THE ARUP JOURNAL

SUMMER 1987

THE ARUP JOURNAL

Vol.22 No.2 Summer 1987
Published by
Ove Arup Partnership
13 Fitzroy Street, London W1P 6BQ

Editor: Peter Hoggett
Art Editor: Desmond Wyeth FCSD
Assistant Editor: David Brown

Contents

Front cover: Menil Collection Museum (Photo: Richard Bryant)
Back cover: Lee House redevelopment transfer structure (computer graphic: Terence Haslett)

Menil Collection Museum roof: evolving the form

Architects: Piano & Fitzgerald

Peter Rice

I have worked with Renzo Piano since the beginning of Centre Pompidou in the early 1970s. This collaboration has been through a number of phases but the objectives and method of working have remained the same throughout. Renzo Piano's work and the work of Building Workshop in Genoa is different from the work of other architects and architectural offices. This difference is more in the way the work is done than in the result, though clearly the result bears evidence to the process. The most important element in this method of working is the role played by research into materials and form. Often a design decision will be taken to use a particular material or structural form, generally an unconventional one, such as the use of polycarbonate for IBM travelling exhibition, before the architectural implications of the decision are known. The project then develops by examining the material and how it can be used, and allowing these natural consequences to become the overriding influences on the architecture. The process of working requires a much closer collaboration between architect, engineer and builder than is normal within our industry. It also requires a workshop where ideas and details can be tested and evolved in model and prototype form. Hence the name Building Workshop-Atelier de Paris.

The roof of the Menil Collection Museum is a perfect example of this method of working. The original concept of the building presumed daylight from above and because we had experimented with ferrocement and liked it, that too was part of the original concept. Piano's initial sketches showed a series of ferrocement elements integrated into a space truss. Our reaction to this was to feel that it did not offer sufficient design space to enable us to work on the control of the daylight and we therefore proposed separate beam light trusses composed of a ferrocement bottom chord with steel upper elements. The shape of the ferrocement baffles was indeterminate at this stage.

I had also been interested in ductile iron, a cast iron with a high resistance to cracking, so I proposed that the upper steel elements became ductile iron. Once these decisions had been made, the stage was set for a series of development stages to design ferrocement leaves, the ductile iron truss and the shapes needed to provide the correct daylight inside.

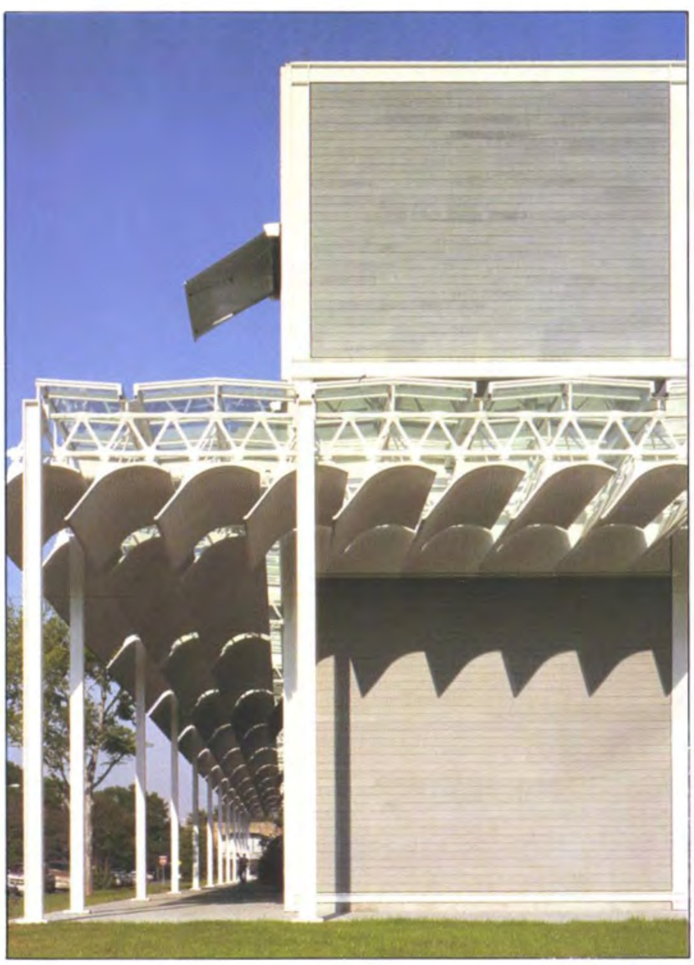
In a certain way each of these parts of the project developed in parallel. The importance of having correct lighting conditions inside meant that this took precedence, but even then the form of the leaves had to be architecturally satisfactory. Physical models were made in Genoa to enable the architect to understand how the lighting worked and what the leaves looked like. In London a computer program was established to examine what the lighting conditions would be like in the gallery spaces under different external conditions. From these different studies a shape emerged which was satisfactory to everyone.

Simultaneously we were working on the process of making the ferrocement. At first we thought it was a typically Italian material. It has an Italian name after all, but we could discover nobody in Italy who remembered how it was made. Instead we worked with a

small boat manufacturer in Norfolk and made some preliminary panels. With that experience we got the contractor from Houston to set up and make some full size samples. Although these samples were structurally adequate they did not look very good and they were very expensive. Further research unearthed an American inventor who had patented a method of making ferrocement by spraying concrete onto a preformed shape and an English company who had taken rights to this patent and were prepared to manufacture the leaves using this method. The price was reasonable so we awarded Ferrocement Laminates the contract.

Further development work was needed, however, to produce elements which were structurally sound and visually satisfactory.

The manufacturer of the ferrocement leaves by this method produced an interesting philosophical and technical problem. This arises because once manufactured the leaves cannot be tested to see if they have been made correctly. The only guarantee



that they are satisfactory is the method of manufacture itself so we had to develop a manufacturing procedure which could be monitored and which guaranteed the quality of the finished product.

A careful elimination of the reasons for flaws in the manufacture of the leaves gradually produced a process which was satisfactory. Some 20 trial leaves were needed before this procedure had been fully established. The ductile iron on the other hand is a well-known material in the industries where it is used. The reason why it is different in character from cast steel and other cast metals is that it is more fluid while being cast and therefore it will flow more easily into fine irregular shapes. It does not need to be heat-treated like other cast materials. This means that it does not distort and change shape after casting, and can be made very accurately using these properties. We designed a nodal clamp system which produced elements with a texture and shape consistent with ferrocement leaves.

The final design and shape of the Menil Collection Museum roof is the work of many people. The client was clear on the standard of light and the atmosphere they wished inside the museum. The architect, the engineer and building contractors have all contributed to the quality of the completed building.

It is a truism to say that until you have tried something, you do not know what is involved. In a design such as this a slow interactive process becomes necessary. The architect's design office becomes a workshop. Each tentative idea put forward by the engineers, the manufacturers (they were involved from the beginning) or the architects, is prototyped and tested. The engineers with their computer and esoteric mathematical models are forced to abandon their usual defensive posture and accept that ideas must come forward and be tested visually and physically before they can be sure that they will work technically. In the everyday fencing among professional consultants no one likes to be wrong. In this process it is essential that from time to time everyone admits to a mistake.

Credits

Client:
Menil Foundation

Architects:
Piano & Fitzgerald

Structural engineers:
Ove Arup & Partners

Services engineers:
Ove Arup & Partners
Galewsky & Johnson
Gentry, Haynes & Whaley

Main contractor:
E.G. Lowry Inc.

Photos:
Richard Bryant

Editor's note

This is the second article on this project to be published in The Arup Journal. *The previous account appeared in the April 1983 issue.*

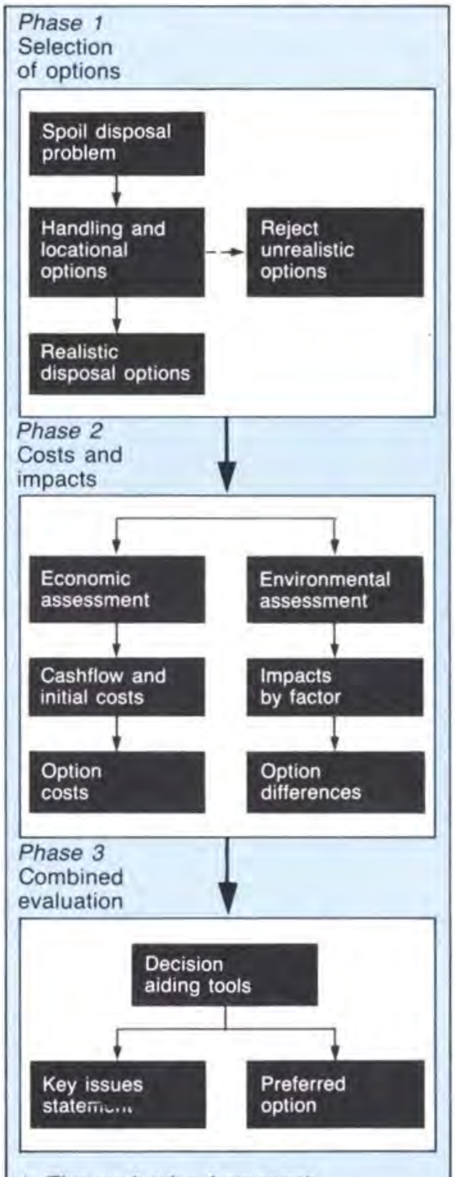
The disposal of colliery spoil

Malcolm Noyce

Introduction

In September 1981 the Government's Commission on Energy and the Environment (CENE), under the chairmanship of Lord Flowers, published a report entitled 'Coal and the Environment'. It reached the conclusion that the disposal of colliery spoil was, with subsidence, one of the two most important environmental issues arising from deep coal mining. The Government itself responded to the Commission's report with a White Paper of the same title (*Cmnd. 8877*), issued in May 1983, which agreed that spoil disposal presented a major environmental challenge and that it suffered from the lack of an agreed policy framework. This clear need for improved decision-making prompted the Government, in the same White Paper, to announce the initiation of a major study within what was agreed to be the most urgent problem area, the main Yorkshire, Nottinghamshire and Derbyshire coalfield. This was aimed at evaluating the main options and establishing a new framework within which decisions could be made.

As part of this, Ove Arup & Partners were commissioned in 1983 to carry out a research project which resulted in the development of an evaluative framework for the assessment of alternative colliery spoil disposal options. The study was commissioned by the Department of the Environment and carried out in consultation with other government departments, British Coal, and local authorities in the study area. Representatives from these bodies formed a technical assessment panel.



1. The evaluative framework

The need for an evaluative framework

British Coal (formerly the National Coal Board) has to apply for planning permission to the relevant mineral planning authority for all new colliery spoil disposal schemes. Since the CENE report, British Coal's procedures have been amended internally so that their Areas are required, before submitting a planning application to the mineral planning authority, to complete an environmental checklist in order to ensure that the disposal scheme has been carefully designed to minimize environmental impact. Extracts from this procedure may sometimes be submitted to the planning authority as part of a reasoned justification in support of the application. No information is normally submitted to the planning authority (nor requested) on the financial aspects of a proposed scheme, nor are alternative locations usually tested, although these may have been discussed at officer level by the two parties at informal liaison meetings prior to the submission of the planning application.

The evaluative framework is designed to assist decision-making in relation to future disposal schemes for deep mined colliery spoil. Its development is, in part, a way of building upon and formalizing the current approach and is a means of placing information before the mineral planning authority enabling it to be satisfied that the best disposal scheme has been selected. It encourages the systematic investigation of a range of alternative schemes in order to compare the advantages and disadvantages of each option against various economic and environmental factors, as well as being able to assist decisions about the best source of fill material for large-scale reclamation sites.

Development of the framework

The two starting points for its design were an understanding of the planning context within which it would be used, and an examination of existing economic and environmental appraisal techniques. The nearest equivalent to the type of framework suitable for assessing disposal options for colliery spoil was considered to be the Department of Transport's framework for trunk road appraisal. This consists of the COBA computer program which uses social cost-benefit appraisal techniques, and the Manual of Environmental Appraisal procedure which summarizes impacts by the relevant environmental factors.

It was decided that the colliery spoil framework should be constructed in a similar way to include two separate appraisals proceeding in parallel. However, the terms of reference required the appraisal to include a combined evaluation, to assist the trade-off between financial costs and environmental effects in the search for a preferred disposal option.

A draft framework was constructed and then tested and revised sequentially against a series of 12 case study schemes. These case studies had been selected to reflect a variety of disposal arrangements and to take account of different financial and environmental considerations. The framework itself was drafted in three phases, and the early studies were generally used to test the structure and content of the questionnaires to be used in phases 1 and 2, as well as the general comprehensibility of the framework.

Phase 1 provides a checklist procedure for identifying the most realistic options for the disposal of spoil from a particular colliery or group of collieries. Phase 2 assesses costs and impacts from both economic and environmental viewpoints. The economic analysis uses financial appraisal techniques and reflects British Coal's costing considerations, whilst the environmental analysis is based on a factor by factor assessment of impact and reflects the wider effects of a scheme on the community. Phase 3 includes two decision-aiding tools intended to assist the selection process. Fig. 1 details the study processes within the three phases of the evaluative framework, and Table 1 shows the case studies.

Table 1: Description of case studies

Scheme	Type of disposal site	Handling and transport
1	Extension to local tipping site including lagoons	Dump trucks on internal haul road
2	Tip extension v. landfill reclamation site (Welbeck)	Stacker spreader (extensions) v. 17km rail (landfill)
3	Tip extension v. landfill reclamation site (Welbeck)	Dump trucks/ Stacker spreader (extension) v. 15km rail (landfill)
4	Adjacent limestone quarry (operational)	Cable belt
5	Tip extension partly over opencast site	Conveyor
6	Worked out sand and gravel pits	4km pipeline
7	Low-lying wet valley land	5km rail and dump trucks on internal road
8	Wet reclamation site	14km rail v. 23km canal v. 25km road
9	Valley site v. 2 derelict voids + 2 operational voids	Conveyor v. 37 or 58km road, 60km rail, 100km rail, 200km rail
10	Reclamation of mudflats	100km rail v. road, canal/river
11	Low-lying farmland Bank construction for pfa lagoon	12km hydraulic pipeline (pfa) 8km road (spoil)
12	Opencast void	4km road then barge

The basic design of a three part process remained firmly intact throughout the testing programme. A certain amount of restructuring was found to be necessary, particularly in the environmental analysis, and minor amendments were also made to the indicators used to summarize costs in the economic analysis. During the case study programme a computer routine was developed and tested to take the tedium out of the financial calculations.

The decision-aiding tools specified in Phase 3 were found to be useful in different ways. The ranking of options is a simple, quick technique which can be presented graphically. Pairwise comparison is a useful way of breaking down a complex problem and eliminating less desirable options in those situations where there are a large number of considerations.

Practical applications

The evaluative framework has been carefully designed to improve existing decision-making processes with regard to the disposal of colliery spoil. It has been tested against a variety of schemes selected as

1 ◁

2 ▷

case studies, and has been shown to be comprehensive, flexible, understandable and clear, although it will obviously need monitoring and further refinement as it is used in practice.

Its use should encourage a more co-ordinated approach to the spoil disposal problem, and is likely to be most effective where there are established liaison arrangements between British Coal and the mineral planning authority. We anticipate that it will be used against a background of discussion between British Coal and these authorities about future spoil arisings and appropriate time horizons for new tipping arrangements, and in this way we hope that the framework will result in earlier agreements between these bodies and thus shorten the timescale for granting planning consent. In the event that agreement cannot be reached and a public inquiry results, the framework should at least identify the areas of disagreement from those of agreed fact, and thereby provide a structured basis upon which investigations can proceed.

Conclusion

During the latter part of its development the evaluative framework has been used in four real applications:

(1) Examination of extension of tipping at two collieries

(2) Examination and justification of the major reclamation and co-disposal scheme at Welbeck, Wakefield

(3) Examination of land-based options as against continuing marine disposal in the North East.

At the conclusion of the project, Ove Arup & Partners presented to the DoE the framework, an accompanying explanatory leaflet, a final report and an executive summary.

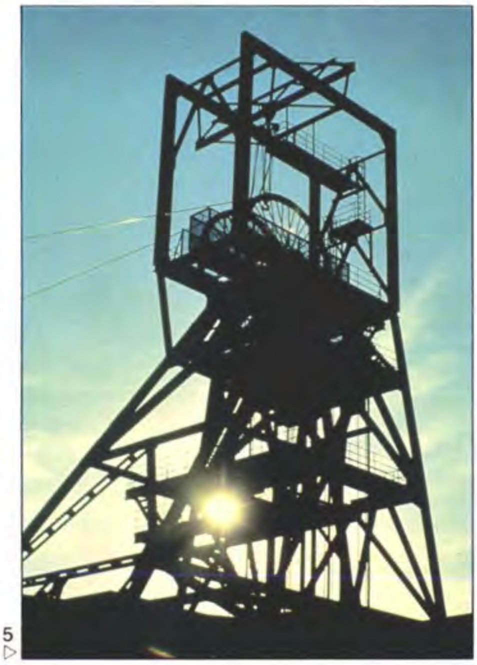
The Department issued the framework by means of a *Circular* in July 1987, in which it encouraged the use of the framework by both British Coal and the mineral planning authorities. The explanatory leaflet is freely available. Copies of these four documents are available from the DoE Library.

Since the completion of this project Ove Arup & Partners has been commissioned to undertake 10 seminars throughout England, Wales and Scotland in order to disseminate the framework and encourage its use. This is particularly important as for the first time the DoE will be formally encouraging a structured and balanced judgement to be made in weighing up the competing economic and environmental issues.

Ove Arup & Partners have also been appointed to monitor the framework in use, to report to the client body and to make amendments prior to subsequent release of a modified framework. This contract will last three years and will yield valuable information, not only in terms of improvements to the design and therefore use of the framework, but importantly the acceptability and willingness of various parties to undertake an assessment stage where two previously different factors are brought together in a declared trade-off.

3△

4▽



5 ▷

6△

7▽

Photos: 1, 2, 5, British Coal. 3, 4, Malcolm Noyce.
6, Dowty Meco. 7, former South Yorkshire County Council.

Konarak

Poul Beckmann

Konarak is a village near the coast of the Bay of Bengal about 360km south-west of Calcutta, in the state of Orissa in India. Its claim to distinction arises from the great Sun Temple, known to early European mariners as 'The Black Pagoda' to distinguish it from the other landmark of 'The White Pagoda': the temple of Jaganath in Puri.

The Temple stands in a rectangular, walled compound, measuring approximately 265m east to west and 167m north to south.

The antechamber, or Jagamohana, of the main temple is roughly square on plan, the vertical elevations being approximately 30m wide and 12m high. The roof which is shaped like a truncated pyramid, but divided horizontally into terraces and tiers of cantilevered shelves, is approximately 36m across and 18m high and is surmounted by an Amlaka (a fluted 'knob') approximately 13m in diameter and 8m high. The masonry inside is corbelled to form a hollow pyramid. To the west of the Jagamohana are the remains of the tower or Sikhara, wider and originally much taller than the Jagamohana, but now barely rising above 10m.

Every preserved original, external, vertical surface is richly carved with a profusion of sculptures and bas-reliefs and even the walls of the niches, in which the sculptures stand, have carved textures.

The Jagamohana and the Sikhara stand on a common plinth, 6m high, with richly carved sides, incorporating the huge decorative wheels of the Sun God's chariot, with sculptures of a team of horses at the east end.

The Sun Temple or, to give it its proper name, The Temple of Surya is generally thought to have been built in the middle of the 13th century AD.

Towards the end of the 16th century, or early in the 17th, the Muslims entered and damaged the temple. Having thus, in the eyes of the Hindu, been desecrated, it was abandoned as a place of worship.

Over the next centuries the temple, no longer used and therefore no longer maintained, suffered from structural deterioration, sand drift and robbery. The tower collapsed in stages, the last part being blown down in a gale in 1848; the plinth was engulfed in a sand dune to considerable depth by the early part of the 19th century, and the Rajah of Khurda had sculptures removed to a temple being constructed in his fort.

Towards the end of the 19th century proposals were made for certain repair works, but significant work did not get under way until 1903, when, alongside excavations which revealed the plinth, the Jagamohana, that had been damaged by the fall of the last part of the Sikhara, and which was thought to be in danger of collapse, was lined with nearly 5m thickness of dry stone walling and the remaining void filled with sand. At the same time, the wrought iron beams that had supported a ceiling inside the Jagamohana, but which had fallen to the floor during the first half of the 19th century, were carried outside and stacked in the compound.

A campaign of preservation under the direction of the Archaeological Survey of India has been going on since the 1950s, and has succeeded in turning the remains of the temple into a very impressive monument and a very popular tourist attraction.

1△ 2▽

1. The Jagamohana as illustrated by James Fergusson in the 1830s. (Illustration courtesy of the Archaeological Survey of India)

2. Location map

3. The Jagamohana in a state of disrepair in 1903, prior to restoration work. The slope to the left is the rubble from the collapsed tower; the plinth with the chariot wheel is completely submerged by drifted sand. (Illustration courtesy of the Archaeological Survey of India)

4. East doorway with iron lintels showing cracking

5. Wrought iron beams

6. Inside detail of dry masonry

3 ▷

4 ◁

5 ▷

6 ▽

The effect of the salt-laden winds on the stone, together with some observed local splitting cracks, did however give rise to concern and, on the other hand, there was a desire to restore the inside of the Jagamohana and make it accessible to the public.

UNESCO was therefore approached by the Archaeological Survey of India with a view to obtaining independent expert advice on these matters.

UNESCO asked ICCROM (the International Centre for Conservation in Rome) to nominate appropriate persons for the task and as a result Sir Bernard M Feilden and I went to Konarak to inspect the Temple.

We found that apart from mechanical damage, the stone was generally in remarkably good state of preservation, retaining an impressive amount of carved detail. A certain amount of local splitting could be seen, but this was of such a configuration that it could be ascribed to rust expansion of the iron cramps used to tie together the dry-jointed blocks of stone or, possibly, to stress concentrations at high spots on the bedding surfaces.

Some calculations, carried out after our return, confirmed that there was no danger from general overstressing of the masonry and it was shown, by the construction of thrust lines, that the general configuration of the Jagamohana was structurally sound.

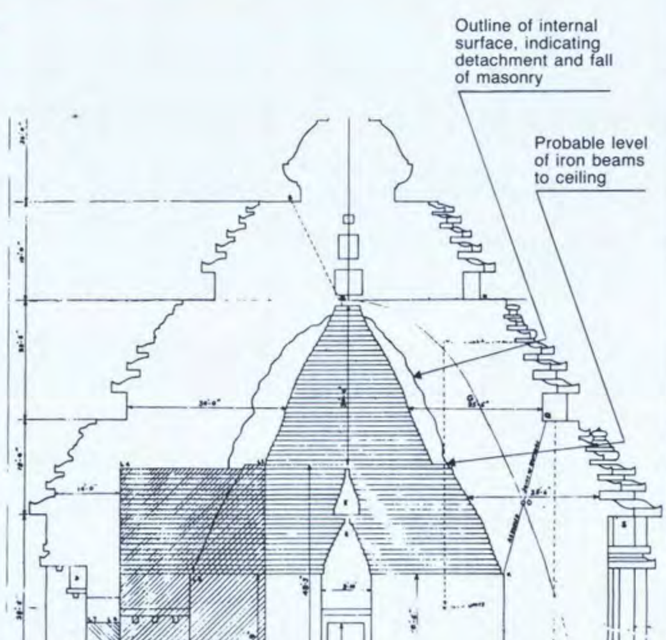
The question of the reasons for the installation of the dry wall lining and the sand fill, and their necessity for the structural stability, remained.

No clear record of the condition of the monument prior to 1903 was available and the drawings that did exist did not explain the total situation.

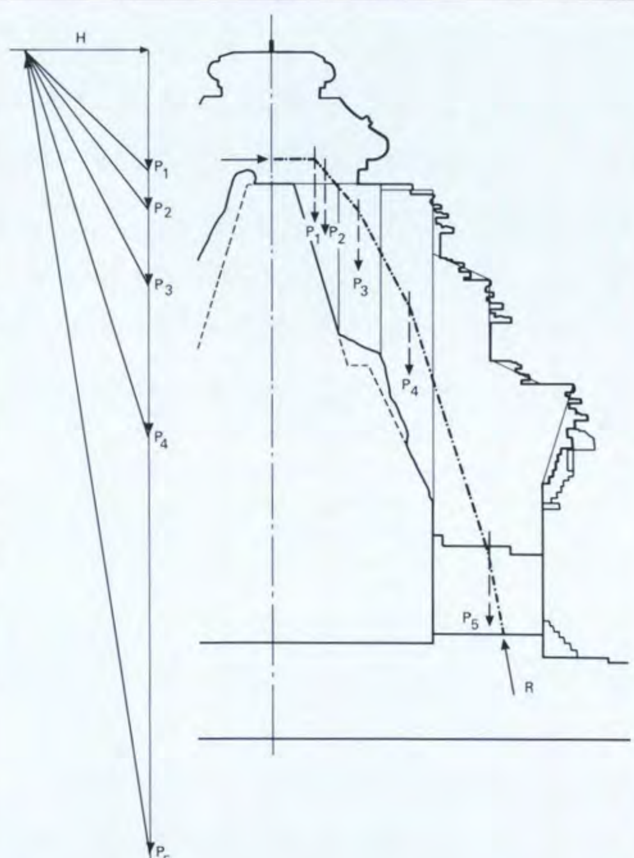
Fergusson's findings

When the architectural scholar Fergusson visited the monument prior to the fall of the last part of the Sikhara he found that the iron beams holding the ceiling had fallen to the floor, but that the Jagamohana otherwise was standing up well.

Cross-sections shown on drawings, produced by the PWD in 1903, indicated that a substantial part of the masonry above the ceiling may have been supported on the iron beams at the time of construction.

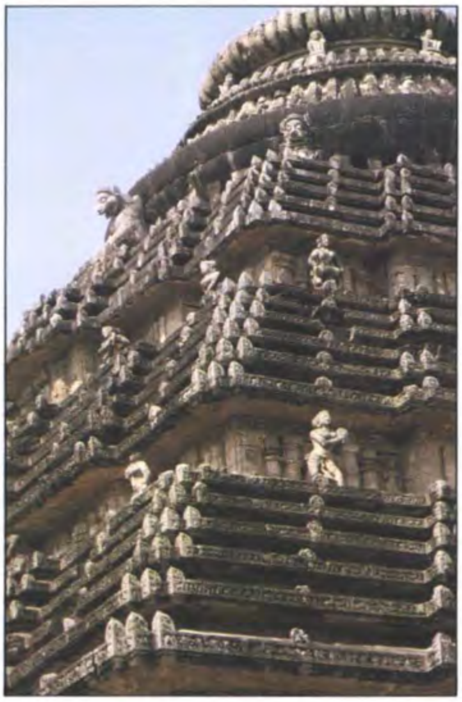


7. Part of PWD drawing no. 1020



8. Thrust line for central slice of Jagamohana

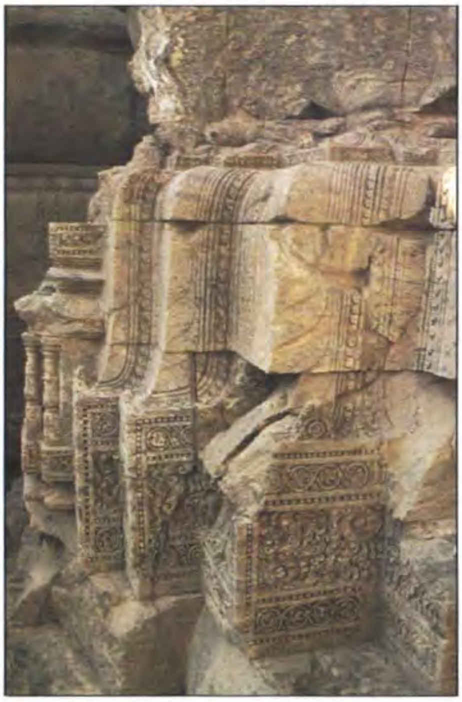
9 ◁



10 ◁

▷ 11

12 ◁



13 ◁

▷ 14

15 ◁

16 ◁

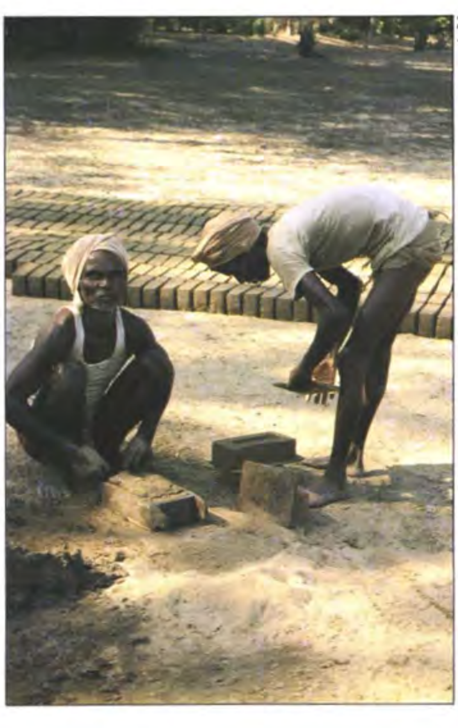
▷ 17

18△

19▽

9. Part of the roof of the Jagamohana
10. Stone erosion on the sculpture terrace
11. Statue of drum-girl on second sculpture terrace, nearly 20m above the plinth
12. Local splitting cracks
13. Detail of chariot wheel
14. Western face of the plinth
15. Sculpture of warhorse
16. Bhogamandapa at Konarak
17. Sculpture of enraged elephant
18. View from the south west
19. The Jagannath at Puri, showing the relationship in height of the Sikhara, or temple building, with the Jagamohana, or antechamber
20. Brickmakers at the roadside

Photos:
Poul Beckmann



20 ◁

We considered it possible tnat the concentrated reactions from the iron beams, progressively exacerbated by rust expansion, produced local failures in the masonry below. Once this had caused one iron beam to fall, its load would have been transferred to its neighbours, which may then have collapsed in turn. The masonry, that originally was supported on the beams, would therefore have fallen as well.

The PWD survey drawings showed an outline of the interior of the Jagamohana, which was consistent with this hypothesis.

The thrust-lines indicated that the masonry on the inside slopes of the roof was not everywhere in compression from the overall structural action. Its stability therefore depended on its bending strength and on the tying-back by the iron cramps. Being laid without mortar, the masonry would have allowed the ingress of rain water, taking with it the salt, deposited on the stone by the wind.

Corrosion of the iron cramps, caused by the salty water, could have caused gradual splitting of stones and this would account for stones falling to the floor during the works in 1903.

A reference from 1910 stated that the dry-stone walls were constructed to contain the lateral pressure of the sand.

We were told by members of the Archaeological Survey that an inspection in the 1950s through a vent hole had found the top of the sand fill about 4m below the base of the Amlaka. This indicated that the sand was not giving any support to that part of the roof.

We therefore concluded that the dry-stone lining and the sand fill were not required for the overall structural strength. We did however think that there might be problems with the stability of individual stones on the inside.

We therefore recommended a staged removal of the sand from the top down, with bolting back, with stainless steel, any potentially hazardous stones.

Preservation of medieval ruins

Architects:
Ahrends Burton & Koralek

Ian McVitty
Peter Evans

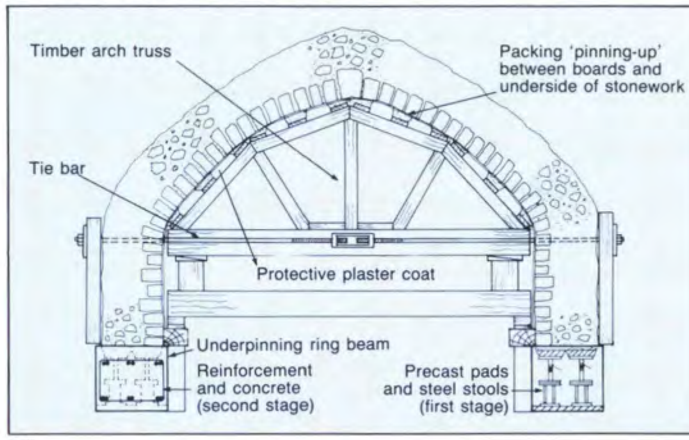
Introduction

Of the many challenges encountered in the design and construction of a new building, the preservation, removal and reinstatement of some 250 tonnes of medieval ruins must be one of the least expected. However, this was a major task that had to be accomplished during the initial stages of the foundation contract for the new development for the John Lewis Partnership at Kingston Upon Thames in Surrey.

The site is situated by the River Thames, immediately adjacent to Kingston Bridge (Fig. 1). The major portion of the development will be a department store for the John Lewis Partnership with a Waitrose food shop. The superstructure features open tiered floor arrangements, linked by escalators and daylit through a glazed roof. The building will have three basements with the lowest two serving as car parks. An unusual feature of the building is that the Kingston Town Centre Relief Road will pass diagonally through the centre of the store from Kingston Bridge. The area by the river will be set aside for public amenities, a river walkway, restaurant or wine bars and night-clubs and it is to this vicinity that the ruins will be reinstated.

Kingston is a major shopping centre for the area, and attracts numerous prestigious developments. However, it also has a prominent history, and the Royal Borough Council is keen to preserve links with the past, while ensuring that new buildings also service the town's current and future needs. The known existence on the site of medieval remains of some rarity was also regarded as highly important, and their safe removal, storage and eventual relocation within the new building was one of the conditions of the planning consent which was granted in April 1986, with the Royal Borough Council contributing to the costs.

1△

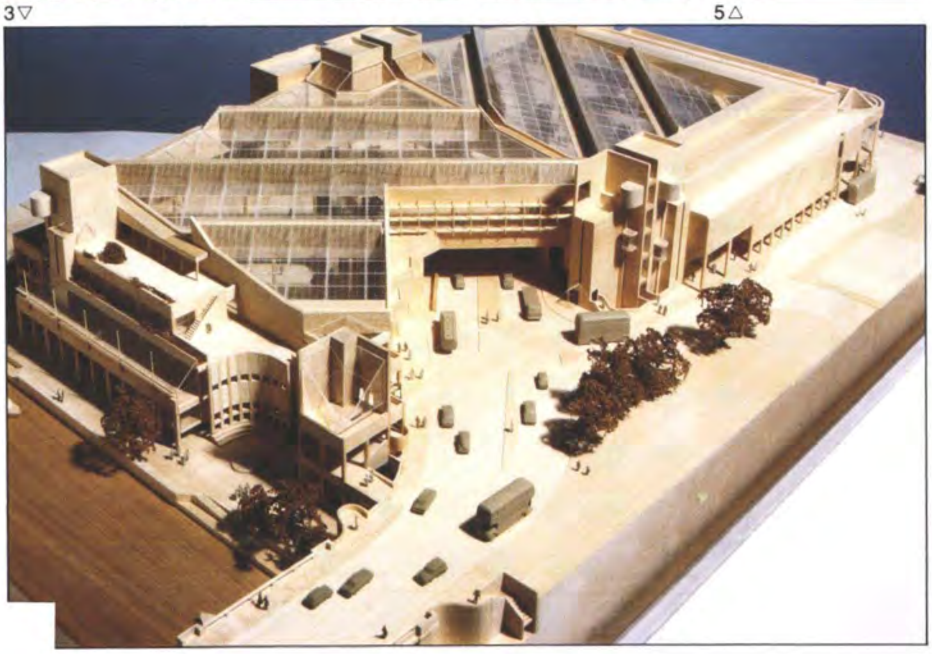


4△

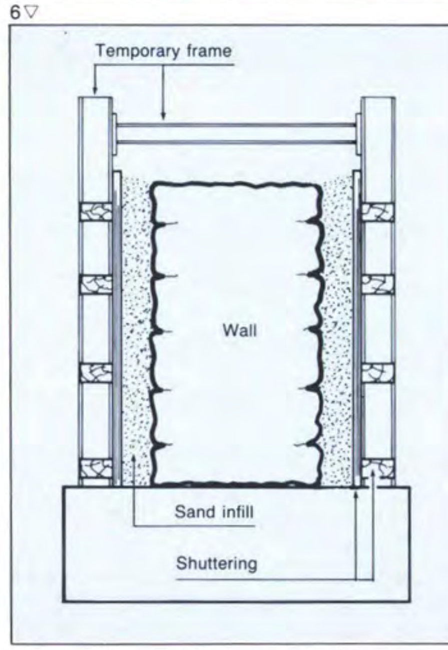
2▽

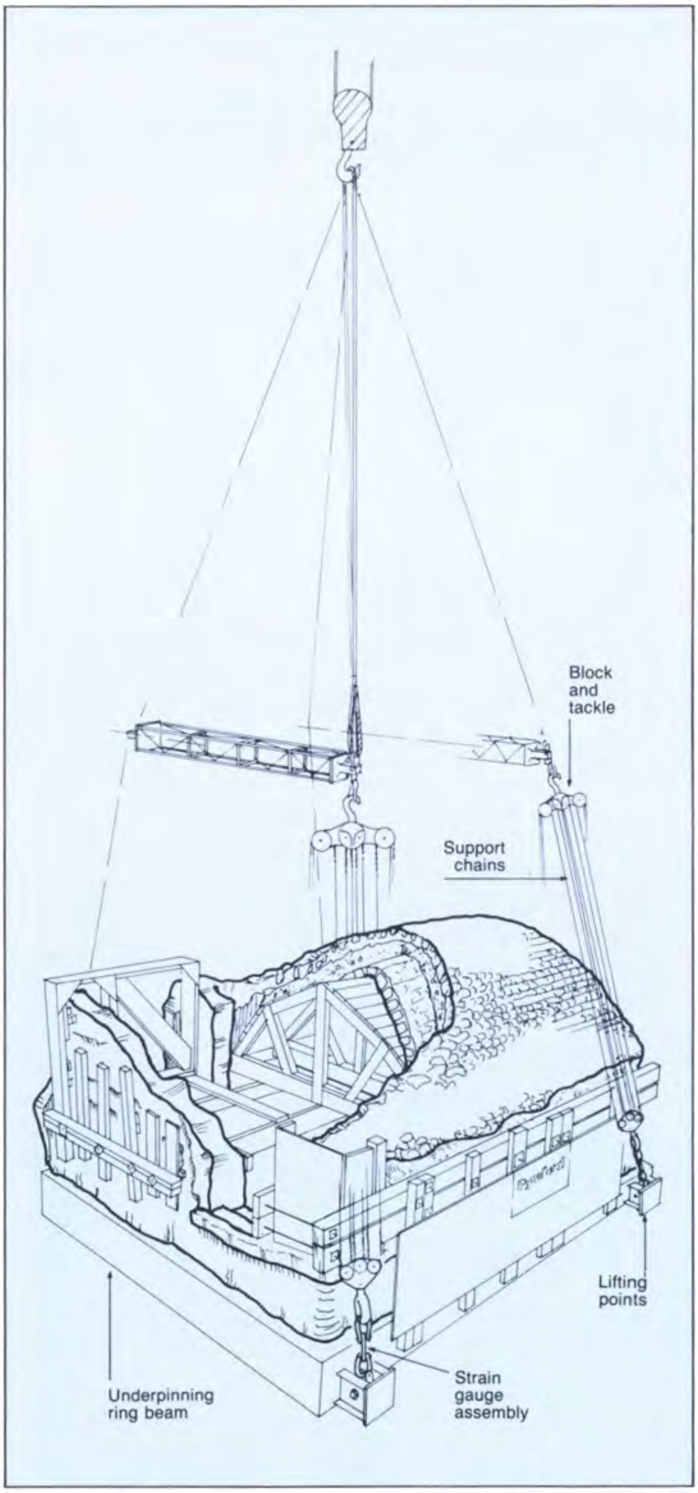
5△

3▽



6▽





7 ◁

8 ▷

9 ▷

1. Key plan of original site
2. Undercroft as originally excavated (Photo: Museum of London)
3. Model of John Lewis development at Kingston (Photo: John Donat)
4. Section through undercroft
5. Underpinning of bridge pier with ring beam (Photo: Mike Long)
6. Section through bridge wall
7. Diagram of undercroft lifting system
8. The undercroft ready for lifting (Photo: Peter Benson)
9. The undercroft being lifted (Photo: Peter Benson)

Drawings: Derek Woodcraft

The medieval remains in question were an undercroft, or vaulted cellar, and causeway walls, piers and abutments from the original Kingston Bridge. Fig. 1 shows their relation to the existing bridge and surrounding buildings. Kingston was, even in ancient times, a major route into London as, in the 12th century and for many centuries after, the bridge was the only permanent crossing upstream of London Bridge. The undercroft was situated adjacent to the busy road over the bridge and its owner was probably a merchant enjoying the trade the position afforded. When first excavated the structure could be seen to be composed of chalk blocks, but with occasional flints forming a chequer-board pattern on the walls, and the closely formed and recessed joints had evidently been executed with some skill. This suggests that the cellar was open to the public during the course of the merchant's business, there being a staircase (partly demolished) leading directly to the street. The vaulted roof, being largely intact, increased the rarity value of the discovery.

On receipt of the planning consent the scope of work involved in removing the undercroft, which had been partially excavated, was relatively clear, being subject only to further investigations in detail by archaeologists from the Museum of London. However, the scope of work concerning the bridge was not as clearly established, being based only on limited excavations. The archaeologists continued their investigations during the summer after which the extent of the remains to be preserved was agreed.

In considering their approval of any proposals submitted by the design team, the Planning Officers took into account the views of local archaeological societies, the Museum of London and the Historic Buildings and Monuments Commission for England, better known as English Heritage.

Feasibility study

Previous discussions, prior to the planning agreement, had established that to leave the remains in situ and construct the building around them would have affected the viability of the building layout to an unacceptable extent. The archaeologists were not in favour of dismantling the undercroft because of their desire to keep the remains as original as possible. Hence the requirement to remove and reinstate, and a scheme was developed to demonstrate feasibility. This scheme involved strengthening and bracing the arch structure, resin injection to maintain integrity and provision of an underpinning ring beam for lifting.

This feasibility study was then developed into a performance specification, which formed the basis for negotiating a contract with Pynford (South) Ltd. Within the overall programme for the project, the removal of the remains were critical items. To meet with commitments to open the relief road in accordance with Kingston's master programme, an early foundation contract starting in autumn 1986 was indicated. It had been intended to remove these remains during the summer but the planning and consultation period took longer than expected and site work commenced in September — with the 12 weeks Pynfords required just being able to be accommodated into the programme for the foundation contract awarded to John Mowlem & Company plc.

Underpinning the undercroft

After their appointment Pynford developed a detailed design and work started on site.

The first task was to construct a retaining wall at the rear of the undercroft which was required to support the adjacent Kingston Bridge approach road. This was achieved with a top-down construction, casting each successive drop of wall by temporarily supporting the one above on 'stools' (as described later for the undercroft). This method avoided the potential problems and vibration involved in a sheet-piling solution. Once completed, work started on the undercroft.

At the suggestion of English Heritage, the inner surface was plastered, using hessian reinforcement, to prevent drying out and cracking of the stones and for protection from resin splashes. The inner facing stones were then bound and consolidated using resin injection into the joints. Timber arch trusses and boards supported the roof, while tie bars (initially unfastened) were drilled and inserted through the side walls at intervals. The overburden was then carefully removed to expose the external surface which was found to be well defined, though voids in the roof required filling with resin. Next, plates and strongbacks were attached to the projecting ties to resist the outward forces from the arch at its springing points. Further excavation exposed the walls which were then underpinned. In some places the base of the walls was poor, and some replacement with mass concrete was required. However, the inner stones at these points (generally below the original floor level) were retained to be replaced on a recess on the underpinning beams at a later date. Further strengthening with drilled tie bars and resin was also used to stitch together fragile sections of wall.

The underpinning process replaced the existing ground with concrete beams. Small sections of ground were removed at intervals from beneath the walls and metal frames or 'stools' were inserted to replace them. Each stool was bedded on a precast pad, and another pad was placed over it. The stool was adjusted to leave a small (25mm) gap between pad and structure, and the space between filled with a moist sand/cement 'drypack' mix, which was rammed home. When cured, this mixture provided a high strength even contact, but with virtually no shrinkage or settlement. Fig. 4 shows the stool arrangement and the reinforcement placed prior to casting of the ring beam.

The staircase, of which only the side walls remained, was underpinned and strengthened as a separate item, with a cut through the sections of wall adjoining the undercroft made from the outside in a 'V' shape, leading to minimal loss of internal facing stone.

10. Cables being attached to stair section (Photo: Peter Benson)

11. The stair section aloft (Photo: Ian McVitty)

Bridge remains

The strengthening of portions of the bridge remains, comprising a pier and two abutment walls, was more conventional. The two lengths of wall were underpinned and boxed as shown in Fig. 6. The bridge pier was hollowed out and the walls underpinned with a ring beam. Perimeter straps and internal 'stitching' stabilized the stones.

Removal of the remains

Prior to lifting, all five items were jacked off the ground. This was to break any adhesion to the ground surface, and to enable measurements to be made of the weight of each item. This was important to ensure adequate crane capacity and confirm the geometry of the lifting arrangements.

The most fragile item was the undercroft, weighing 70 tonnes. An uneven lift could have caused cracking of the supporting ring beam and possible damage to the structure. Consequently strain gauges (which gave direct readings in tonnes) were connected between the lifting points and the support chains (Fig. 7). As the crane gradually lifted, the chains were adjusted with block and tackle until the gauges gave readings as had the jacking loads. In this way a lift without distortion was achieved. The other items, being more robust, were lifted directly with cables (Fig. 11) the largest item weighing about 80 tonnes.

Reinstatement

The remains are currently in storage with the Royal Borough of Kingston. It is intended that late in 1988 they will be returned to the original site and incorporated into the riverside amenity area. The remainder of the building will be constructed over and around the remains, preserving them as a link with the Royal Borough's past for the interest of future generations.

Postscript

Following the removal of these remains the archaeologists continued their investigations in the area of the bridge and found the line of the old river wall, part of which had been constructed from the timbers of a boat. These were removed and identified as being from the port side and part of the bow and stern of a merchant ship dated at about 1250AD. Between the Easter 1987 completion of the foundation contract and the start of the main works, the archaeologists returned to site and have made further discoveries, including a timber quay side construction and the remains of another boat.

Credits

Client:
John Lewis Partnership
Royal Borough of Kingston

Architect:
Ahrends Burton & Koralek

Main contractor:
John Mowlem & Co. plc

Specialist contractor:
Pynford South Ltd.

Lifting and transporter sub-contractor:
Sparrow Industrial Services Ltd.

Lee House redevelopment transfer structure: a painting by Ben Johnson

Architect:
Terry Farrell Partnership

Colin Sanderson*

In the years to come when people look back to study the history of the Lee House redevelopment project, it will appear commonplace that it should have involved architects, engineers, modelmakers and construction companies, each contributing their special skills to the single endeavour. The following article, however, has been written primarily to record an unusual by-product of the project — a painting which grew out of discussions and collaboration between an Arup engineer working within Building Engineering Group 8, Christopher McCarthy, and Ben Johnson, a well-known painter, much of whose working life has been devoted to the celebration of excellence and the appreciation of beauty in the best of architectural and engineering design.

The site and the building

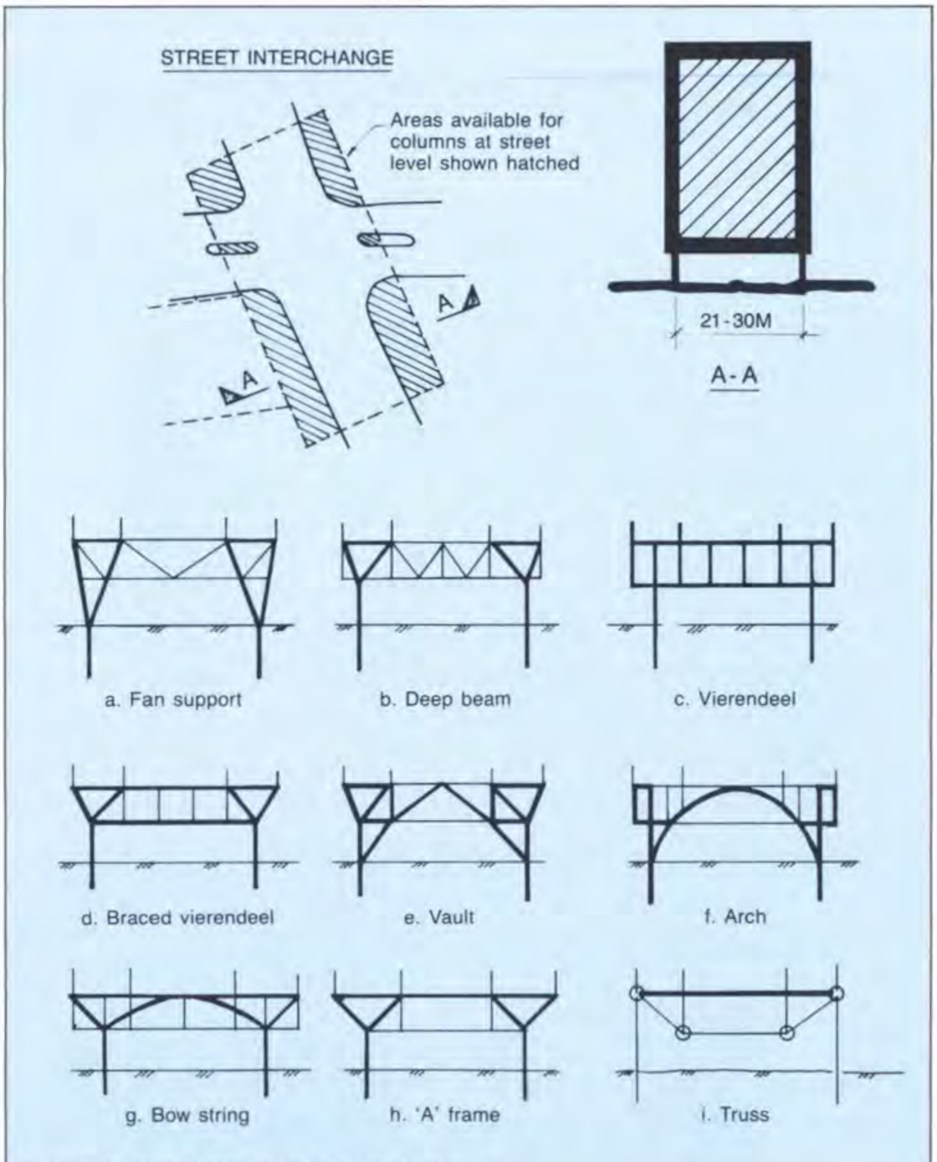
Almost 47 years ago the area round what is now London Wall was bombarded with high-explosives. Today it is proposed to cover this major thoroughfare in a more constructive manner: a £90M., 18-storey building astride the London Wall/Wood Street intersection, mid-way between Aldersgate Street and Moorgate, on the boundary between the City and the Barbican Centre. This is the proposed Air Rights building designed by the Terry Farrell Partnership for MEPC as part of the redevelopment at Lee House.

The floor area will total some 57,000m², the upper levels housing financial trading floors and offices. Farrell's design was inspired in part by the mediaeval Cripplegate which, until 1760, stood on the site of the present Roman House in Wood Street. The main facade of the proposed building incorporates the appearance of two flanking towers, linked together from the first floor upwards by a cylindrical projection and extensive areas of glass surmounted by a shallow curved roof.

Farrell, however, has paid particular attention to the street and to the first floor level, known also as the 'podium' level, where the highwalks along London Wall will enter a pedestrian shopping area, providing a lively bridge between the City and the Barbican. This open public space will be slung dramatically over the road and run the length of the building, some 60m, partitioned only by glass walls. Similarly, at each end, traffic entering through the massive archways of the tunnel created by the building will be confronted by a glass facade.

The transfer structure

A major task for Building Engineering 8 of Ove Arup & Partners was to design a transfer structure to span the six-lane dual carriageway of London Wall. Their assignment was complicated by the fact that at ground level two of the columns would have to be located on the islands in the middle of Wood Street, one of which was set back from the edge of the adjacent pavements running along London Wall. This meant that the necessary minimum distance between the columns at ground level varied between 21 and 30m.



1. Development of options for transfer structure

Apart from supplying the necessary structural support for the building, the design also had to take into consideration the architectural requirements. A transfer structure at roof level would have been partially external to the stepped roof line and was therefore discounted on architectural grounds. Amongst the alternatives, a structure at the podium level was considered. Such a solution had the added advantage that it would obviate the need to build a temporary platform over the road during the construction phase. The requirement that the first floor public area should be open, and as far as possible free from columns, precluded the use of a three-dimensional space frame, and so the Group started to consider various forms of truss. Along with other standard designs, the traditional trapezoidal truss in which the upper chord is shorter than the lower chord had to be discounted because the diagonal lateral struts would have obstructed movement along the walkways at the sides of the pedestrian area. To get round this, the designers developed a truss where the traditional trapezoid form is inverted.

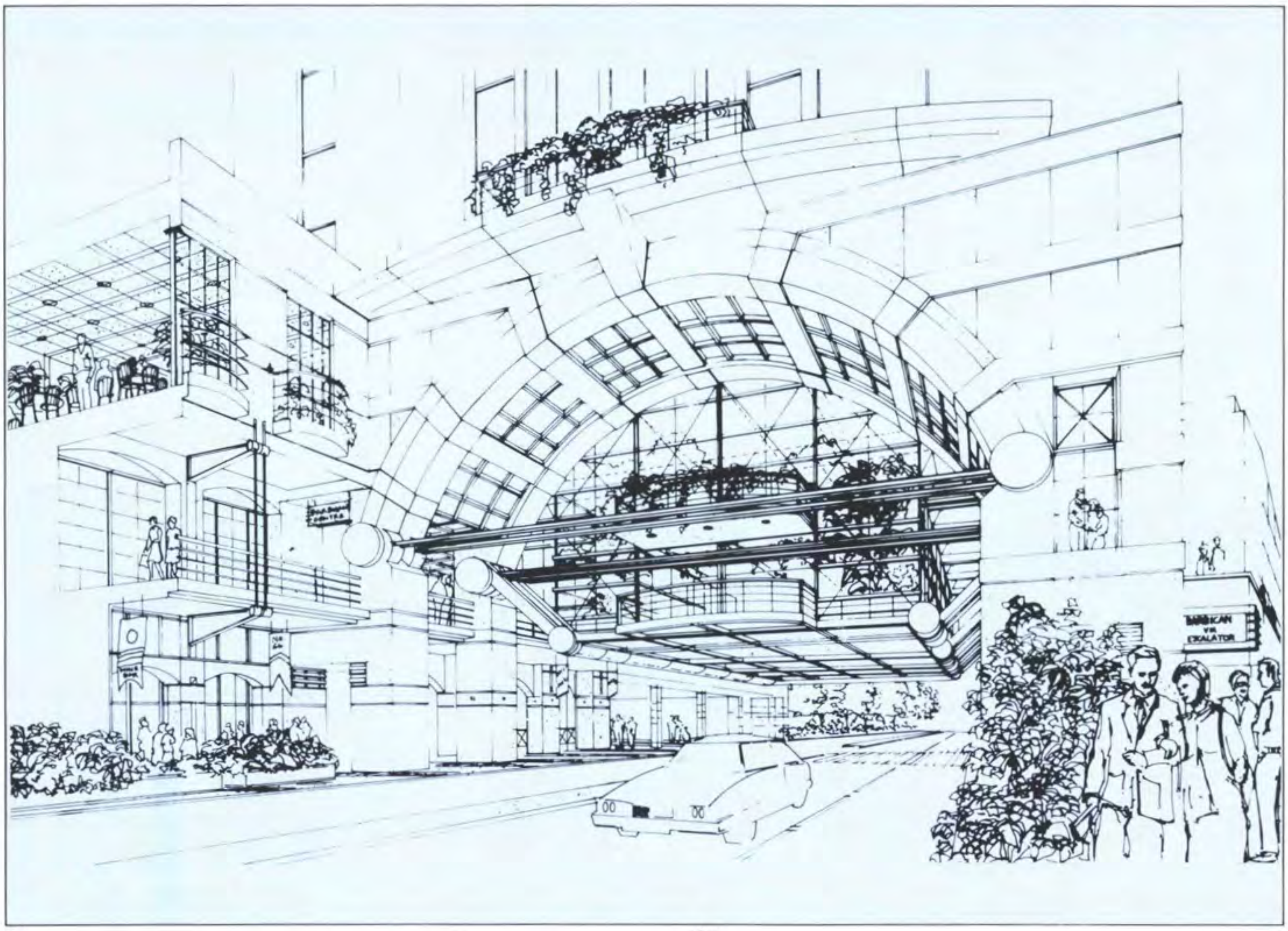
The final solution is thus a system of four cable-stayed trusses, with two additional bowstring arches at either end. The load coming down through the main columns, sandwiched between and bolted onto the giant cross-girders of the trusses, is some 12,000kN; that on the exterior columns of the trusses, some 6,000kN. Each truss has four joints comprising cast-steel 'noduli' about 2.2m long by 1.4m across, weighing about 15 tonnes. These noduli are of octagonal cross-section and from the upper pair, located at the extremities of the main girders, two clutches of 16 ties (tempered steel Macalloy rods), run diagonally down to the lower pair which are also pierced through by a further 24 rods in between them. Each rod is secured on the outer surface of the opposite side of the node by a large steel nut.

Such a brief verbal description of the structure is no match for the models made up by Arups' model shop, nor will it substitute for the sight of the full-size structure when it is eventually erected. Yet, as does the act of drawing, such description helps one to appreciate what one is looking at, and what one sees here is a structure which certainly deserves to be seen in terms of its constructive sculptural design as well as in terms of pure functional engineering. It was this dual aspect of the design, its visual as well as its technical interest, which led to its becoming the subject of the present painting.

The structure as inspiration behind the painting

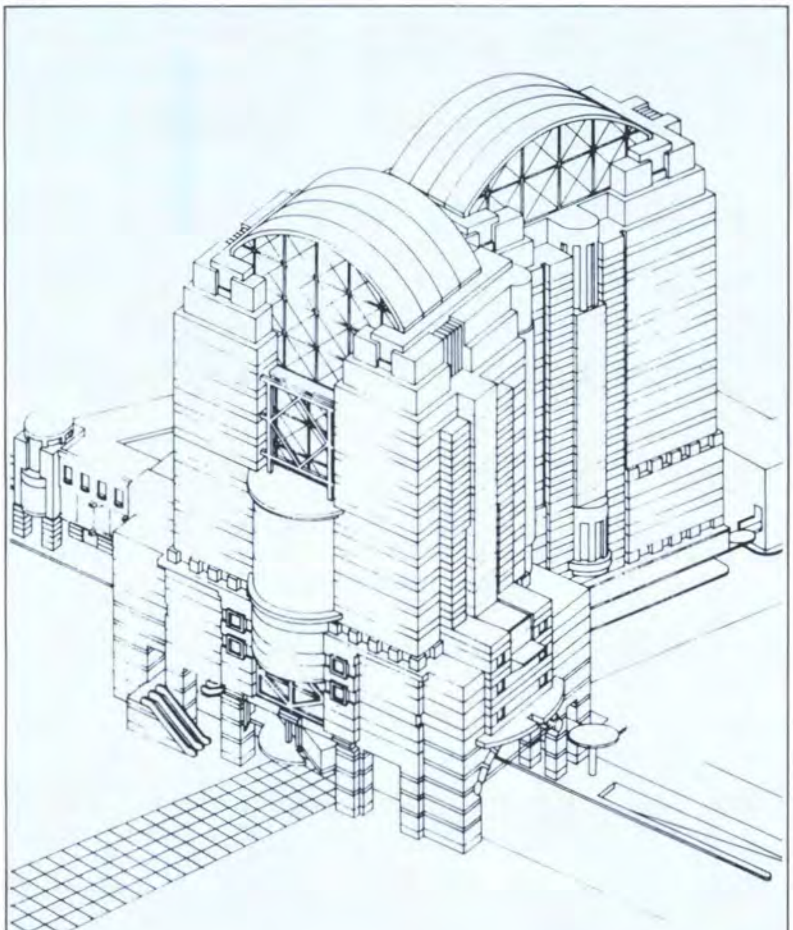
Just as the design team had arrived at its solution, Christopher McCarthy met the painter, Ben Johnson. The significance of

**Colin Sanderson graduated in Botany from the University of St. Andrews, in 1973, but subsequently turned to the study of Art History, first at the University of Edinburgh, and since 1978 at the Courtauld Institute of Art, London. His particular interests lie in historical and contemporary relations between art and science. He is completing a PhD thesis on the sculptor Naum Gabo.*



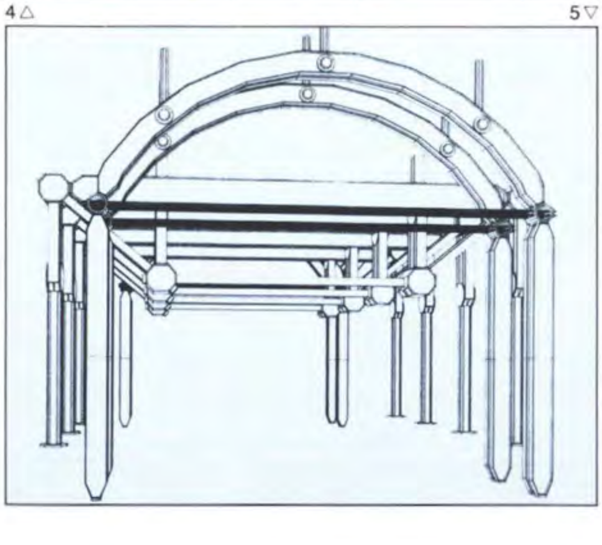
2△

3▽



4△

5▽



2. Architects' drawing of Air Rights building and 3. View through archway (Reproduced by courtesy of Terry Farrell Partnership)

4. Computer plot of transfer structure from the air and 5. From the road (Graphics: Terence Haslett)

their meeting lay in the fact that while McCarthy is an engineer who has also had some training as a sculptor, over the last 15 years Johnson, in his painting, has paid close attention to the products of architecture and of engineering and is well-practised in creating striking emblematic portraits of such subjects. Amongst those who have commissioned work from Johnson are IBM, the Volvo Car Corporation, and the architects Arup Associates, James Stirling and Norman Foster. Yet, in retrospect, Johnson found that even in some of his most architectural paintings it was an aspect of the engineering involved in the building which had excited his curiosity.

On seeing drawings of the Arup transfer structure, Johnson expressed his enthusiasm for it. His immediate response was no doubt stimulated by certain formal characteristics which enliven and unify the structure. Within the overall geometry of the design, for example, the zig-zag descent from the main columns through the paired noduli to the lateral columns of the trusses is enhanced by the alternation between single and double I-beams in the pattern 1:2:2:1. The diagonal symmetry of this passage is also reinforced by the octagonal facing plates on the upper and lower girder connections.

Yet Johnson was also impressed by the correlation of such formal qualities with functional performance. Considering the structure purely as a formal composition, one notes the way in which the rectilinear geometry of the noduli is picked up in the ends of the main girders, and in the ends of the arches and of their columns. Functionally, however, the trilateral form of these elements also provides neatly both for the slight rotation which might take place between column and footing, and for the connections between the primary and the secondary arches which occur at the western end of the structure. It is such correlations of form and function which appear, whether or not it be true, to confirm the intuitive belief that fitness of form leads in some inevitable way to beautiful solutions.

The idea was floated that Johnson might produce a painting based on the project.

Though doubts were expressed whether such a commission should be initiated on a project which remained unexecuted and to that extent unfinalized, the idea eventually received the firm's wholehearted support.

During several hours of discussion between himself and the artist, Christopher McCarthy explained the development of the design from the engineering standpoint. Johnson has for a long time used photography as a means of drawing prior to painting in acrylic on canvas, but he has also often expressed the view that the field of computer graphics offers new possibilities not only as a medium in itself, but also as a drawing medium for painters. He therefore welcomed the opportunity at this stage to explore the structure using Arups' computer graphics program. Here he was able to look at the transfer structure from different angles and distances with a view to choosing one aspect to develop in a painting. While wishing to display the various elements of the structure in one view, Johnson was not aiming simply to illustrate the structure. He was seeking an arresting image. At the same time he felt that there was a danger of making the structure look excessively elegant.

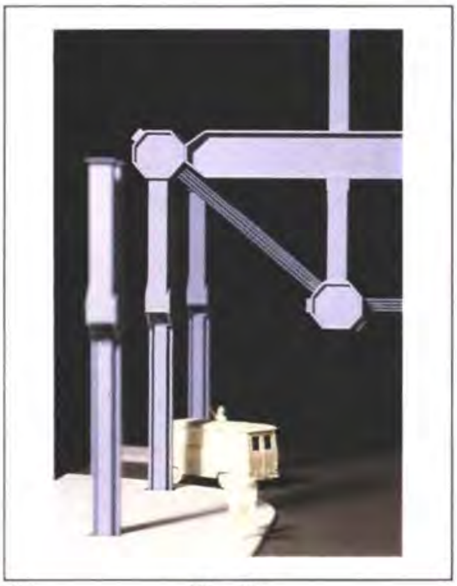
The painting

They finally settled on a view from directly beneath the structure looking skyward. The drawing, plotted using the Benson Plotter, was turned over to the firm of Cook, Hammond and Kell, who have facilities for photographic enlargement up to 4ft. × 9ft. Useful as this enlargement was, however, it completely lacked the necessary detail and Johnson had to reconstruct that detail from plans and sections and with the aid of models of the structure. The work which this implied is illustrated here in the underdrawing for a single nodulus. Drawn with Rotring pens directly onto the canvas, a heavy fine-weave linen hand-primed with acrylic gesso, this shows the intricate web of construction lines.

Johnson used De Vilbis spray-guns rather than finer air-brushes for his paintings, but as with the latter technique the first task remained the time-consuming process of masking off the drawing of the detailed structure in order to apply the background colours. Johnson favours American-made Liquitex acrylics, the pigments of which he considers to be better ground than many others. The background colour runs from sky blue through to a sunset pink signifying the east-west orientation of the structure.

Once the background was substantially completed Johnson added the dark strips of purple down each side. These help visually to anchor and compress the image, preventing it, as it were, from either floating around or exploding apart, and perhaps suggest the solid foundations on which the new structure will eventually stand. The transfer structure itself is coloured with the sequence of the background running in the opposite direction, from light blue to light pink. Deep shadows are painted in the same purple as the edge-strips and details are highlighted with a strong bright green pigment. The picture is thus one of high contrasts, and although it was hanging in the Royal Academy galleries rather higher than I would choose to see it, the painting nevertheless benefited from the strong lighting it received from the skylights.

From the time Johnson saw the original computer drawings, given the detailed construction and the repeated masking, spraying and drying involved in such a painting, the work took about nine weeks to produce. The result is without doubt an arresting image which, from an historical point of view, will serve as a worthy record of this major structural project. More importantly, however, it perhaps signals a development for which Johnson himself hopes and works, and one which he expects to see gather pace: that is, that due regard be given to the creative potential and achievements of engineers. For a painter to take such pains in celebrating and encouraging fine engineering is not unprecedented. Yet at a time when the social value of the 'fine arts' and, employing another unfashionable expression, of the 'mechanical arts' are being re-evaluated, the collaboration involved and the successful outcome of this commission should be applauded.



9 ▷

6. Line detail on canvas preparatory to painting

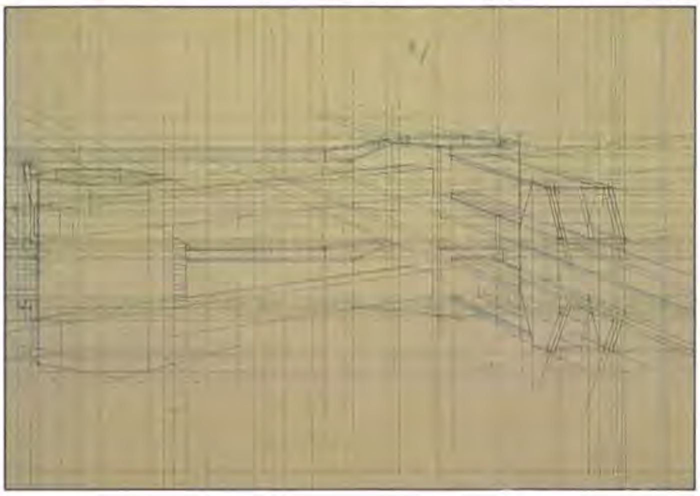
7. Model of transfer structure showing scale

8. Ben Johnson masking and spraying

9. Ben Johnson detailing

(photos 8-9: Ben Johnson)

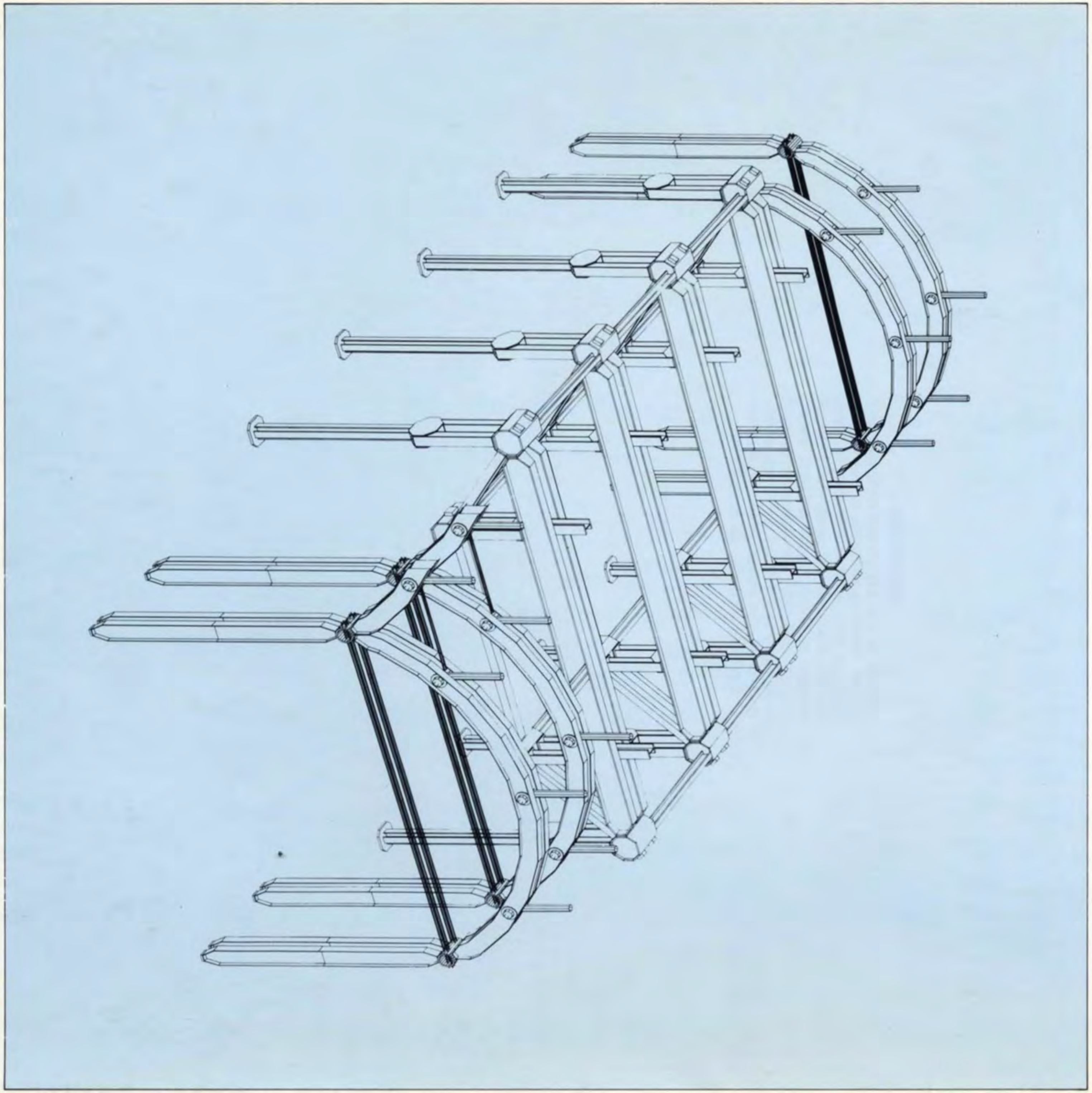
6▽ 7△ 8▽



Ben Johnson's painting
Acrylic on canvas: 102in × 68in. Internal image (without purple strips): 102in × 51in, i.e. a double square.

Exhibitions

Models for the Lee House redevelopment project including elements of the transfer structure were exhibited recently in 'Terry Farrell in the Context of London', at the Royal Institute of British Architects Heinz Gallery until 13 June 1987. Ben Johnson's painting is presently on exhibition in the Architecture Section of the Royal Academy Summer Exhibition, 6 June – 23 August 1987.



Printed in England by Reedprint Limited, Windsor, Berkshire