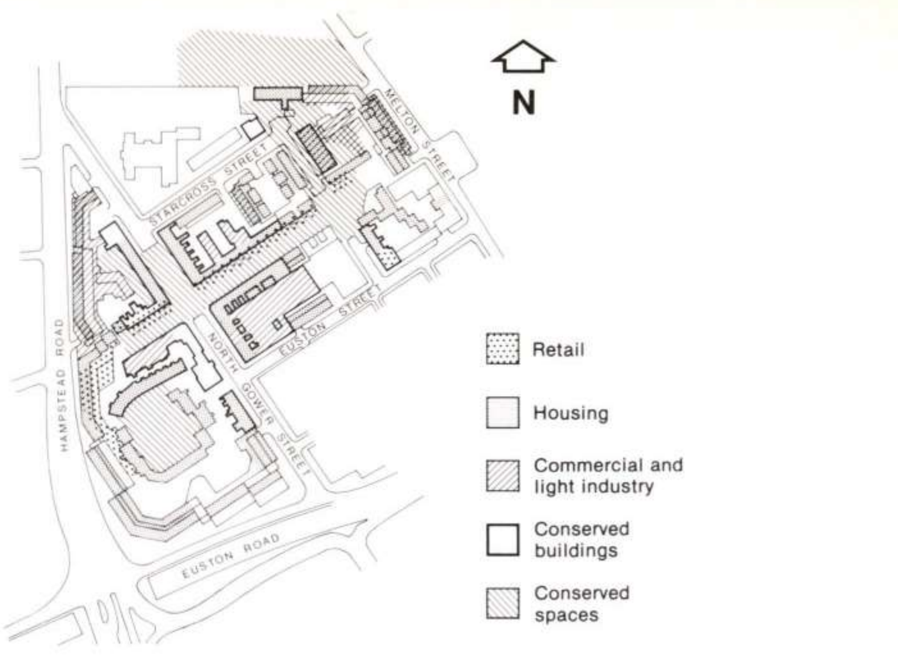


Fig.1
Site plan and development proposals

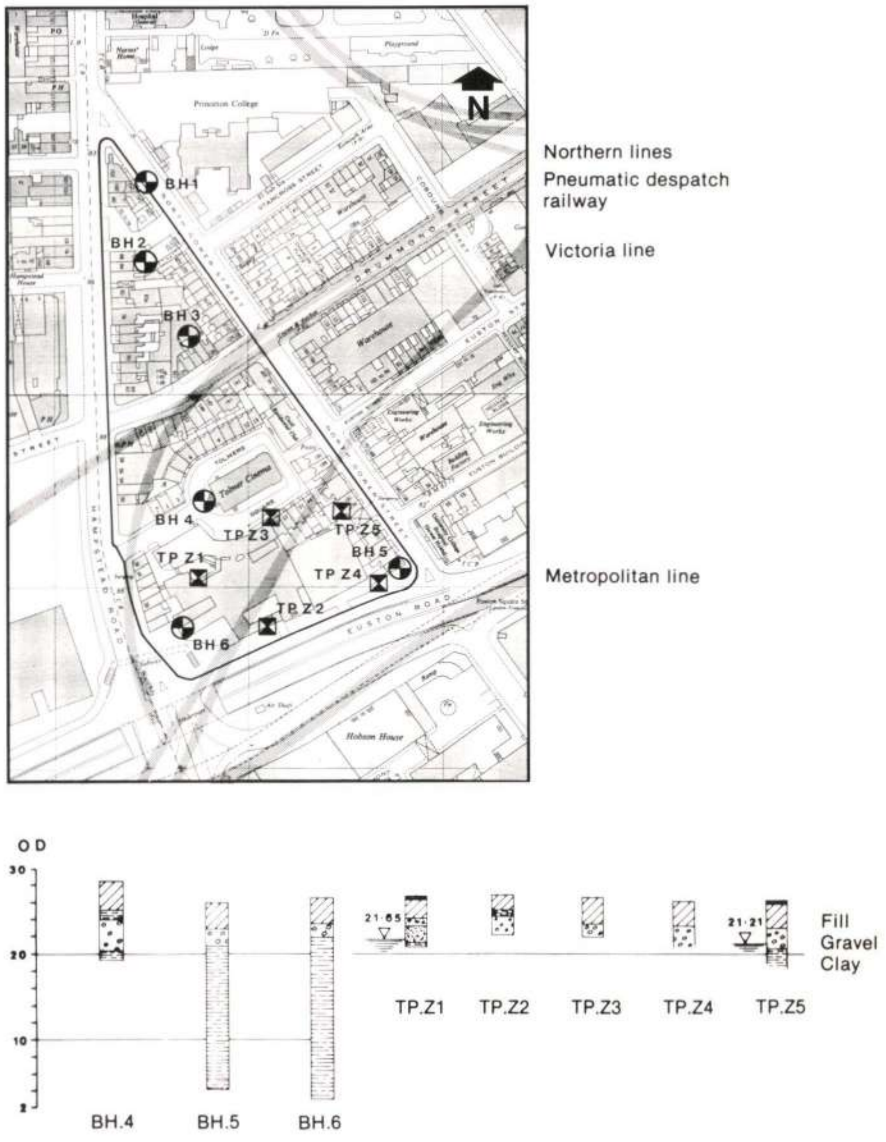


Fig. 2
Subsoil information

Passing beneath the site are the Victoria Tube at 33m depth and the Northern Line at 18m depth. Nearby is the Euston Road underpass and Metropolitan Underground Railway (Fig. 2).

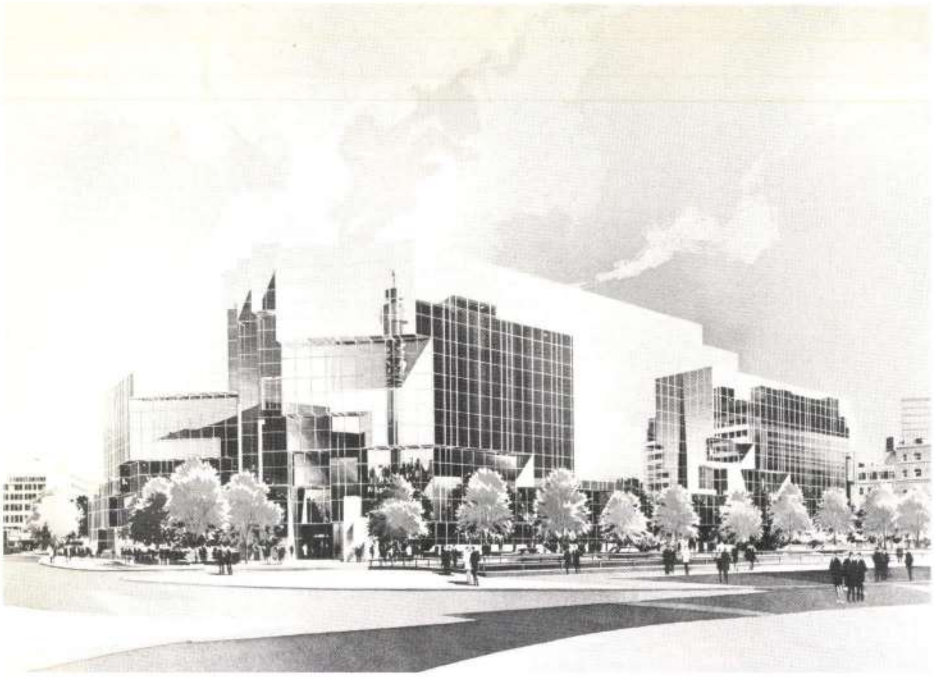


Fig. 3
Perspective of architectural concept

Architectural concept

In 1977 Greycoat London Estates Ltd. submitted a proposal for the designated commercial development area of the master plan at the Euston Road and Hampstead Road intersection.

The architect's concept envisaged the creation of a secluded pedestrian precinct replacing the old Tolmers Square with local authority housing to the north, west and east and office building to the south. The offices would shelter the housing from the noise of the traffic on Euston Road.

Many factors influenced the scheme. The total building height, as a medium-rise development, was restricted not only by planning approval but also to avoid the imposition of excess height requirements of the London Building Acts. The building was to be primarily open plan, 14m across, on a 1.5m module, with variable volume air-conditioning and be adaptable for internal planning. The shape and planning produced a very irregular form but a short building period was required.

The economics of the concept depended on the foundation solution. Previous work in the area for low and medium-rise buildings had established that pad foundations, at depths up to 4m on the Taplow gravel or London Clay, were cheaper than short bored piles. London Transport Executive were concerned about increased loading on the crown of the Victoria Line tunnel, so short bored piles into the London Clay were unacceptable. The tunnels would have to be bridged and deep piles sleeved to transfer load to a level below the tunnels. High level pad or raft foundations were however acceptable.

Initial analysis of the site investigation results indicated that pad footings could be founded on the gravel at 200 kN/m^2 or on the clay at 100 kN/m^2. Crude calculations on likely building weights, pressures and settlements suggested that the most economic height for a standard 14m wide office block on a 1.5m module was therefore eight storeys without a basement and nine storeys with one.

Agreements were reached and design commenced in December 1978.

The noise wall concept developed to be a block building, as if cut out of solid glass, wrapped along the Euston Road boundary, stepping down and marrying into the brick houses of the Square. As well as the noise the glass would reflect back the buildings, life and movement, round, over and under it.

To achieve this, and to match the stepping down and out towards Tolmers Square, parts of the building were undercut to provide a reflective glass overhang (Fig. 3).

Structural concept

The structural concept was developed on a typical cross-section which was later extended to suit the many variations. Structural steelwork was considered but discarded due to the height restrictions, the additional cost and the problems of the irregularity of the building form. For the medium rise building the likely small saving in construction time would not produce sufficient financial benefit to offset the increased cost and additional pre-construction time needed.

A reinforced concrete, flat coffered slab and column frame was chosen to provide a minimum thickness and weight of structure and a fast superstructure construction period. The stability of the building under lateral load is provided by the reinforced concrete walls of the lift, staircase and service shaft complexes. These loads are transferred to the complexes by the floor slabs acting as horizontal beams.

The major structural difficulty was the stepping in and out of the building. To accomplish this by a simple beam and column frame would obstruct the services routes and force an increase in the building height.

By recognizing, however, that the front; Euston Road; side of the building was a different problem from the rear, Tolmers Square, side and by defining a zone for longitudinal services distribution in the front, it was possible to adopt a transfer beam solution for the rear of the building and a different solution at the front.

A vertical column on the edge of the first floor slab with the upper overhanging slabs as cantilevers was unacceptable as the quality of the space generated was too low.

A vertical column on the line of the outermost slab, connected by a slab bridge, to the inner slab, was unacceptable due to the appearance, the difficulties of providing a weatherproof enclosure and the extra costs of the additional mirror glass cladding.

A corbel solution maintaining the columns always in the facade of the building was therefore developed. (Fig. 4).

The corbel-supported columns were conceived as pin jointed, restrained by the slabs to avoid accumulation of moments and to recognize the relative stiffness. Tie forces in the slabs become horizontal loads on the cores (Fig. 5).

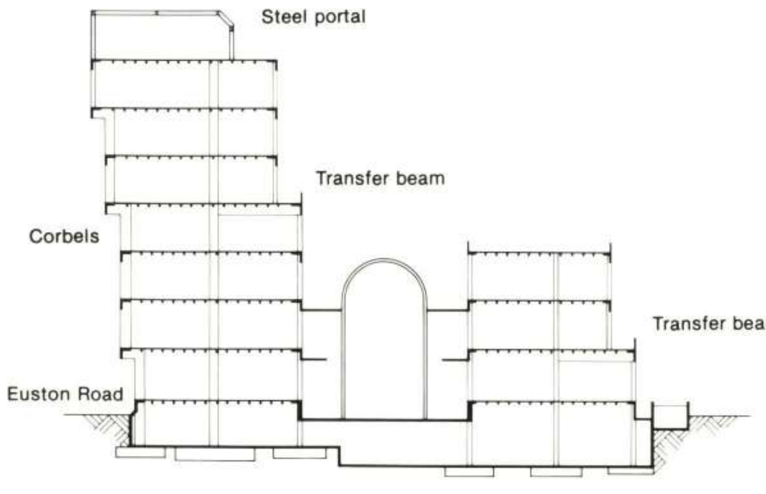


Fig. 4
Section showing structural concept

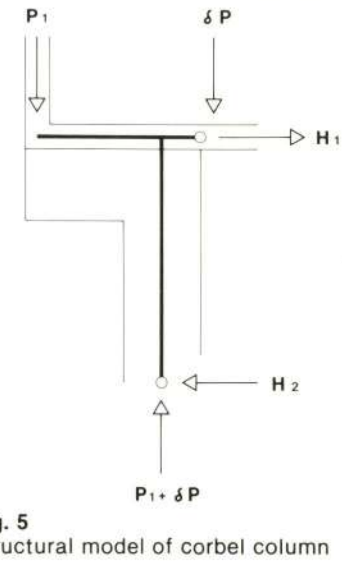


Fig. 5
Structural model of corbel column

STRUCTURAL DESIGN

General

The materials used for the building were concrete grade 30 for the slabs, walls and foundations and grade 40 for columns and corbels. The reinforcement was grade 410 and the structural steel grade 43 to *BS4360*.

A single uniform live load of 5 kN/m^2, together with an allowance of 3.55 kN/m^2 for partitions, finishes and services, was adopted apart from plant rooms where a live load of 7.5 kN/m^2 was taken. This approximation simplifies calculations without appreciable penalty on the structure.

Movement joints

The length of the Euston Road block, with restraint structure at both ends, and the difference in height between the two blocks, suggested a need for movement joints in the long block to avoid distress from drying shrinkage and thermal movements, and between the blocks to avoid possible distress from differential settlement.

Initially it was intended to place movement joints through the main cores, but the development of the planning and the structural stability considerations precluded this, so a single joint was detailed midway between the main cores using a double frame system.

It was also the intention to detail rotation joints between the two blocks. The planning of the basement and ground floor made the detailing of these joints extremely difficult, forcing a searching appraisal of the likely effect of differential settlements. Predicted settlements were calculated using Newmarks Charts and the estimated rotations from differential movements compared with the results of Skempton and MacDonald[1]. The results were acceptable for this type of building so joints were not provided. Actual settlements of the building have been and are being measured to compare results with predictions (Fig. 6).

The coffered slabs and column frames of the superstructure were treated as two-way subframes in accordance with *CP110*. Coffers adjacent to column heads were made solid and shear reinforcement provided.

The moments and forces derived from the stability analysis were added to the subframe analysis to derive the total forces and moments on the members (Fig. 7). In order to assist fast construction the concrete wall structure in the cores was kept at a minimum and downstand edge beams were detailed as precast units and fixed later.

The columns were designed to the forces and moments derived from the subframe and stability analysis. Although the analysis assumed each was a pin at the foot of each corbel column no attempt was made to detail one but the reinforcement was made continuous.

The corbels were designed and detailed in accordance with Kritz & Raths[2], and checked by a truss analogy. The large bars needed were anchored by a plate welded on site (Fig. 8).

The floor slabs were checked for buckling by finding the critical buckling stress in the presence of shear for a safe equivalent panel following deep beam theory and comparing with actual stress. There was a very large factor of safety.

Substructure

The substructure is relatively straightforward in reinforced concrete. In the high block the vertical load-bearing members go down to a ground-bearing slab and pad or raft foundations. Where eccentricities would cause a problem due to the site boundary foundations are combined. Retaining walls span as propped cantilevers from basement to ground floor slabs.

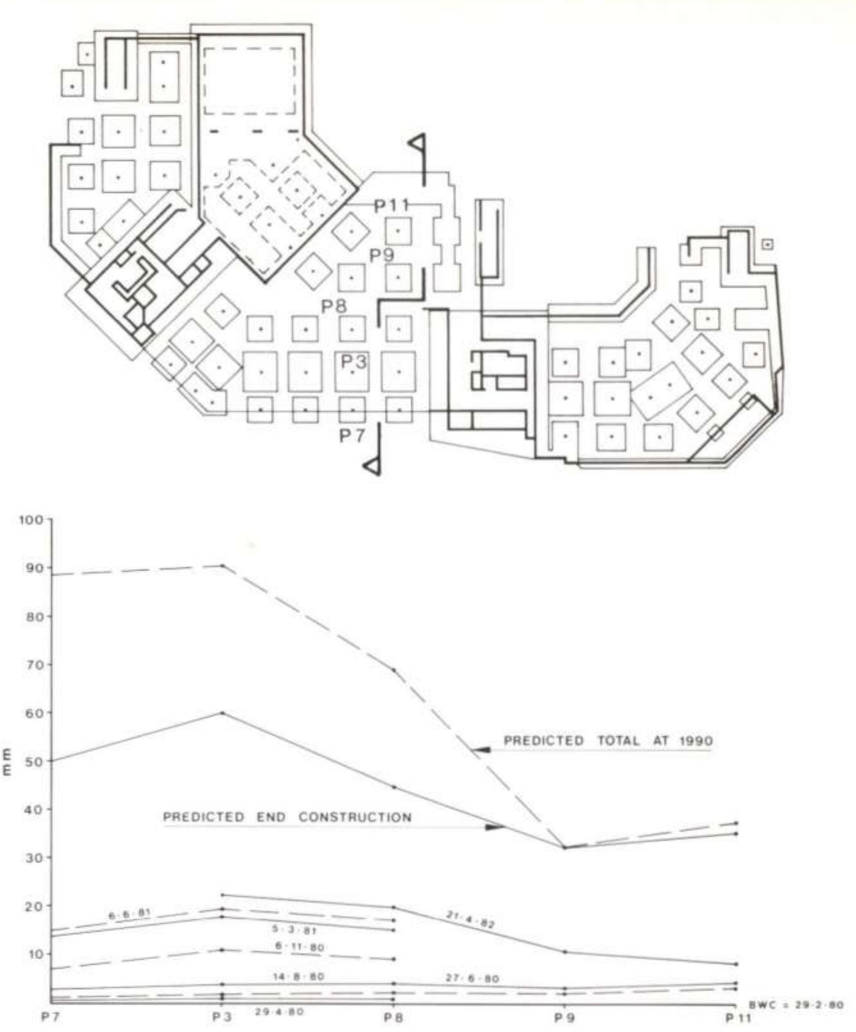


Fig. 6
Foundation plan and settlements: predicted and observed

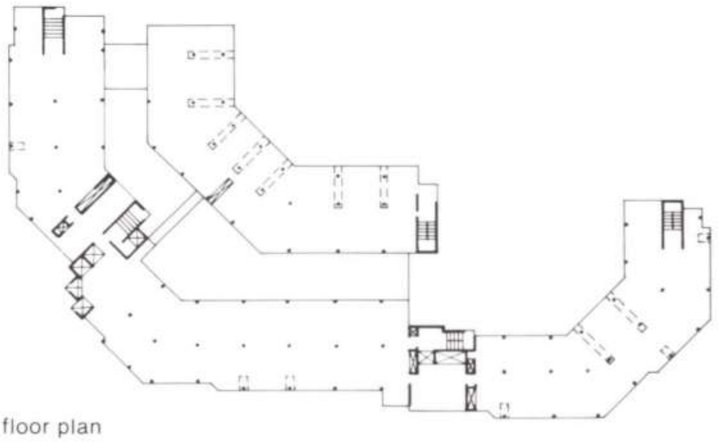


Fig. 7
Typical floor plan

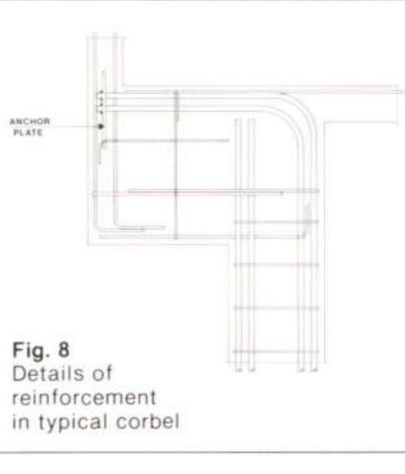


Fig. 8
Details of reinforcement in typical corbel

The basement under the low block forms a gymnasium and squash courts so the central columns are transferred to the external wall line by large beams. The basement is deep so the retaining walls spanning between the slabs are designed to resist water pressure and a drained cavity construction maintains a dry interior.

All the foundations are simple reinforced concrete pad or raft footings, situated to suit the wall and column geometry. The areas are designed to limit the ground pressure to a maximum of 200kN/m^2 on the gravel or 150 kN/m^2 on the clay taking a dispersal at 1 in 2. A triangular distribution is assumed under the core rafts when assessing the effects of moments. The resulting pressures and areas were used as the data for the settlement calculations.

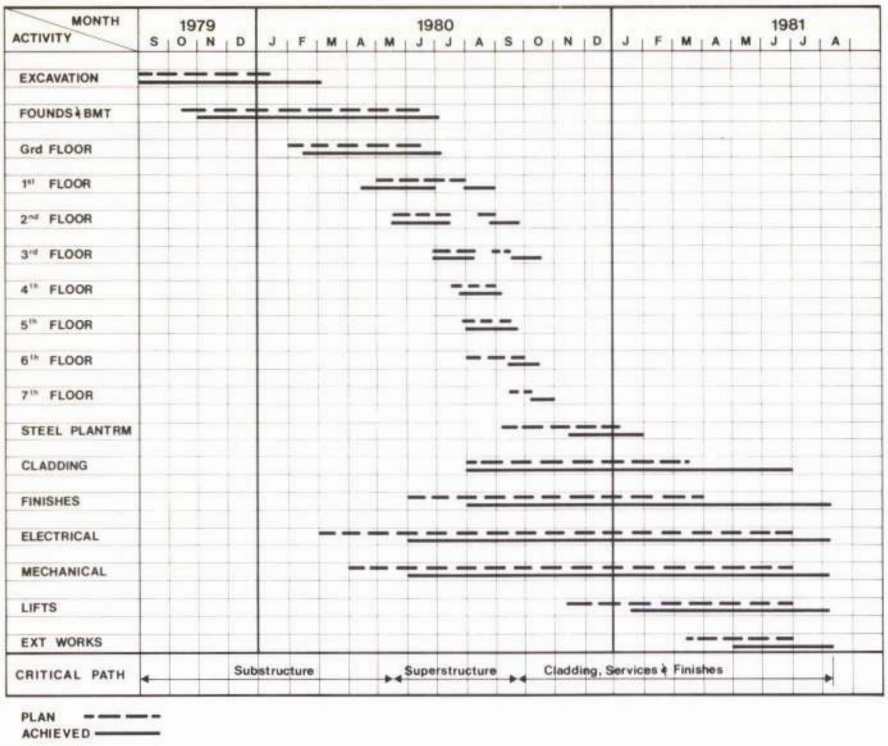


Fig. 9
Programme of construction

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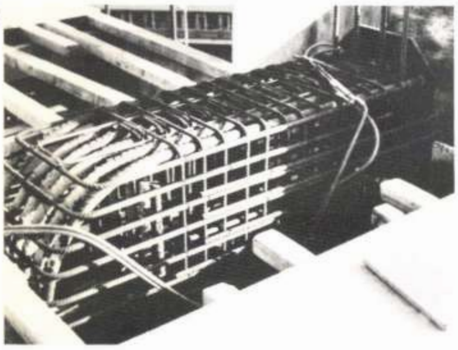

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Fig. 10
Column corbel: reinforcement placed

Fig. 11
Column corbel construction

Fig. 12
View from Euston Road during construction

Stability

The wall complexes of the cores have to resist the shear and moments generated by horizontal forces from wind load on the building facade and tie forces from the column corbels. The cores were analyzed in detail using a program based on the theory of A. Coull and A.W. Irvin[3]. This relates the bending and torsional stiffnesses of the wall elements to a single resultant horizontal load at relevant levels. Where there are major variations in building geometry the structure is effectively cut and the loads in the walls applied thereafter to the levels below. As an independent check on the concept and this analysis, two cross-sections were analyzed as continuous frames with the effect of the slab and core restraints applied as springs at each floor level. The results showed good correlation with the simpler concept which was therefore accepted as safe.

The arcade

The space between the two buildings is a walkway featuring a fountain, planting and seating covered by a glass roof. To express lightness the structure is thin tube columns rising vertically from the ground floor slab and arching over at second floor with spans between 4m and 8m. The buildings are used as abutments to the arches to keep the bending moments and hence members sizes small. The slender columns are then the critical members. The effects of small horizontal and vertical movements of the abutments of the arch were analyzed and found to be insignificant.

PROGRAMME

The financial appreciation of the project was improved by achieving the shortest possible period between agreement to proceed and building completion. Design and construction were integrated minimizing the period before work started on site. It was advantageous in developing a rolling programme of clear priorities and related implications to be able to incorporate advice on construction, design and programming from both the main contractor and the services contractor with whom the project was negotiated. From client approval of principles and instruction to commence detail design in February 1979, the programme anticipated five months for initial design, tender documents and negotiation, with site start in July 1979, two months demolition and a construction period of 22 months to project completion in July 1981 (Fig. 9).

CONSTRUCTION

Due to site difficulties the substructure works took longer than originally foreseen but the superstructure was completed remarkably quickly. The superstructure work demonstrated the ability of a well organized contractor to shutter, reinforce and concrete large areas of heavily reinforced coffered slabs extremely quickly.

This very rapid construction of a variable geometry floor form and the very short time between production of final construction information and construction itself, in some cases as little as 24 hours, justified the original design decision that flat coffered reinforced concrete slabs are a very rapid, economical and efficient construction form, particularly for the irregular shapes planned.

Practical completion was achieved in July and certified in August 1981; the tenant has moved in and commissioning and fitting out have been completed (Fig. 10).

Fig. 13
Completed building

14

15

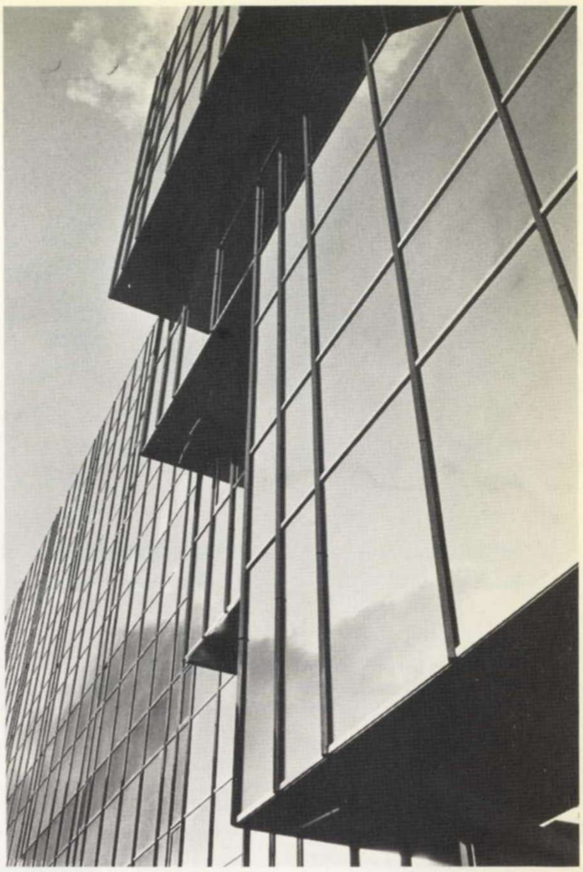

Fig. 14
Overhang at eastern entrance to arcade

Fig. 15
Glass overhang showing corbelling of floors
at secondary entrance to Euston Road

Fig. 16
Tolmers Square from
Tottenham Court Road/Euston Road intersection

Photos:
10-12: Michael Courtney
13-19: Harry Sowden

16

17

Fig. 17
Local Authority Housing
view across square from south-west

THE HOUSING

The local authority housing round the other three sides of the Square was designed and constructed in parallel in the most economic combination of brickwork, blockwork, timber, steel and reinforced concrete.

The time between commencement of design and site start and the time on site were much longer than the period for the commercial development but the development has also now been completed.

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(3) COULL, A. *and* IRWIN, A.W. Analysis of load distribution in multi-storey shear wall structures. *The Structural Engineer, 48* (8), pp. 301-306, August 1970.

Credits

Client:
Greycoat London Estates Ltd.
Local Authority:
London Borough of Camden
Architect:
Renton Howard Wood Levin Partnership
Structural engineer:
Ove Arup & Partners
Services consultant:
Rybka, Smith and Ginsler
Quantity surveyor:
Gardiner & Theobald/Gleeds
Main contractor:
Sir Robert McAlpine Ltd.
Services contractor:
Matthew Hall

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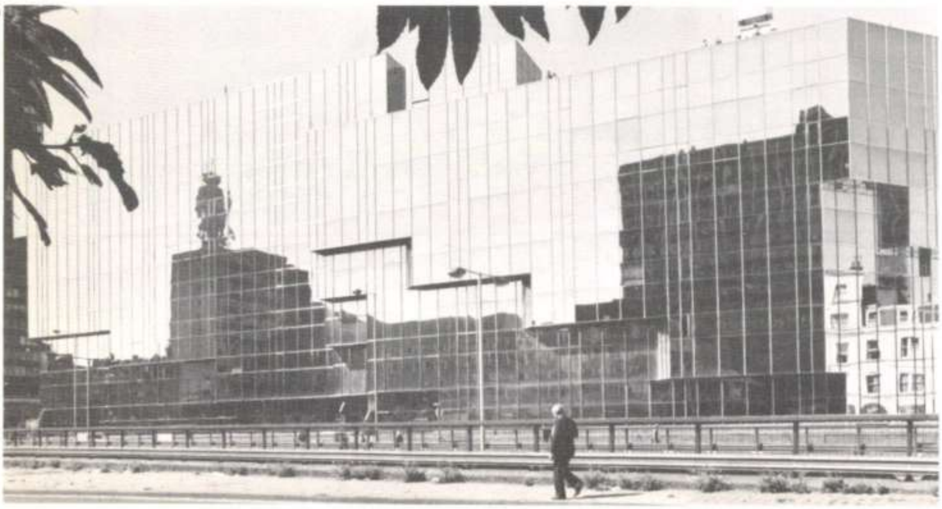


Fig. 18
Detail from square looking from north-east

Fig. 19
General view from Euston Road

Sanitary connections: a case history of innovation

John Roberts

This paper was given at THE ARUP PARTNERSHIPS seminar 'Innovation in Practice', November 1983.

INTRODUCTION

This paper discusses the process of innovation in the building industry. It does not question the motives for innovation.

The instigator of any innovation has a responsibility to ensure its success. Unlike other industries the building industry is peculiar in that projects are realized through the efforts of a number of separate organizations brought together on a temporary basis usually for one project only. There is an inherent disparity of objectives among these participating organizations.

Arguably therefore, the process of innovation must be understood and its effect on other members of the project team must be foreseen and taken into account before the feasibility of any proposed innovation can be confirmed.

The paper is in two parts. First, a theoretical view of innovation is presented. The second part is feedback from a particular project: the design and manufacture of 33 prefabricated toilet modules that are being installed on the outside of the new Lloyd's building in London. Details of the case history provide a salutary comparison of theory and practice!

INNOVATION IN THEORY

Definitions

The term innovation can be applied to both the physical end product (the'what') and the means to realize it (the'how'). Innovation should be defined not only in terms of absolute originality but also in terms of the norms of each industry. Therefore innovation includes the application of technology of other industries to the building industry.

Innovation and risk

The definitions given above are by no means clear cut and need interpretation. Innovation can be understood by linking it to the concept of risk. All innovation is characterized by increased risk. The additional risk is distributed among the project team members; in most cases it is ultimately carried by the client. What level of risk is acceptable depends upon the perceived benefits if the innovation is successful and also on the measures that can be taken to reduce risk to acceptable levels. The process of innovation therefore can be thought of as the process of redistribution of increased risk among project team members.

The effects of innovation on the building process

There is a delicate balance of responsibility in the building process. Formally this is embodied in the system of contracts between client and contractor and client and designer. This 'Formal System'[1] comprises a series of theoretically exclusive operations applied in sequence to the different phases of the building process. Officially, it is the way in which the control of the building process works.

However, in isolation, the Formal System is recognized as insufficient to operate the building process. Consequently an 'Informal System' develops to complement and overlap with the Formal System. It is a system of interpersonal relationships between the individual project team members based on familiarity and the need to harmonize objectives. It is not documented and its presence will often be denied, as any deviation from the Formal System has connotations of expediency or even corruption, but without its palliative effect, the Formal System would probably not be sufficient to control the building process effectively.

Innovation not only increases the overall risk to the project but also is likely to change the pattern of risk within the project team. The risk taken by each project team member is implicit in his contract though it is important to realize that this does not necessarily represent a mutually exclusive division of responsibility.

Therefore the first step in introducing innovation in a controlled way is to decide whether the existing system of contractual responsibility can cope with the risk pattern which the innovation represents[2].

If this proves impossible there is a strong argument to revise formal contractual responsibilities. Often however there is reluctance to take such steps since to vary contract responsibility represents, in itself, innovation. Instead recourse is made to the Informal System as a way of enabling the Formal System to be sustained intact.

All of this presupposes that the risks of innovation are perceived clearly by the participants. Often they are not, either by the innovator or by the other team members.

Only when problems arise do the consequences of a disparity of risk and reward become clear.

Possibly then it is too late!

INNOVATION IN PRACTICE: A CASE HISTORY OF MODULES FOR THE LLOYD'S BUILDING

(Architect: Richard Rogers)

Definition of the problem

The need for an innovative solution stemmed from the architect's requirement for prefabricated toilet modules supported separately from the main building on a series of reinforced concrete frame satellite towers.[3]

The architect's original invitation to tender for the modules had been unsuccessful because of the high cost of the few tenders received. The tender called for a contractor to take responsibility for both design and construction. Tender documents contained little detailed information. In addition the mixture of technology required was outside the normal range of the building industry as it involved activities common in the process, offshore and aircraft industries, as well as more conventional building trades such as shop fitting.

The tenders received indicated that the tenderers perceived the risks imposed on them were high. Since no specific means to offset these risks was proposed in the tender documents, there were only two alternatives: to decline to tender or to include the cost of the innovation in their tenders.

Table 1: Elemental weights: prototype modules

	Weight (kg)[1] (contract document)	Weight (kg) (prototype completion)	Notes on changes
Main steelwork	3009	3072	2
Secondary steelwork	203	346	3
Services	788	707	
External cladding	2552	2802	4
Internal linings	1367	1793	5
Internal fittings	510	508	
Floor finishes	1670	1942	6
Total	10099	11170	

Notes

1 The weight shown is the lifting weight, i.e. with partitions and doors not installed
2 Firring pieces were transferred from the cladding
3 Revised architectural requirements
4 Cladding subcontractor not meeting the design weight
5 Increased thickness of lining stainless steel
6 Revised floor specification (in situ option)

By this time events were rapidly overtaking options and a number of other key constraints had emerged:

(a) The maximum installation weight of the modules was fixed because the tower cranes were on site. Lifting capacity could be increased marginally at some cost. There was insufficient space around the site and road restrictions which prohibited the use of large mobile cranes. The weight limits of the tower cranes varied from 10.2 tonnes to 10.8 tonnes.

(b) The internal finishes had already been agreed with the client. They consisted of stainless steel internal lining panels, ceramic floor tiles, large mirrors and marble vanitory units. Table 1 shows the breakdown of weights calculated at the time of letting the contract and the weight recorded on prototype completion.

(c) A contract for the stainless steel external cladding to the modules had already been let.

(d) The programme for manufacture was dictated by the progress of other sub contracts in the overall project.

(e) The GLC had informed us that all materials in the modules were to be 'incombustible' to *BS 476, Part 4.*

The solution proposed

Arup Industrial Engineering Group (IE) was asked to prepare a feasiblity report to determine whether:

the design was technically possible within weight limits

there were manufacturers ready, willing and able to construct the modules

the modules could be built within the budget and programme constraints.

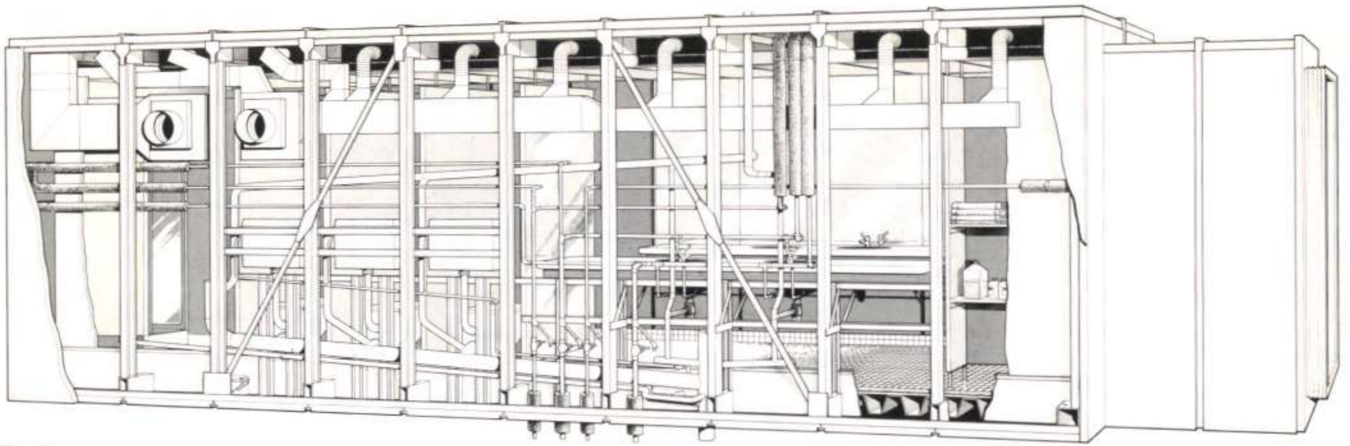


Fig. 1
Scheme design stage: cutaway external view (Illustration: Fred English)

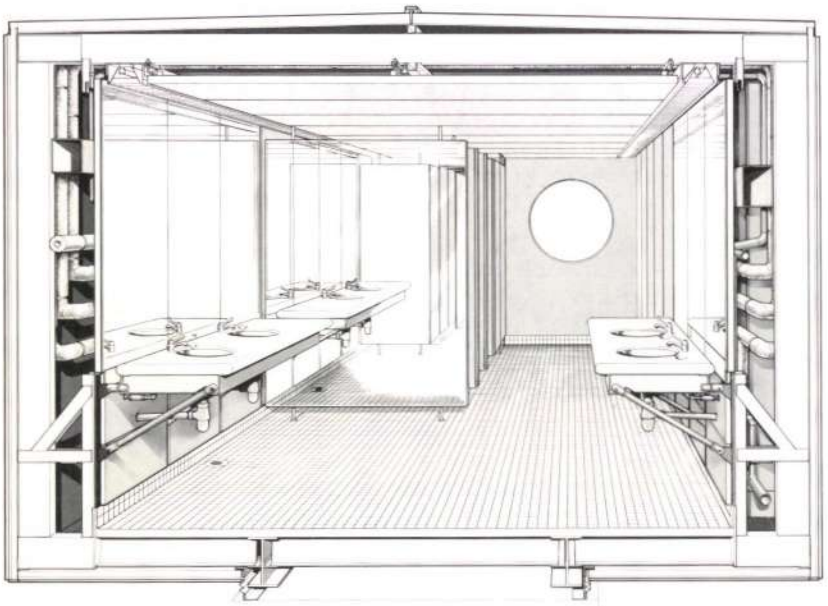


Fig. 2
Scheme design stage: interior view (Illustration: Fred English)

The Feasibility Report was positive on all counts subject to the following provisions:

(a) that risks to the eventual contractor were reduced by preparing very full tender documentation which would be used unchanged for construction. The aim was to increase the tenderer's confidence. In practice this has meant that almost all the construction drawings and steel shop drawings have been prepared by IE;

(b) that the contract was let to a single contractor recognizing firstly that he was unlikely to come from within the building industry and secondly that he would be unlikely to have experience with all the types of work involved;

(c) that the contract would be in two stages – a prototype would be constructed modified as necessary, and approved prior to the start of batch production. The aim was to reduce the contractor's risk once the design, manufacturing and installation methods had been validated;

(d) the prototype would be tested and a trial installation procedure carried out on site in London. Again the aim was to reduce both the designer's and contractor's risk (a local test was considered initially).

The innovative aspects of the design solution proposed were not explicitly enumerated but were nevertheless described in the feasibility report. It proposed:

(a) An all-welded light-gauge steel structure with all but the main floor members from 16g material (uncommon in the building industry but common in vehicle manufacturing). Stainless steel was chosen to achieve a 50-year design life without maintenance.

(b) Stainless steel lining panels designed by Arups to the architect's requirements (uncommon in the building industry but similar to domestic appliance industry)

(c) A lightweight floor finished with ceramic tiles (normal practice in the offshore industry)

(d) Copper or stainless steel pipework throughout (uncommon in the building industry)

(e) The need for stringent weight control (common in the aircraft, shipbuilding and offshore industries)

(f) The difficulties in predicting damage to brittle finishes during transportation and installation.

The proposals were explained to the client and accepted. The cost of the prototype and testing was also eventually accepted though other members of the design team and the management contractor had initial doubts. The client also accepted our fee proposals without which it would have been quite impossible to carry out the design solution and still make a profit.

The tactics worked. Three out of four prequalified tenderers submitted valid tenders. The lowest tender was within the cost allowance and the spread was 20%. The fourth tenderer was from the aircraft industry. Just prior to tender he received a large order for converting military aircraft for transport to the Falkland Islands. He admitted this contract was likely to be more lucrative than ours! Thus far it had been possible to work within the established Formal System to reduce risk.

The design proposed for the prototype module is shown in Figs. 1 and 2. Superficially it resembles the production units now being produced. At the detailed level there have been a limited number of refinements reflecting the feedback to both designer and manufacturer obtained from the prototype. The structure has performed in tests much as predicted to the extent that the prototype will eventually be refurbished and one less production unit manufactured.

Evaluation of the strategy for innovation adopted

The four tenderers who bid for the project operate in the aircraft, nuclear and offshore industries. No firm in the building industry was found that could be prequalified.

The main workload of the contractor appointed is the fabrication of stainless steel containment vessels for the nuclear industry fabricated to high standards on a batch production basis. The contractor had been accepted on the tender list because it was felt he possessed the essential skills of stainless steel fabrication, and he could apply his management skills successfully to the supervision of subcontractors with whose work he was unfamiliar.

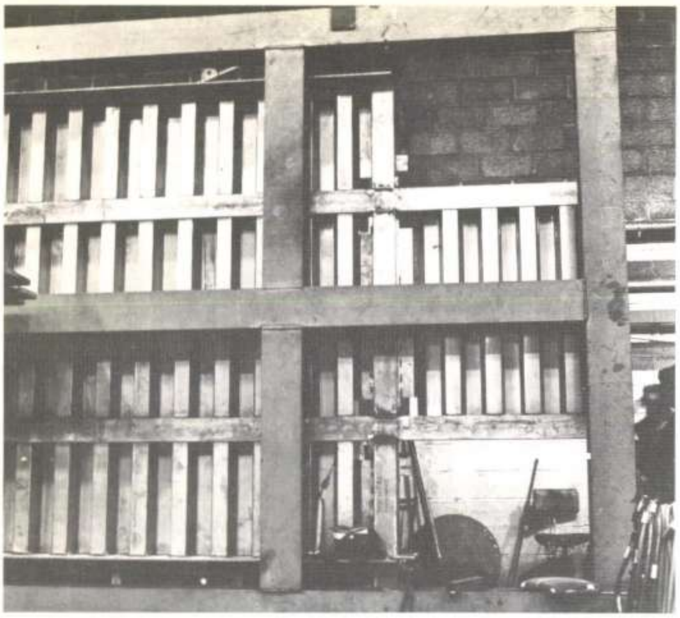
Feedback on technical innovation

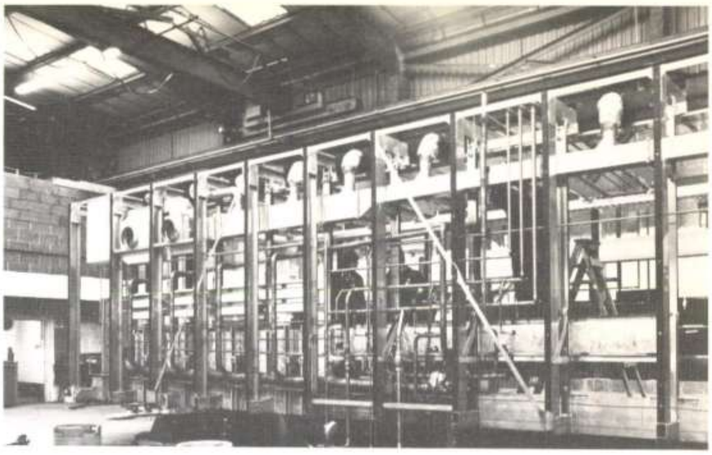
Stainless steel fabrication

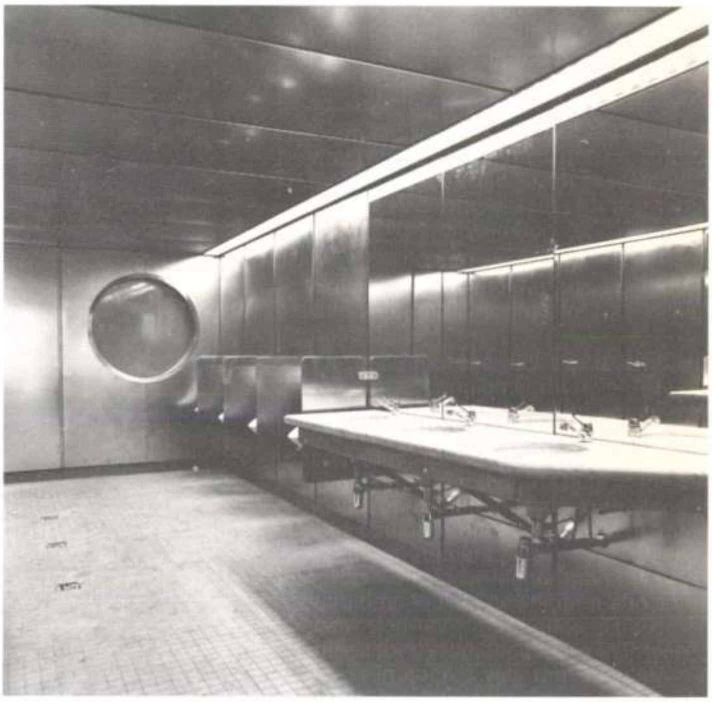
A full set of detailed construction drawings was issued at the beginning of the contract. Very little changed as a result of the load testing or design refinements. Fabrication has gone well and very good workmanship has been achieved. The contractor did underestimate the amount of welding involved and there have also been problems with fabricated sections provided by subcontractors. The distortion which occurs in stainless steel fabrication was well-known to the contractor but its effects were underestimated on the prototype chassis. The problem has been satisfactorily contained in the subsequent production chassis.

Fabrication of internal lining panels

We had little experience of designing internal lining panels in stainless steel, the contractor even less at fabrication. Again a full set of shop drawings was provided. Fixing details have been refined but not changed in principle. By adopting cottage industry type methods, the contractor was able to manufacture a high quality product whose appearance is satisfactory to the architect.







Lightweight floor
The design of the floor was not fully developed at the time of tender. As a result the contractor probably did not fully appreciate the differences in the level of care and workmanship required between the floor as finally developed and its usual application in the offshore industry. The technology involved was borrowed from the offshore and shipbuilding industry. The floor comprises a relatively thin (20mm) latex-modified sand-cement screed laid on sheets of phenolic foam. The foam acts as thermal insulation and helps prevent drumming under foot. The phenolic used initially was hygroscopic. This led to problems of workability of the screed mix and to shrinkage cracking of the floor in the prototype and subsequent samples. The problem was remedied with the help of the material supplier by introducing a slurry layer over the phenolic before laying the screed. At a late stage we were informed that the cost of the floor as originally specified could not be contained within the contract sum. We were obliged to resort to a more conventional in situ sand-cement screed laid on phenolic foam. This was a great disappointment because the floor had been successfully developed and was an appropriate solution to the design problem.

Piped services
The pipework is of brazed copper throughout including drainage and vent pipes. Again full construction drawings were provided at tender stage and almost no changes have been required. The mechanical sub-contractor operates in the building industry and has produced very good quality results.

Transportation and lifting
As designers we were concerned about the behaviour of thin gauge sections under load and particularly under dynamic overload during transportation and lifting. We were also concerned about the interaction of the flexible portal frames and the shear stiff cladding panels. The structure was designed to resist 1.8 dead load to take account of transportation and lifting. The static and dynamic load testing validated the design without destroying the prototype structure!

The testing of the prototype enabled both the contractor and ourselves to make detailed refinements to the structure, to ease the problem of fabrication and reduce welding. It also gave the contractor and the management contractor the opportunity to deliver and carry out a trial installation on the Lloyd's site well in advance of actual delivery dates.

Fig. 3-5
Production stages:

3: Chassis in welding jig

4: Services fit out

5: Approaching completion

(Photos: Frank Gadd)

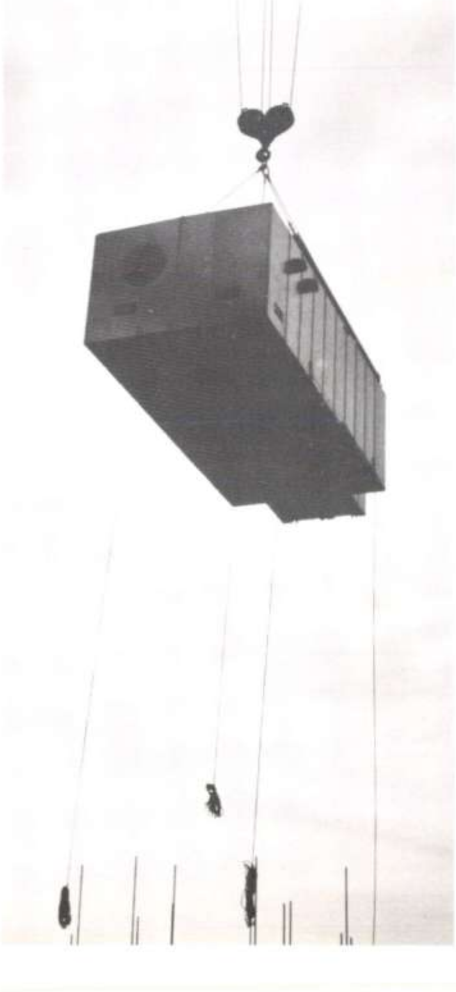


Fig. 6
Installation by tower crane at Lime Street

(Photo: Gordon Jackson)

Weight control
The problems of weight control in those industries where weight control is of paramount importance such as the aircraft or offshore industries are well-known (as detailed in Ref. 4). The problem is best overcome by the contractor appointing staff dedicated to monitoring the weight of incoming items combined with periodic weighing of the module. The tender document asked for such a system. The results have been disappointing. Weight has increased partly as a result of design changes and partly as a result of factors beyond our control since they were not contractually binding. This applied to the weight of the external cladding. Another problem was that the importance of feeding back weight measurements of the prototype were not fully appreciated, so that by the time the information was obtained, it was too late to take corrective action.

Feedback on the process of innovation

Full documentation at tender stage

The decision to commit ourselves to very full information at tender stage (which in practice has changed little subsequently) has proved of great value. It imbued tenderers with confidence, that the job was 'real'. A competitive set of tenders was returned and the contractor was able to start fabrication quickly. However the approach has disadvantages for the designer in that any subsequent changes represent proportionally more work and often appear to others of more consequence than they really are. This effect is not provided for in the normal duties of the ACE Conditions of Engagement.

The provision of a prototype

Initially there was considerable opposition to a prototype on the grounds of cost. We were asked to confirm that it would be possible to use the prototype as a production unit. This we tactfully declined. In practice the value of the prototype is now universally accepted. It has enabled:

- the designers to confirm the design and to modify details for ease of manufacture (It also however enables the architect and client to change their minds once the results are seen!)
- the contractor to assess the man hours required for each activity to optimize his use of jigs and equipment to change the fabrication procedure in the light of experience
- the management contractor to carry out trial installation ahead of time and clear all the procedures involved
- the quantity surveyor to establish a final account figure early in the contract – virtually on completion of the prototype.

It has also given the whole team confidence in the project.

As a guide the cost of the prototype as a percentage of the overall contract sum is:

- about 2% if the prototype could be refurbished as a production unit
- about 8% if the prototype could not be re-used in its entirety.

Formal system of contracts

The work is being carried out within the framework of the management contractor's own contract. This means there is no formal relationship between ourselves and the contractor and it is at the discretion of the management contractor to decide how authoritative this channel of communication should be. We provided resident factory staff, part of whose duty was to collect factual information on the progress of the works for the architect's and management contractor's use. Close liaison between ourselves and the contractor was essential, particularly during the construction of the prototype. The Formal System was not modified to take this functional need into account. Instead regular design meetings were held with the contractor which we chaired and which all parties attended. These fulfilled a need not provided by the management contractor's own management control system. However they were not as sufficiently effective since decisions taken lacked formal authority. The Informal System has coped – just.

Programme

The original period of time discussed with tenderers and stipulated in the contract for prototype manufacture and testing was five months. This was probably too little. Even less time was finally allowed because of delays in appointing the contractor.

We recognized the importance of completing the prototype before proceeding to the commitment of batch production and this was embodied in the tender documents. The contractor shared this view. Unfortunately an overlap has occurred in practice. The reasons are partly due to the short period of time allowed, partly because of design changes arising from the prototype and partly because the contractor made a late start on some aspects of the work and did not achieve an adequate rate of progress. The overlap which occurred has not invalidated the purpose of the prototype but has clouded some contractual issues.

Problems of operating outside the building industry

In the building industry we are used to contractors having the managerial structure to act on instructions on an *ad hoc* basis. It remains to some extent a jobbing industry. This is less true of the contractor's own industry. As a result we have found that instructions to make simple changes in the prototype can often take weeks to be completed because they are processed by the same management system which is employed in a batch production situation. The contractor was requested to adopt a system more suited to the concept of a prototype. His own efforts were often thwarted by the inertia of an organization not accustomed to modifying procedures on a job by job basis.

The contractor is also largely unaware of the mores that operate in the building industry – the Informal System. In practice this has meant that many more instructions are required and we have been called upon to supply much more information than is usual, e.g. procedures and method statements. The contrast between the contractor's approach and one of his subcontractors who does operate in the building industry (the mechanical subcontractor) has been pronounced.

CONCLUSIONS

Feedback from the case history

The innovative aspects of the modules relate mainly to the transfer of technology from other industries. The design solution developed led to a manufacturer outside the building industry being appointed.

Some aspects of the innovation were recognized at an early stage and methods were proposed to offset the risks of design and manufacture. Other aspects went unrecognized.

Proposals were made to the client and accepted. They included:

an additional role for Ove Arup and Partners in return for a revised fee

the provision of a prototype and testing

detailed documentation at an early stage.

The proposals were made within the framework of the management contractor's contract already in use on the project. Bearing in mind the need for a close working relationship between the design team and the contractor in the most straightforward and unbureaucratic form possible, we should probably have argued in favour of a modification of the Formal System for this part of the overall project.

Instead an informal system was developed which although essential, has led to a duplication of effort and a wastage of resources.

The means to offset the increased risks of innovation have generally worked well.

The provision of a prototype has been very successful from both the designer's and the contractor's point of view.

Detailed documentation at an early stage was an essential component in obtaining competitive tenders. When such information was not provided in time as planned, the Informal System was no longer able to cope (the contractor was exposed to the additional risk). Thus, there was no means to control late changes inspired by ourselves or the architect (other than through contractor's claims). This affected the contractor's performance both during the prototype stage and into batch production.

Implications

Innovation is a key aspect of our work. Our reputation depends to a considerable extent on the fact that we are successful innovators. It may therefore seem heretical to suggest that we do not understand the process of innovation very well.

As an aid to this end a check list covering the process of innovation can be suggested. The check list which follows is an attempt to redress this situation, increase our awareness and improve the chances for successful innovation.

Check list for innovation

(1) Has the innovation been recognized as such?
Bearing in mind the definition proposed in this paper, is the innovation original or does it represent the application of technology already existing in other industries?

(2) How would its introduction affect the pattern of risk and responsibility traditionally assumed by the project team members?
(This depends on the scale of the innovation proposed and the commensurate level of financial risk. It also depends on the nature of the innovation.)

(3) Can the enhanced risk be offset:
(a) by methods within the Formal System, e.g. testing, longer contract period and so on?
(b) by adjusting the Formal System to more closely resemble the pattern of responsibilities required, e.g. varying the contractual responsibilities of project team members?
and consequently: what is the cost of adopting such methods to reduce risk?
Are they acceptable to the rest of the project team?
Can the cost/benefit of the innovation be established?

(4) Has the matter been fully explained to the client and does he understand the advantages and disadvantages accruing to him?

(5) Does the client accept the proposals?

(6) What mechanisms have been established to monitor the situation and take corrective action if required?

Methods to reduce overall risk

Some methods of reducing risk are mentioned in the case study. There are others.

An initial list might include:

(1) Testing, parametric studies, sensitivity analysis, etc.

(2) Use of mock-ups

(3) Use of specialists, consultants, etc.

(4) Stage contracts so that the risk taken by the contractor is commensurate with the progress made

(5) Separation of design/development from production/construction

(6) Full constructional drawings made available at an early stage

(7) Provision of stronger technical support to the contractor particularly in areas where he is weakest

(8) Insurance.

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