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Art Editor and Designer: Desmond Wyeth FCSD, Deputy Editor: Karen Svensson
Editorial: Tel: +44 (0)20 7755 3828 Fax: +44 (0)20 7755 3716 e-mail: david-j.brown@arup.com

Published by Arup, 13 Fitzroy Street, London W1T 4BQ, UK. Tel: +44 (0)20 7636 1531 Fax: +44 (0)20 7580 3924 e-mail: corporate@arup.com

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Front cover:
The City of Manchester Stadium (pp25-36) Photo: ©Arup Associates/Dennis Gilbert/VIEW

Roundabout Outdoor

Chris Twinn

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Editorial

Most of the projects and processes described in this issue of *The Arup Journal* were designed to enhance and improve various aspects of the human environment. In his 2002/03 Brunel International Lecture 'Poverty alleviation: the role of the engineer' (pp3-9), David Singleton analyzes the ways in which human poverty is often rooted in infrastructure issues, and how engineers can work with local communities, regional authorities, and national governments to alleviate and solve them.

In Zimbabwe, the local Arup practice pulled together much of the country's troubled road construction industry in a consortium to design and deliver, quickly and with minimum adverse environmental impact, a vital new road (pp49-52) for the wealth-creating Zimbabwe Platinum Mines.

Making energy resources sustainable is a major environmental concern, and for the BedZED scheme in south London (pp10-16) the design team, including Arup, tackled head-on the challenge of creating such a live/work environment with hitherto unprecedented net zero energy fossil consumption.

In New York, the new Austrian Cultural Centre (pp17-20) and the 'epicenter' store for the Prada fashion house (pp21-24) are both designed in different ways to respect, complement, and enhance the unique dynamic of NYC. Arup engineering was vital to this, as it was at the City of London corporate headquarters of bankers Merrill Lynch (pp53-59). This building was designed not only to have its considerable bulk and footprint discreetly accommodated in a tightly packed and historic area - in particular with respect to the sightlines to St Paul's Cathedral - but also to preserve, display, and celebrate the major historic remains on the site.

In Denver, Colorado, ArchitectureDenver and Arup worked together to create the Millennium Bridge (pp37-39) as a central marker and icon for a new residential and commercial area. The City of Manchester Stadium (pp25-36) in the UK was designed by Arup Associates and built not only to accommodate the XVII Commonwealth Games and subsequently be the new home for Manchester City Football Club, but also to form the focal point for the long-term regeneration of the city's Eastlands region. This urban location is a far cry from the deserts of Abu Dhabi, where the Arup-engineered roof of the Zayed International Cricket Stadium (pp46-48) presents a comparably bold profile.

Both of these major sports projects have marked sculptural qualities. In London's Tate Modern gallery, significant engineering input was needed to create a single 'sculpture'. An Arup team enabled the artist Anish Kapoor to realise his conception for the gigantic 'Marsyas' installation (pp40-45) that filled the volume of the gallery's Turbine Hall for six months until May 2003.

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Back cover:
Denver Millennium Bridge (pp 37-39) ©Arup/Frank Ooms

Poverty alleviation: the role of the engineer

David Singleton

Introduction

The statistics on world poverty are frightening. Close to half the world's 6bn people live on less than US$2 a day; conversely 1% of the population has an income equal to that of the entire bottom 57%[1]. But poverty is not only about lack of wealth in monetary terms; it also implies the 'denial of various choices and opportunities basic to human development. These include the ability to lead a long, creative and healthy life, to acquire knowledge, to have freedom, dignity, self-respect and respect for others, and to have access to the resources needed for a decent standard of living.'[2]

Community infrastructure is key to alleviating poverty – and thus engineers have an essential role to play. Without ready access to clean water and sanitation, productivity is severely reduced through illness and time spent in water collection. Without roads, the poor are unable to sell their goods at market. Basic infrastructure is not a luxury that can wait for better economic times, but a precondition for creating them, and its provision is an urgent and ongoing requirement. *The Economist* has observed that 'over the past 50 years rich nations have given US$1 trillion in aid to poor ones. This stupendous sum has failed spectacularly to improve the lot of its intended beneficiaries. Poor countries that receive lots of aid do no better, on average, than those that receive very little'[3]. Poverty is thus not being ignored, but alleviation strategies must be more effective for relief to be achieved.

The origins of poverty

To begin solving poverty, its origins must be clearly understood. The basic causes are:

- **lack of access to safe water and sanitation**
- **lack of facilities for adequate health care**
- **lack of access to educational opportunities**
- **shortage of adequate nutrition**
- **lack of adequately paid employment**
- **inadequate or expensive transport facilities**
- **limited or expensive power supplies.**

Urban and rural poverty generally have different causes, though not mutually exclusive. The main causes of urban poverty are likely to be:

- **lack of adequate income or no income, due to underemployment or unemployment**
- **inadequate housing, sanitation, and water supply**
- **limited opportunities for education**
- **inadequate or expensive transport facilities.**

Poor health and lack of access to education tend to minimize skills, compounding the problems of un- or underemployment, leading to reduction of income-earning capacity.

The predominant causes of rural poverty are likely to be:

- **lack of access to health care and education**
- **inadequate shelter, sanitation, and water supply**
- **lack of access to markets for agricultural products**
- **limited opportunity to earn income**
- **inadequate or expensive transport facilities**
- **no access to power and telecommunications facilities.**

Poverty in rural areas tends to be more widespread and more intense than in urban areas, because:

- **Employment opportunities are more limited.**
- **Access to a range of key facilities is much reduced.**
- **Many households are headed by women – often due to abandonment of families by the males, with commensurate reduction in income.**
- **Sanitation and water supply deficiencies are more intense, leading to ill health.**

The trend in developing countries worldwide - whereby male family members gravitate to urban areas in search of employment - often reduces the rural family's ability to survive in a subsistence economy.

Poverty alleviation strategies

Historically, poverty alleviation strategies have focused on direct intervention to provide facilities that are lacking. Investments by international lending agencies over the past two to three decades have concentrated on solutions to deficiencies in infrastructure that are usually expensive, often with apparently limited thought to ongoing operation and maintenance. Local observers in several recipient countries, and other stakeholders, have commented on inadequacies in the implemented projects and programmes:

- **lack of planning for ongoing operation and maintenance of the facilities**
- **limited attention to the development of a sense of ownership by the local community**
- **political interference and intervention**
- **allocation of funds to countries without a poverty alleviation strategy of their own**
- **corruption, leading to ineffectiveness of investment.**

At the recent Rio+10 Sustainability Summit, both the United Nations and the World Bank called for alleviation strategies involving 'no more hardware', noting that major investments over the last 20-30 years in water infrastructure schemes had often failed to benefit the people at whom they were aimed.

This is because most facilities involving technology are generally abandoned within two years, as revenue streams are insufficient to pay for repairs and maintenance and because of the lack of local skills to carry out repairs. Corruption is also often a barrier. In agreeing to a target to halve the number of people without sanitation globally by 2020, the Summit noted that emphasis should be on smaller-scale solutions suited to local capabilities, understanding and skills. The role of engineers in delivering infrastructure schemes needs to change significantly.

Again over the last 20-30 years, experience with implementing large-scale infrastructure improvement projects has led to an improved understanding of the conditions necessary for sustainable reduction in poverty levels:

- **The local community must be empowered by the decision-making process.**
- **The local community must be involved in ongoing operation and maintenance.**
- **National and regional governments must also be involved in the project.**
- **Project selection must favour those projects that lead to economic growth.**
- **Strength of the market economy is a prerequisite to economic growth.**
- **Close involvement of the local community will improve the chances of project success; it needs to be 'owned'.**

Poverty alleviation requires interventions that involve considerable social and cultural change. Poverty has many aspects, and solutions require more than a technical or engineering basis. Provision of infrastructure alone will not alleviate poverty, without access to that infrastructure.

We can ask such questions as:

- **What good is a road if there is no means of transport?**
- **What good is a latrine if it is not being used?**
- **What good is a water supply system if it is in disrepair?**

In developing strategies to alleviate poverty, we must take account of and address these wider issues.

1a & b. Problem and solution (see Case study 2, p5).

This article is an edited version of the Fourth Brunel International Lecture 2002/03, given under the auspices of the Institution of Civil Engineers, by David Singleton, Chairman of Arup Australasia.

Sound engineering solutions to poverty alleviation

Engineering solutions are integral to mitigating poverty; however, engineering is not the sole contributor to successful poverty alleviation programmes, which also entail attention to social, economic, and political influences. Sustainable engineering will be achieved when the engineering solutions adopted take into account their use of natural resources. Optimum solutions will have a positive or neutral impact on natural resource consumption. Unsound engineering solutions, by comparison, may leave the environment depleted and society poorer over time.

Life-cycle engineering takes into account the operational and maintenance cost of the engineering solutions proposed, such that the completed projects have effective and affordable operational and maintenance regimes.

Empowered engineering will take into account the capabilities of the local community, particularly its engineering and technical professions. Where possible, the solutions developed will involve local professional and technical staff and will establish an on-going engineering and operational resource.

Appropriate engineering will consider various options that meet the engineering needs of the project and may adopt techniques of labour-based construction, which differs significantly from labour-intensive construction. The latter basically substitutes men for machines, eg constructing a concrete-framed building where the concrete is mixed by hand without a mechanical mixer. Labour-based construction, by contrast, aims to change the technology involved to what is appropriate for manual labour, eg eliminating the concrete frame and building the structure of load-bearing masonry. Labour-based construction has been shown to compare favourably with plant-based construction[4]. In addition, it facilitates knowledge transfer, creates jobs, encourages private enterprise, creates ownership, and may reduce cost.

The following five case studies illustrate engineering applications to poverty mitigation programmes and identify the associated social, economic, and political actions put in place.

Each shows sound and appropriate engineering.

Case study 1:
Australian remote Aboriginal communities

Arup has undertaken many projects across the globe addressing the lack of access to basic infrastructure. For example, we have extensive involvement in water supply and sanitation projects in Botswana[5], and in health, housing, and community infrastructure projects for indigenous communities throughout Australia[6].

Project background

The Infrastructure Operation and Maintenance Project for the Aboriginal Co-ordinating Council (ACC) commenced in 1999, with a budget of A$6M and a planned duration of three years. The project was instigated in response to the challenges faced in Queensland's remote indigenous communities in developing and maintaining infrastructure. Limited recurrent funds and the difficulties in acquiring appropriate technical and management skills in remote communities resulted in low infrastructure lifecycles, and thus lower standards of living and poor health.

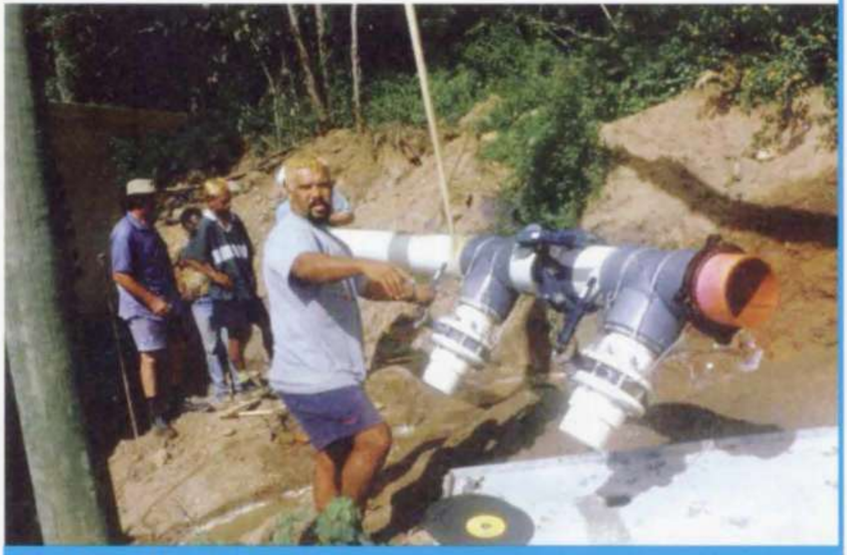
Project details

This pilot project was implemented in six remote communities in Queensland. It was a 'grassroots' initiative for indigenous communities that aimed to:

- **improve the health and wellbeing of their people**
- **develop and support a culture of asset management**
- **protect investment of capital funds in their infrastructure.**

Arup was appointed as project co-ordinator to oversee the project and liaise with communities, funding and training agencies. The firm's role included the development and implementation of technical and management 'on the job' training (during Stage 1, 21 Trainees completed Certificate 2 in Essential Services for Aboriginal and Torres Strait Islander Commission (ATSIC) communities through the Technical and Further Education Programme (TAFE)), the implementation of best practice in infrastructure asset management, raising awareness among community members of the importance of caring for infrastructure assets, and the need to establish mechanisms for permanent Essential Services Officer positions.

2. Drilling a borehole.



3. Installation of piped water services.

Case study 2:
South African roundabout HIV/AIDS initiative

Project background

The AIDS epidemic is tearing apart the social and economic fabric of many African nations. 70% of the world's AIDS-infected adults and 80% of infected children live in Sub-Saharan Africa.

There are 11M child AIDS orphans, and grandparents are forced to assume the responsibility for childrearing[7]. Affected families lose income-earning capacity, both through the absence of the income earner and the time and cost incurred in nursing the infected. The problem compounds itself: poverty is a key factor leading to the behaviour that exposes people to risk of HIV infections, and the resulting HIV compounds the poverty.

Project details

The concept is simple: a child's playground roundabout bolted on top of an existing borehole, with the energy of the children at play harnessed to pump drinking water into an overhead storage tank screened with billboards promoting HIV/AIDS awareness to the children and communities. There is a communal tap at ground level. Each roundabout/pump costs US$5000, and is based on standard windmill equipment located below ground[8].

The above-ground equipment includes the tank and galvanized sheet as advertising boards, available at any farm supply store. Project construction and replication are helped by the use of standard and easily procurable materials.

'Play power' has advantages over conventional energy sources. It is clean, renewable, and robust, and the borehole recovers naturally during the night. There is no risk of pumping dry or engine burnout if the pump is 'accidentally' left on overnight.

At least 50% of the billboard space promotes health-related information, in particular on HIV and AIDS. This is an effective advertising medium in the absence of conventional 'first world' media like newspapers, magazines, television, and the Internet.

Revenue from commercial advertisers in the remaining space will provide a regular flow of income for the manufacture of new roundabouts and to cover maintenance costs. Women and young girls benefit from the saving of time and energy previously spent fetching water for daily needs from deep wells at long distances, and are placed at less risk. Also, they benefit from the HIV/AIDS awareness campaign.

4. 'Play power'.

Progress report

More than 300 roundabout pumps have been installed in South Africa, each serving a community of over 2500 people. Various improvements to standard of living have been noted, including the ready availability of clean drinking water. This reduces water-borne diseases like cholera, and helps in the development of thriving vegetable farms providing fresh produce for schools and for sale at market.

5. Southern Africa.

6. Children at play turning a roundabout bolted above an existing borehole. This action works a pump enabling drinking water to be pumped into an overhead storage tank screened with billboards promoting HIV/AIDS awareness to the community.

Case study 3:
Micro-finance in Bangladesh

Project background

Bangladesh is one of the poorest, most densely populated, and least developed nations in the world. With more than 125M inhabitants, it is the eighth most populous country in the world - but with a per capita annual income estimated at around US$280[9]. Situated in a low-lying delta where four major river systems come together, the country is blessed with highly fertile soil, but also suffers regular and severe flooding. Shelter is one of the most basic requirements, but many Bangladeshis cannot afford the cost of housing able to withstand the monsoon and winter periods. Typical houses are made of jute sticks placed side-by-side and cost between US$25 and US$30. Such houses tend to collapse in moderately severe weather. Even if constructed with bamboo walls and hay/thatch roofing, at a significantly higher cost, they are not very durable. As a result, almost every year, people replace or repair the roof of their house at a cost of up to US$40. This cost is increasing with the constant rise in price of bamboo and hay. This ongoing expenditure is a heavy burden on the poor. If they have no access to cash, people are forced to borrow money from moneylenders at very high rates (10% per month)[9]. This situation could be avoided if more durable shelter could be constructed; in turn this depends on finance.

Project details

The Grameen Bank[10], the largest rural credit institution in Bangladesh, with 2.4M borrowers (95% of them female), was established in 1976. The Bank recognizes that it is lack of access to collateral rather than inability to make loan payments that perpetuates poverty. Regular micro-enterprise loans are typically disbursed to individuals for one year and are paid back in weekly instalments at 2% of the loan amount, which is normally no more than US$20 for the first loan. To participate in the loan programme, a member must gather five people with similar economic and social backgrounds who will agree to apply for and sign together on loans (a 'group'). A cluster of groups (between two and 10) constitutes a 'centre', which is presided over by two officials[9]. The borrower's group and centre members must agree to stand behind the loan for the individual member. The collateral system, based on peer support, means that families help each other out with payment to ensure that all repayments are made on time. Grameen Bank operates as a specialized bank for the poor, generating income from its investments; it is not reliant on donor funding. When the Bank was formally incorporated in 1983, the original rural members provided 40% of the initial capital: the Bangladesh government contributed the rest. The Bank has since become largely self-sufficient, with the government now holding less than 10% of the equity.

Housing loans: In 1984, the Bank started to lend money for housing, and to date 450 000 houses have been built using these loans. An average of 7000-8000 new loans are made every month. Although exceptions are made for the poorest of poor in dire need of shelter, relatively strict rules govern these loans. To qualify for a housing loan, a member must fulfil the following:

- **be an existing Bank borrower, with a 100% repayment record, and have completely repaid their first two loans from income generating activities**
- **prove that they have an adequate income and have acquired savings**
- **have a history of regularly attending weekly meetings**
- **provide legal documentation of land ownership where the house will be built (if the member does not own land, he/she is encouraged to use the loan towards land purchase), and**
- **must submit a proposal on the type of house planned and devise a repayment schedule.**

House design: The Grameen Bank developed house designs for borrowers. The houses, although varying in appearance, have the same basic structural components: four reinforced concrete pillars on brick foundations at the corners and six intermediary bamboo posts, with bamboo tie beams, wooden rafters, and purlins supporting corrugated iron roofing sheets. This design provides stability in flood and strong monsoon winds and protection from rain. Although the borrower is responsible for the construction of the house, the Bank ensures that it meets basic health and safety requirements and achieves minimum Grameen standards. Since mid-1998, the Bank has required members to install a sanitary latrine with each house.

7. Bangladesh.

Progress report

The Bank operates efficiently and is widely considered innovative, progressive, and corruption-free. The rate of repayment for all loans is 98%, and for housing loans it is close to 100%, compared to 25-30% for other banks. Loans are currently available at 8% interest, again comparing very favourably with the 20% interest charged for regular or short-term loans from other banks[9]. The Bank provides employment for 12 600 people.

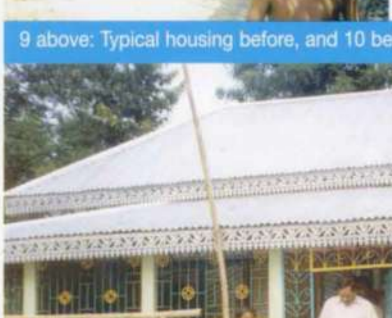
To date, the Grameen Bank housing programme has assisted hundreds of thousands of Bangladeshi families to break out of the downward spiral of poverty. A sturdy, well-built house is a symbol of social status, so borrowers gain dignity and standing within the community.

The larger houses give improved environments for work and study, and hence have directly contributed to higher income generation. It is estimated that 95% of borrowers' children attend school, well above the nationwide average.

By demanding standardized construction practices like the use of cement pillars and installation of sanitary latrines, Grameen Bank assists in improving the health and safety of borrowers. In one survey, the general health of those with the new Grameen houses compared well with those in pre-existing or more traditional houses. Fever, influenza, and typhoid (among other diseases) were down by almost 50%[9].

Micro-credit programmes based on the Grameen experience have been established in 56 other countries.

8. A group of borrowers at their micro-credit weekly meeting with the Grameen Bank manager.



9 above: Typical housing before, and 10 below: after Grameen programme.

Case study 4:
BP solar energy project, Philippines

Project background

The Philippines archipelago comprises around 7100 islands, 1000 of them inhabited. Less than a half exceed 2.5km^2 in area. Many of the villages (Barangays) dotted over the country are remote and difficult to access by land or sea, so for many connection to a national power grid is not feasible. Most district hospitals and regional health units have little or no electricity, and lack of lighting in community halls limits opportunities for further education and involvement in community affairs. Many villages rely on shallow wells or surface springs for their water, hence water-borne disease is endemic. Latrines are unsanitary, if existing at all.

Solar power can provide a highly effective, low-cost and environmentally friendly alternative to extending power lines and/or transporting generator fuel to these areas.

Project details

After the success of a solar power project completed in Sri Lanka in 1993/94, BP Solar Australia approached the Philippines government with a concept for large-scale implementation of solar power across rural communities, and received a favourable response.

The initial objective was to install about 1000 stand-alone solar-powered equipment packages in 400 villages in remote areas of Mindanao and Visayas provinces. At its time, this was the largest solar contract in the world, at a total project cost of US$27M. Fundamental to the project's success was the simplicity of the funding, via a single loan recipient - the Department of Interior and Local Government (DILG) - through a grant (33%) plus a 'soft' loan (67%), both from the Australian government.

Community mobilization phase: Community involvement throughout the entire duration of a project, fostering a sense of ownership and responsibility, is essential for success. The Municipal Solar Infrastructure Project (MSIP) was implemented with the help of two full-time BP staff from Australia, but the other 500 staff involved were Filipino, selected from the communities they were to work in, enabling communication in local dialects.

Prior to project finalization, officials used community assemblies to introduce the project, discuss the benefits both to individuals and the entire community, and explain the basics of solar electricity. If the community - in particular the mayor - was interested, agreements were made to proceed. Site and social surveys were used to determine the development needs of each community and to identify the means by which solar energy could be best used as the enabling technology to meet these needs. BP also spent time with each Barangay, exploring revenue-generating activities that would enable them to pay for the services provided by the solar-powered systems.

Provision of systems: Solar systems were supplied and installed in the specified areas, though the logistics were challenging, due to the difficulty of getting construction materials, equipment, and systems into the communities. As this was a 'tied-aid' project funded by the Australian government, BP Australia was obliged to source a minimum of 87% of components from Australia. However, some construction items, videos, and televisions were sourced locally/nationally[11].

Training and capacity building: In each Barangay, two people were elected to form the Barangay Technical Team (BTT) and trained on simple system maintenance: cleaning the modules, topping up the battery electrolyte, etc. Municipal engineers and operatives were trained on the more technical repairs and maintenance of system components. Spare parts were distributed to the municipality to give the communities easy access to replacement parts. High-level training was provided for the universities, with staff and students being able fully to dismantle, repair, and reassemble the components. After the commissioning and handover of each system, BP Solar carried out three separate follow-up visits with the groups that had been formed.

Over 2000 people have been trained (including 'training of trainers') on both project governance (how to organize meetings, accounting and reporting; how to collect fees/local revenues for sustaining services/maintenance, etc) as well as on the technical aspects (maintenance, including local repair and replacement of parts). Experience has clearly shown that without such training, systems fall into disuse and disrepair and communities are then left disillusioned.

Progress report

MSIP commenced in November 1997 and completed in May 2001. In total 1145 packaged solar systems were installed in 11 Provinces, 53 Municipalities and 435 Barangays. The quality of life for over 720 000 people in some of the most remote and poorest provinces of the Philippines has been improved[12]. Improved health, safety, education, governance, and easier access to potable water will bring about poverty alleviation. The project improved local governance by enhancing the ability of the Local Government Units (LGU) to deliver essential social services and elicit the participation of community organizations and individuals in improved governance. Although it was necessary for BP Solar to pull out of several areas over the life of the project due to political uncertainty, an impressive list of community facilities were upgraded:

- **Four district hospitals, 11 rural health centres, and 104 Barangay health centres:** More than half a million people will directly benefit from improved services. Improved capacity to store and utilize vaccines, and other medicines will reduce infant maternal mortality rates, assist in tetanus prevention, and improve general illness treatment.
- **289 areas of communal lighting for markets and fishermen's wharves:** These facilitate safer night vessel navigation and reducing night fishing wharf accidents.
- **260 Barangay potable water supply systems:** These will lead to substantial reductions in water-borne disease. Women in particular will benefit from time savings in water collection and caring for ill family members.
- **266 schools, six municipal halls, and 201 Barangay halls:** Access to school facilities at night for adult education or entertainment will further improve quality of life.

11. The Phillippines.

12 left: Lighting for improved education facilities.

13 below: Communal lighting to wharves.

Case study 5:
Communal sanitation, Myanmar

Project background

Access to clean water and adequate sanitation is essential to the development of a sustainable community. Access for the poor is a key factor in improving health and economic productivity, and is therefore an essential component in any effort to alleviate poverty.

In 2001, 16% of the world was without water supply and 40% without access to adequate sanitation. Water-borne diseases are responsible for more than 80% of all sicknesses in the world, resulting in the deaths of over 4M children annually. Diarrhoeal diseases are the third most significant child killer (after respiratory infections and malaria), accounting for 15% of the under-five years' mortality rate, especially in rural areas. Substantial decreases in the frequency of contagious disease from inadequate sanitation and water supply would result in substantial savings in healthcare costs. These could be invested in national development, thus further increasing national productivity.

In 1997, Myanmar was crippled by diarrhoeal disease, killing 30 000 children. Sanitation coverage stood at only 39% of the population, and personal and domestic hygiene was poor[13]. Myanmar ranked 190th out of 191 in the WHO Report 2000[14].

Project details

Over the past decade, significant attempts have been made to improve sanitation in Myanmar. In the mid-1990s the government, in a bid to promote community participation, adopted a strategy in which families were provided with free latrine pans. However this proved too costly, failed to achieve community support, and was phased out. The government then recognized that it could no longer be the sole provider of sanitation services, and that the key role of government should be to facilitate and stimulate local communities to recognize and meet their own needs. This was to be carried out through organizing and financing community mobilization and household motivation, and running an awareness campaign, known as the National Sanitation Week (NSW). For the past five years, UNICEF has supported this programme. National Sanitation Week activities are carried out under the guidance of the National Health Committee and with the active involvement of the entire nation.

The Week has three key objectives:

- **to educate the general public in the values of sanitation**
- **to assist people in actual implementation of sanitary work**
- **to reduce the spread of communicable disease.**

Community mobilization: As individual users are the ultimate 'decision makers' who embrace or reject new technology, community involvement is widely accepted as a key ingredient in the success of any aid project. As noted in previous case studies, participation of local people in all stages of a project, from design and construction to operation and maintenance, is paramount in fostering a sense of ownership and ensuring that facilities are properly used and maintained.

Use of sanitation cannot be imposed - it has to be 'created' by demand. In the past, supply-driven approaches to sanitation provision have led to widespread disuse of latrines, leaving latrine slabs as a health hazard and a negative influence on any future sanitation attempts. Demand for use of sanitation systems is thus not is easily generated, as rural populations do not often perceive the health benefits arising from sanitation. It is therefore fundamentally important that sanitation be effectively promoted, as part of health education, to create demand.

Promotional campaign: This treated sanitation as a product to be marketed to individual households, with all available and affordable media and communication channels being used to promote sanitation messages. The approach was broad-based, emphasizing not only potential health improvements but also benefits such as privacy and convenience, elevation of household status, respect and dignity (especially for women), environmental awareness, and the potential economic benefits of generating resources out of waste.

Social mobilization was intensified through community meetings organized at various levels, supported by visiting health teams and input non-governmental organizations, schoolteachers, and local leaders. A range of information and communication materials, such as posters, pamphlets, and models of affordable latrines, was produced. National television and media also played a significant communication role. UNICEF contributed about US$100 000 per year to these promotional activities[15].

The communication and social mobilization package has been improved each year to give greater attention to upgrading unsanitary latrines and integrating washing of hands into the sanitation cycle. Interested households form a village sanitation committee, which plays a fundamental role in co-ordinating activities.

Implementation: Construction activities commenced only after the awareness campaign had been launched and hygiene and sanitation education provided. Thus construction took place only in motivated communities and with the co-operation of the end users; indeed, it was promoted as a 'do-it-yourself' construction programme. Families were responsible for installing and financing their own sanitation facilities, with subsidies only made available for schools and for the communities that could not afford self-finance. Households were in fact subsidized during the 1997 floods but even then an element of self-help was expected. A low-cost (Kyat 900 or US$2.75) locally-manufactured plastic pan and pipe set was made available to each household that had excavated (and lined where necessary) a pit and then built as good a superstructure as it could afford[16]. A wide range of low cost and appropriate latrine designs was developed, suited to individual family preference and affordability. Every effort was made to promote capacity and income generation activities among community members, to allow them to participate by contributing labour, cash, and/or materials towards building the project. The private sector responded, to meet the rising demand for parts. Local production of plastic latrine pans has increased by a factor of six in the last five years, from about 40 000 in 1995 to more than 250 000 annually[16]. To reduce costs, locally available materials were widely used and some village leaders organized the bulk purchase of bamboo.

Progress report

In 1997, before the national campaign was launched, the sanitation coverage throughout rural areas stood at 39%[13]. In 2001, sanitation coverage stands at 57%[17]. Hand-washing with soap and water after latrine use has also increased, from 18% in 1996 to 43% in 2001[18].

Too frequently, the success of sanitation programs is measured by the total number of latrines constructed, with little attention to actual operation, maintenance, or usage. Long-term success of these systems depends on the availability of supplies, parts, equipment, and the availability of trained people needed to monitor, maintain and repair the systems, as well as continued community demand for their use.

As sanitation coverage in Myanmar grows, campaigning continues. Programmed follow-up to the National Sanitation Week is being provided in selected townships through more intensive social mobilization targeted at 'hard to reach' households and communities, and activity-based sanitation and hygiene education in selected schools. This approach recognizes that schools create an excellent participatory and enabling learning environment in which to promote sanitary habits and hygienic practices. There continues to be widespread general training of decision-makers, planners, and trainers in social mobilization programmes for hygiene. The 2002 National Sanitation Week accordingly gave special emphasis to activities to be carried out in 73 of a total of 324 townships, where 50% or more of the households still do not have access to a sanitary latrine[18].

Myanmar's success is a model to other countries and has been internationally recognized by South East Asian Region Countries. Government delegates from Indonesia, Pakistan, Bhutan, China, Vietnam and Laos have come to Myanmar to observe their activities and learn from their experiences. Nepal launched its own National Sanitation Action Week: March 2001.

14. Myanmar.

15. Rural water supply.

Conclusions

Each case study illustrates the application of relatively low technology engineering in small-scale investments which nonetheless enjoy high levels of community engagement. The success of these programmes is due in significant measure to this level of community commitment and to the extent of understanding of social, economic and political influences in that local community.

As Sir Ove Arup said, 'Engineering problems are under-defined, there are many solutions, good, bad and indifferent. The art is to arrive at a good solution. This is a creative activity, involving imagination, intuition and deliberate choice.'

In these case studies and in many similar scenarios, the solutions developed have not been primarily engineering solutions, although engineering plays a key part in the outcome adopted. It is not known which profession took the lead in which scenario, but it is clear that engineers with appropriate sensitivity could have led in all of them.

The case studies therefore illustrate the application of sound engineering solutions to poverty alleviation:

- **Sustainable engineering was achieved, as the solutions adopted will have a positive or neutral impact on natural resources.**
- **Life-cycle engineering took into account the operational and maintenance cost of the engineering solutions. The completed projects have effective and affordable operational and maintenance regimes.**
- **Empowered engineering took into account the capabilities of the local community, in particular its engineering and technical professions. The solutions developed involve local professional and technical staff and will establish an on-going engineering and operational resource.**
- **Appropriate engineering considered various options that met the engineering project needs and adopted labour-intensive construction where relevant, so as to create community involvement and knowledge of the projects' operations and to stimulate community income.**

The challenge for the engineering profession is to revisit our 'Brunel' roots and develop a suite of solutions to the issues raised in this paper. These should include solutions not only to the alleviation of poverty when it occurs but also to the development of sustainable urban infrastructure; solutions that recognize rather than resist the inevitability of migration to urban centres and then make provision for these rapidly growing populations.

Engineers can work effectively with other professions and community leaders to develop sustainable solutions to poverty. And engineers can take the lead in developing sustainable concepts for the urban areas of the future, concepts in which:

- **Access to and opportunities for employment are enhanced.**
- **Housing, sanitation, and water supply are provided at affordable prices.**
- **Access to and opportunities for education are enhanced.**
- **Affordable transport facilities are available.**

This is our 'Brunel challenge'.
It is worthy of our commitment.

Author's acknowledgement:

Nicole Hahn undertook the research for this paper. Her enthusiasm and personal commitment for this topic is unbounded and exemplifies the commitment of many young engineering professionals to 'make a difference'.

I am grateful for her contribution and support.

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2, 3: Arup
1, 4, 6: Roundabout Outdoor
5, 7, 11, 14: Daniel Blackhall
8-10: Building and Housing Social Foundation
12, 13, 15: BP Solar

'The difference between what we do and what we could do would suffice to solve most of the world's problems': Mahatma Ghandi

'No other issue suffers such disparity between human importance and its political priority': Kofi Annan (on water and sanitation

BedZED

Chris Twinn

1. BedZED virtually completed.

Introduction

In early 1999 the UK's Peabody Trust appointed Arup as part of the design team for the Beddington Zero (fossil) Energy Development (BedZED). Peabody, one of the largest housing associations in London, is a long-established and forward-thinking social housing provider. It manages almost 20 000 homes, and with a history spanning some 150 years, is constantly re-examining the challenges in providing urban homes.

The design appointment was the culmination of many years of ideas testing between Arup and the architect Bill Dunster, who before starting his practice had been a unit leader specialising in environmental design at the Architectural Association architecture school in London. Many of the debates and discussions in this forum revolved around fully harnessing renewable natural resources, achieving closed-loop material use, site resource autonomy, social involvement, and how all of these could respond to ever-increasing lifestyle expectations. At that time he also worked for Michael Hopkins & Partners on several Arup projects, included Bracken House[1], Inland Revenue Centre Nottingham[2], Portcullis House, and Nottingham University's Jubilee Campus[3].

Most of them had high environmental aspirations.

2.
BedZED sustainability 'triple bottom line'.

(1) Social amenity

- mixed tenure, home type, and occupiers
- living and working community activity
- urban density community critical mass
- proximity to wider community facilities
- private open space for homes
- sunlight and daylight amenity
- air quality and comfort
- reduced need for car
- local car pool
- community-led management
- community internet
- individual choice for carbon-free lifestyle

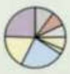
(2) Financial effectiveness

- housing association build costs
- affordable / key worker accommodation
- high demand for private sale elements
- commands margin over market value
- planning gain to add development value
- live / work to assist business start-ups
- links improve public transport viability
- addresses fuel poverty
- low energy running bills
- Internet links: community / local businesses / service

(3) Reduced environmental impact

- zero fossil fuel
- 100% renewable energy use
- zero heating homes
- passive solar heating
- PV power for 40 electric vehicles
- 50% reduced potable water
- on-site ecological water treatment
- wind-powered ventilation systems
- low embodied energy materials
- recycled timber
- reused structural steel
- urban tree waste bio-fuelled CHP
- improved site ecological value
- land as a finite resource
- bike facilities
- recycling facilities

3. Ecological footprint for UK lifestyle in ha/person, based on a four-person household (data source: BioRegional).

		Car mileage	Car ownership manufacture maintenance road infrastructure	Public transport	Air travel	Electricity and gas	Water	Domestic waste	Office footprint energy and paper	Food including transport but not packaging	Overall eco-footprint		
Typical UK lifestyle	Owns car Yearly holidays by plane Recycles 11% Eats out of season, highly packaged, imported food	0.90 10 000 km/yr	0.41	0.00	0.30	0.45 22 500kWh/yr electric and gas	0.002 140 litres/day	1.70	0.80 Brown energy and virgin paper	1.63	6.19		🌍🌍🌍
BedZED Conventional lifestyle	Owns car and commutes to work by public transport Yearly holidays by plane Recycles 60% Moderate meat eater and some imported food	0.45 5000 km/yr	0.32	0.30 4000 km/yr	0.30	0.10 Waste wood CHP inc landfill diversion credit	0.001 91 litres/day	1.02	0.80 Brown energy and virgin paper	1.06	4.36		🌍🌍
BedZED Ideal	Lives and works at BedZED Recycles office paper No car - ZED car member Two-yearly holidays by plane Recycles 80% at home Low meat diet with local fresh food	0.09 1000 km/yr	0.04 20 people per club car	0.30 4000 km/yr	0.15	0.10 Waste wood CHP inc landfill diversion credit	0.001 91 litres/day	0.34	0.16 Closed-loop office paper scheme	0.72	1.90		🌍
Global Average											2.40	●	🌍🌍🌍
Global Available	Leaving 18% of bio productive land for wildlife										1.90	🟡	🌍

Exploring the design ideas underpinning BedZED began some five years before any potential client, site, design fees, or development capital was available. Bill Dunster had previously built his own house to investigate some of the ideas, and the close collaboration between him and the Arup team enabled the ideas to be developed and tested, seeking to address the social and financial aspects of future sustainability alongside ecological impact and resource consumption. BioRegional Development, a charity dedicated to bringing sustainable business into the commercial market, recognized the project's potential. They secured funding from the World Wildlife Fund (WWF) for marketing the concept, located the potential site in Beddington, southwest London, and introduced the Peabody Trust, an innovative housing association, as funder/developer.

Advanced detailed design work was needed to prove the cost viability sufficiently for Peabody to feel confident enough with the innovation to put in a competitive tender for the site. Their bid, although not the highest, was judged with its sustainability proposals as offering best value by Sutton Borough Council. This was one of the first occasions that a UK local authority had accepted sustainability benefits as adding value. This needed the approval of central government because prior to this the local authority's obligation to sell public assets for the best value had been assumed to mean the best price.

A planning submission was submitted in February 1999, with outline approval given in July and full approval gained in November 1999. The planning approval included many sustainability issues in its Section 106 Agreement.

Construction started on site in May 2000 with the phased occupancy during 2002. Peabody Trust is overseeing an extensive programme of post-occupancy monitoring.

The context

Realization is dawning that to attain a more harmonious equilibrium with our planet, our consumption of virgin natural resources, with its waste and effluent, needs to reduce by 80-90% over the next 100 or so years. Much of the built environment we are creating will within its lifetime be expected to adapt to this agenda. Incorporating the ability to respond may well be incremental for many projects, with them successively taking larger steps toward sustainability. BedZED, by contrast, sets out to demonstrate what is possible by taking big steps now.

Buildings are key to generating social advancement and prosperity, yet are one of the largest consumers of natural resources and generators of pollution and waste. It is often quoted that about 50% of atmospheric carbon emissions is from buildings - a considerable underestimate if you include the need to travel to and from them. This emphasizes the challenge ahead: the built environment is the largest consumer of natural raw materials and the largest single generator of landfill waste.

Addressing environmental impact requires a whole-life approach, involving for any one material its sourcing from nature, its processing, transport, in-use by-products, recycling and reuse ability, and avoiding its final waste disposal. For fossil fuels, the current dominant issue is in-use by-product or waste, ie global carbon emissions. Stabilising the increasing atmospheric CO_2 levels is expected to need around 60% emissions reduction by 2050 - well within the life of many buildings we are constructing now. This is but the first part of the scenario. With the world population expected almost to double by 2100 before stabilising at about 10bn, that same consumption level spread more thinly means a reduction of almost 90% by the developed world by 2100!

For many areas of natural resources similar effects and scale of reductions are anticipated. This suggests that we should build with only 10% of the virgin materials we currently use; and intriguingly, on closer inspection this is not as difficult as it first seems. The 20% of materials delivered to site that end up as waste could be eradicated, and there is probably a similar level of waste in the materials sourcing and component manufacturing processes.

4.Typical live/work studio.

And if we design buildings for double the useful life, at a stroke we begin to halve the amount of material needed in whole life terms for the social benefit gained from that site. Added to this, there is much material already taken from nature in circulation and in our buildings.

If we could develop processes for recycling this as high quality 'secondary materials', then it appears quite possible to reduce our overall demand for new natural raw material by 90% in almost all fields of human activity. This sets our future agenda for designing the built environment.

Why BedZED?

BedZED's new-build development of 83 mixed tenure homes (social, key worker, and for sale), plus some 3000m^2 of live/work, workspaces, retail, and leisure uses, occupies an urban brownfield site in South London. Its chosen high build-density reflects the importance of using limited land resources to the full, being based on the density needed for accommodating all the UK's projected new homes needs entirely on available brownfield sites, to avoid sacrificing any more limited greenfield amenity. Such high density helps build coherent communities and provides critical mass for facilities like public transport, but still allows the massing and orientation needed for good passive solar and daylight access. Making the roof areas 'green' helps increase the site's ecological value and its carbon absorbing ability, as well as giving the occupants private gardens.

BedZED was conceived to show that in large-scale construction a high level of sustainability can be practical and cost-effective. If the sustainability concept is to have any sort of meaningful overall effect on the environment, it must move into the volume mainstream, satisfy economic and social objectives, and benefit all stakeholders.

A fundamental shift in financial approach was needed. Normally, sustainability and its technologies are seen as 'add-ons', ie additional cost unwelcome to most building funders. Often, heat recovery will be added to conventional mechanical plant to save energy, yet with diminishing carbon-emission returns and more capital cost. Likewise, simply adding solar thermal collectors still requires a full conventional boiler back-up.

Instead, the approach for BedZED was to identify materials and engineering systems whose need was often marginal, and design them out. Advanced analytical techniques explored how passive systems could be enhanced enough to allow active systems to be completely omitted. This yields direct cost and resource reductions at several levels: in capital costs for engineering systems, in control complexity to likewise reduce capital costs, in plant maintenance costs, and in energy cost.

The H&V Awards 2002:
Building Services Engineer of the Year:
Chris Twinn

Energy grading

For BedZED, Arup developed a technique to evaluate and match renewable energies to energy demands.

Until all energy sources have their full environmental cost factored into their retail price, making renewable energies cost-effective is quite a challenge. The technique is 'energy grading': ranking the full range of possible renewable sources against end-use energy needs, to generate a checklist of building design priorities. The key issue is to match the lowest possible grade of source against the grade of the end demand. This process also involves mapping demand and availability, given that most renewable energies tend to be more finite and need coupling via energy storage to allow this demand/availability match.

Designing the building concept around these principles allows the most cost-effective use of renewables. Covering a building in photovoltaic (PV) solar electric collectors may show environmental awareness and highlight new energy technologies, but in energy grading terms, PV's modest output and current high cost suggest there may be more pragmatic ways to provide renewable energy.

Energy grading highlights interesting issues, like the inherent inefficiency of many conventional systems that consume high-grade energy and deliver only low-grade energy to building users. Should we be using so much high-grade electricity to drive pumps and fans for what is in effect low-grade energy for room comfort needs?

Likewise, are the high-grade electrical energy needs of heat-pumps appropriate for delivering heating and cooling? It emphasizes the significant cost benefits of passive solar heating and passive cooling for room comfort, and the cost-effectiveness of designing buildings for reduced energy demand in the first place.

Zero-heating homes

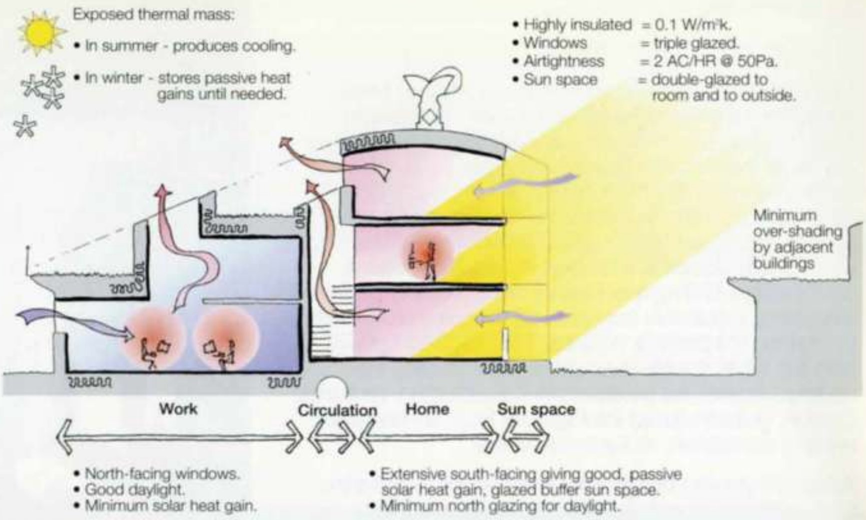
One result of applying energy grading at BedZED was to question the need for conventional room space heating, in which a system is simply sized to provide comfort, with regulation minimum thermal insulation. Yet many buildings have internal heat gains from people and their activities. So why not size the insulation, with thermal mass heat storage, so that this heat is sufficient to provide space heating through day and night, thus avoiding the need for any conventional heating? As the UK Building Regulations have increased thermal insulation minimum standards, so the proportion of the year when heating is needed has shortened. Yet the system cost does not reduce in proportion. So - what level of insulation will completely eliminate the heating system and hence reap a capital cost dividend?

Building physics

The design aim was to reap these cost and energy dividends by fully exploiting the building envelope and fabric as primary modifiers of the indoor climate, to the point where complete mechanical systems could be omitted.

For UK mainstream housing this early design analysis time is rare because the industry tends to work to rigid perceptions of market expectations. At BedZED the project team was committed to demonstrate the viability of the principles even before land purchase. As is often the case, much complex analysis was needed to demonstrate that such a simple solution is achievable.

In thermal analysis terms the availability of heat from occupants, appliances, cooking, washing, and solar heat is highly variable both in timing and quantity. There are other parameters, too, like the extent of glazing: at times it can contribute useful solar heat, yet be the largest heat loss component. Also, steady-state building energy flows do not necessarily represent reality. Low-grade heat will take time to pass through a thick wall during which external influencing conditions will change, often to the extent that the heat may not pass through at all, but instead reverse its flow. Adjusting the thermal capacity and thermal insulation characteristics of materials and energy transfer mechanisms can significantly affect what happens to the energy and whether it can then be reused. Many of the construction industry's usual materials, with their significant thermal inertia, can give significantly different results from steady-state theory.



5. Building physics.

> *'BedZED fully exploited the envelope and fabric of the building as the primary modifiers of the indoor climate, so that complete mechanical systems could be omitted.'*

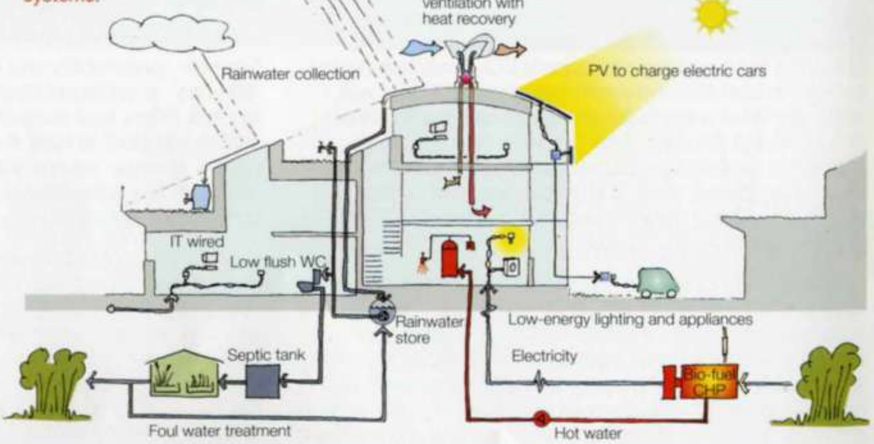
Dynamic thermal analytical and simulation tools, plus real weather data sequences, established the material performance and building massing needed for the zero-heating homes: the first time, it is believed, that such advanced computer tools - developed over the past 10 years for analysing passive cooling techniques in office buildings - have been used on a major housing project. For BedZED, these were the tools needed to show that normal home heating might be omitted. Super-insulated homes with extensive areas of exposed high thermal capacity materials could thus match heating needs against naturally occurring passive internal and solar heat gains.

The analyses revealed several different 'design worst' cases. The very coldest outdoor air temperatures usually relate to clear night skies, which in turn most often relate to daytime solar heat gain. Extended periods of overcast skies are critical, although they normally relate to higher outdoor air temperatures. Different occupant lifestyles are also factors; for example, how much top-up heating makes for the comfort of a new-born child? Then there is the prolonged absence of occupants from home, with their consequent lack of contribution to heat gains.

Ensuring room temperatures do not fall when this happens is another critical design case, given the absence of a large heating system to recover temperatures when the occupants return. Terraced blocks work well for reduced overall heat loss, as long as large temperature differences in adjacent homes are avoided. Building envelope airtightness is particularly critical. For the north-facing workspaces they could have lower machine heat gains than a typical office, ie if used as live-work studios, and thus need some supplementary background heating.

Computer analysis and simulation can explore solutions to all possible scenarios, allowing the design to pursue the simplicity of passive heating in a robust solution.

6. Mechanical and electrical systems.



7. Kitchen adjacent to sunspace.

Building massing and orientation

One analysis result was to recommend distinctly different orientations for the varying building uses of homes and workspaces. The latter have potentially high occupancy levels and office machine heat gains which, added to solar gain, can at times give too high a room temperature and prompt a need for summer supplementary mechanical cooling. These spaces are thus best orientated north; maximising natural daylight, reducing the need for daytime artificial lighting, and avoiding excess solar heat gain. The high thermal inertia room surfaces mean that workspaces can easily accept institutional standards of office equipment heat gain, and maintain peak summer comfort conditions using only passive cooling plus cool night natural ventilation. Homes, on the other hand, have less occupancy density and less internal heat gains, so by facing south, gain useful benefit from supplementary solar heat gain.

The thermal inertia coupled with cool night ventilation also keep summer room temperatures low enough when otherwise well-insulated homes would need mechanical cooling to avoid overheating.

Bio-fuelled combined heat and power (CHP)

The earliest concepts for BedZED centred on the idea of home energy autonomy, with each dwelling operating solely on the ambient energy it could harvest from its own site. This led to the energy-consuming systems in the dwelling being reduced enough to match the energy harvested from solar via PV, thermal collectors, and a small wind turbine. However, in cost terms this was not viable within current cost yardsticks and so the thinking turned to wider local community autonomy, eventually identifying bio-fuelled CHP as a potential solution.

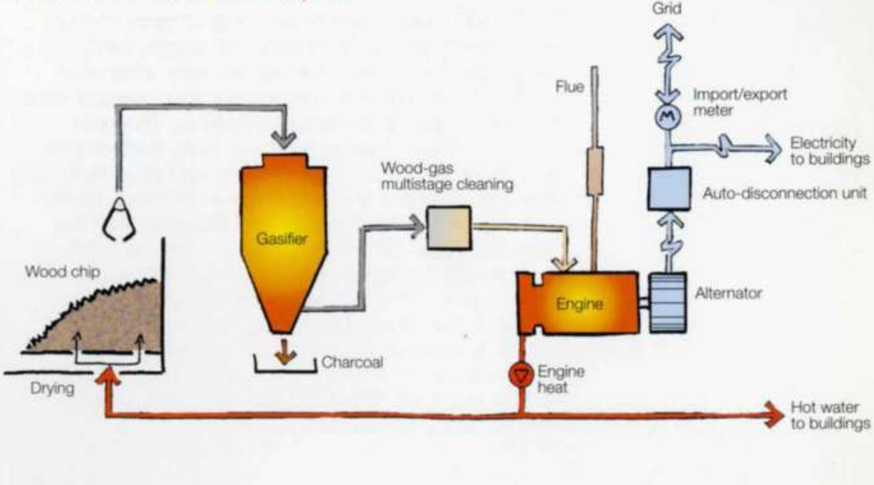
A key element of sustainability and its resource productivity is finding waste streams and using them as raw materials. An existing local community waste stream was identified in the form of urban tree waste. Tree prunings had previously been consigned to landfill by the local authority, but the increasing landfill tax made them an ideal alternative low cost energy source. Its origin from trees also gave renewable credentials to this waste, with the carbon emitted from combustion being re-absorbed by the continued tree growth. A proprietary gasifier system converts woodchip into a wood-gas suitable for fuelling the CHP's spark ignition engine.

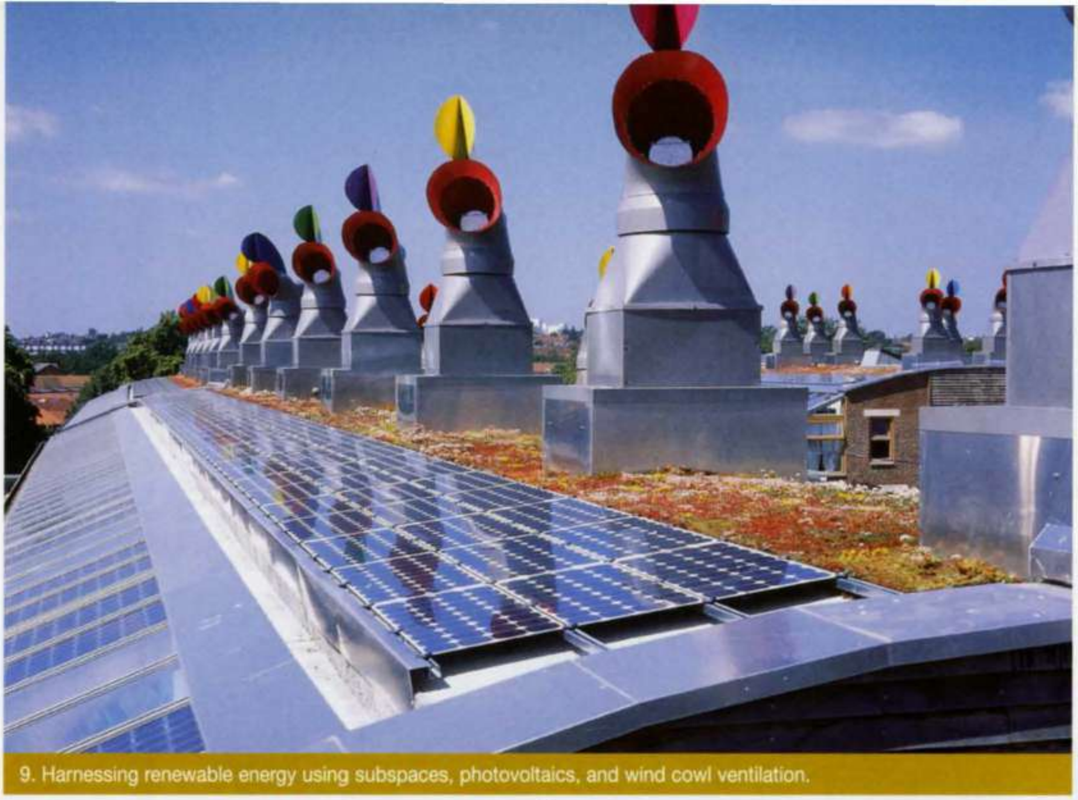
Establishing capital cost viability for small-scale CHP is at best difficult, but for a prototype bio-fuelled version is even more challenging because the gasifier fuel treatment system all but doubles its cost until such time as it can be mass-produced. Consequently, the aim was to roughly halve the building's energy demand, so reducing the plant size needed and making bio-fuelled CHP viable. The mix of building uses with their diversified overall demand peaks also helped.

Likewise, the elimination of fans and pumps, and the use of EU 'A' rated domestic appliances, low-energy compact fluorescent luminaries, and meters visible to the consumers, were all aspects of reducing electrical energy demand.

The design identified other capital costs to help fund the CHP. As well the 100 or so gas-fired boilers normal for a project of this size, also omitted were radiator systems in the dwellings and the piped mains gas connections. Similarly the passive building design for non-domestic uses helped reduce mechanical and electrical fitout costs.

8. Bio-fuelled combined heat and power.





9. Harnessing renewable energy using subspaces, photovoltaics, and wind cowl ventilation.

'Demand for the BedZED homes has been exceptional. There is a long waiting list of people wanting a modern green lifestyle that has an innovative design approach.'

The need for the boilers normally provided alongside CHP to cope with peaks of winter heating demand was also eliminated by reducing these peaks enough for heat demand to match the CHP peak heat output.

The Grid electricity import/export connection is used as a cost-effective alternative to conventional standby boiler plant. Thus, the total heat and domestic hot water demand is met by a CHP unit sized to match the annual BedZED electricity demand.

Heat recovery wind cowls

The wind cowl ventilation system illustrates the application of energy-grading. Conventionally, much high-grade fan and pump electricity is consumed to deliver low-grade energy for room comfort temperature control and ventilation. This tends to be significant because these systems run for extended operating periods. Nonetheless, as building envelopes become more airtight to reduce uncontrolled heat-loss, then provision of controlled minimum ventilation becomes particularly important. Fresh air provision is needed plus removal of condensation moisture from kitchens and bathrooms, toilet smells, and kitchen fumes.

The UK Building Regulations permit ventilation fans to be eliminated if trickle ventilators and passive stack extract vents are provided. However, introducing unheated winter fresh air via window trickle vents would require heating to be reinstated in each room. At BedZED the wind cowl system was developed to deliver preheated fresh air to each home and extract its vitiated air, complete with heat recovery from the extracted ventilation air.

The BedZED wind cowls crown some 10 years of Arup development work on harnessing low velocity wind, and are the first to introduce heat recovery using wind power, with both positive and negative wind pressure used to deliver supply air and extract vitiated air. They also generate enough pressure for the air to be ducted down into the building, delivering their preheated air to each living room and bedroom, and extracting air from each kitchen, bathroom, and toilet. The cowl was designed from first principles, tested, and then refined in a wind tunnel at full scale. A specialist test method was developed to permit the ventilation airflow and pressure characteristics to be quantified. This allowed the cowl to achieve a certifiable ventilation and heat recovery performance, and hence the omission of all ventilation fans, trickle vents, electrics, controls, and fresh air heating in the homes, thus providing a system using only renewable energy.

Photovoltaics

PV for powering the buildings was originally discarded because its capital cost is too high to recover through savings in relatively cheap mains electricity. Nonetheless, the buildings were still future-proofed to accept solar collectors on their southern façades in anticipation of when PV costs reduce. Subsequently the opportunity of EU demonstration grants arose. Given that the buildings were already carbon neutral with the bio-fuelled CHP, this prompted detailed study of BedZED occupants' likely lifestyle eco-footprint, and from that the significant carbon emissions due to transport fossil fuel. Further investigations confirmed the significant higher cost per kWh of UK petrol compared to grid electricity, together with the inherent higher efficiency of electric vehicles, giving clear running cost benefits from electric cars. With 95% of all urban journeys less than 40km - well within the range of electric cars - this presented the opportunity for building-mounted PV to power electric zero carbon emissions urban-use cars. Whereas PV providing electrical power to buildings had a payback of around 75 years, using it instead of the high-taxed petrol reduced this to approximately 13 years. With EU/UK grants equating to 50% of capital cost, the theoretical payback period went down to just 6.5 years. 107kWp of PV has been integrated into the south-facing BedZED façades, sufficient for 40 electric cars. Charging points have been installed and occupants can have free parking and charging if they use electric cars. Now BedZED is occupied, environmental consultant BioRegional Developments has started a car hire scheme, with plans to expand with electric cars (which also are exempt from the new central London Congestion Charge). The use of solar power for electric cars effectively changes BedZED from being just carbon-neutral into a net exporter of renewable energy. Perhaps this is the future for our buildings.

Water

Clean water is increasingly seen as a finite natural resource even in the UK climate. Increasing demand highlights the large resource needed to deliver clean water without waste and then transport and treat the resulting discharges.

BedZED seeks to reduce treated potable water demand by more than 50% and then treat the effluent on site - with less resources used and the water available for recycling.

Various good practice measures have been incorporated, including restrictors to prevent excess flows, mains pressure showers to avoid power-showers, meters visible to consumers, EU 'A' grade water-consuming appliances, and very low/dual flush toilets. Rainwater is collected from roof surfaces and stored in underground tanks for irrigation and toilet flushing. An ecological on-site foul water treatment system was added to the development after a statutory water authority agreed that it would adopt and operate the completed system. This uses vegetation as a cleaning agent in the secondary and tertiary treatment stages, partly because of its low energy consumption. The system treats the water to a high enough standard for it to feed recycled 'green water' as a supplementary feed into the rainwater storage tanks.

Surface water runoff is handled using SuDS (sustainable drainage system) principles for surfaces where there may be slight contamination by cars, animals, or garden treatments. Use of permeable hard surfaces, foundation filter media for cleaning any contamination, and site water holding features avoids draining surface water into the local sewers. Instead the rainwater slowly soaks into the ground and local water-courses, as would be the case had there been no buildings on the site.

Materials

Sourcing materials is where the construction industry still has most progress to make to reduce its environmental impact, requiring co-operation and working practice changes right along the supply and procurement chain. This is the area most difficult for designers to influence, as they are expected to take and use the products already available on the market. Locating reused and 'secondary' material sources, establishing their provenance, and guaranteeing their performance is currently difficult, requiring significant manpower resources. On previous projects with Dunster, almost 80% use of secondary materials had been achieved, but limited time and cost meant more modest levels at BedZED.

Nonetheless, there was considerable success. Most existing site material was retained there, whilst much of the heavier building materials was sourced within a 55km radius to reduce transport impact and allow source checking. Reused structural steel was used in the workspace framing structure, and reclaimed timber for internal partition studwork.

Materials with a recognized environmental standard, like Forest Stewardship Council (FSC) certified wood, was used extensively. Kitchens units are of plywood from a checked source, instead of the normal chipboard. Waste was addressed both at construction and for the buildings in-use. Building waste was segregated on site and sent for recycling. For the homes, a domestic segregation strategy was agreed with the local authority, with segregation bins provided in all kitchens and around the site for local authority collection. There is on-site processing of green waste.

Identifying and recording the full extent of the building materials' environmental impact and the amount of consumer waste recycled forms part of an on-going research programme.

10. Use of materials: triple-glazing + locally-sourced untreated oak cladding + local brick.

Information and communications technology (ICT)

BedZED was designed to take full advantage of ICT. The ability to access knowledge and communicate it will define future successful communities, with the Internet starting to become the primary means to identify services, and gain community information. Access to Broadband is available to all BedZED occupants, giving them the potential of almost instantaneous Internet access as well as the option of being permanently on-line. This complements BedZED's live/work objectives, as well as allowing the growth of community-related services providers. The ICT cable routes are intended to be fully rewireable so they can respond to future changing requirements.

A clear distinction has been made between ICT for occupants' use and for the general operation of the buildings. ICT by its nature is rapidly developing, and equipment procured today can be expected to be obsolete within five years. This is completely at odds with buildings, which are intended to function and last with minimum maintenance and renewal for many decades. In addition, occupants tend to prefer buildings that are simple and easy to operate, without needing to understand computer protocols or requiring sophisticated technical backup. Thus in almost all day-to-day use of their buildings, occupants are in manual control, ie opening windows, without any computerized automatic controls. Not only does this complement the passive building design, but also it is highly cost-effective. For selected site central management functions, however, a computer-based system allows such functions as remote reading and billing of electricity, heat, and water meters, etc.

Feedback

A demonstration project should be a source of useful feedback and BedZED is already providing much, a good deal of it to be published. Peabody is overseeing more than 20 BedZED-related research projects, so a significant amount of information is expected over the next few years. Much of this is related to lifestyles, and monitoring how the occupants settle in, use and develop the facilities provided. The first period of monitoring has already shown that compared with current UK benchmarks:

- Hot water heating is about 45% less.
- Electricity for lighting, cooking, and all appliances is 55% less.
- Water consumption is about 60% less.

During construction a constant challenge was to achieve a consistently high build quality. The results are considerably better than current UK benchmarks, and demonstrate that general industry improvement is achievable. They highlighted that specific effort is needed in certain areas, notably site supervision and training for the many smaller sub-contractors upon which the industry depends. The nature and structure of the industry means that explaining the thinking behind innovation is difficult to pass down the supply chain.

The need to achieve high levels of building envelope airtightness is a particularly important example of this. The implications of potential remedial works costs and supplementary energy use far exceed the small effort needed to get it right at the appropriate stage of the construction process.

It is interesting that since BedZED, the UK Building Regulations have been revised in an attempt to start to address this airtightness issue for first time.

The availability of skilled site staff for construction, and particularly housing, is another wider issue for the UK industry. There has been low take-up of local labour training initiatives; perceptions of construction are at odds with the aspirations of our younger generations. Much of this points towards a future of off-site manufacturing where skills and training, materials and waste handling, and efficiency can be better provided.

This is an area where Arup is now deeply involved with Peabody, with the development of factory prefabrication, volumetric housing, and the manufacture of completed building sections ready for simple finally assembly on site[4].

Awards

Building Energy Globe Award for Sustainable Energy:
First Prize for Buildings & Houses

The H&V Awards 2002:
Air Movement Product of the Year (for the heat recovery wind cowls)

The Building Services Awards 2002:
Environmental Initiative of the Year

European Association for Renewable Energies (EUROSOLAR) Awards 2002:
Solar Construction Award

The BedZED tendered build costs were based on Peabody's budget for good quality social housing on brownfield sites in London. On top of the basic build price there were costs related to extra project staff training, management, supervision, and quality control. There were also one-off innovation costs related to design research, materials sourcing and establishing their environmental impact, establishing quality control methods for recycled materials and non-standard components, obtaining the associated statutory approvals, and the added programming time this needed. On site, particular care and effort were needed to ensure that the complete construction sequence was fully thought through in advance.

All the sub-contractors needed proper briefing on the work methods needed to avoid substandard workmanship, thereby attracting high remedial costs.

Demand for the BedZED homes has been exceptional. The level of early enquiries was so high that Peabody felt confident enough to hold back until purchasers could see the finished buildings, instead of selling from the drawings. This interest has continued to increase so that the homes command a significant premium above market rates. There is a long waiting list for people wanting a BedZED-type home with supply being largely constrained by the difficulty of securing new sites. The most frequent reason given for wanting to live at BedZED is the modern green lifestyle (63% of occupant survey respondees), with innovative design coming a close second (61%). Popular design features include the sunspace, the gardens, and the sense of space in the homes.

The wider interest and response to BedZED to date has been very positive with:

- weekly organized guided site tours over-subscribed, reflecting high interest from other building professionals and building procurers
- extensive media coverage
- growing demand from building clients and building procurers to explore the potential of sustainability for them
- local authority planners seeking help in understanding what practical sustainability benchmarks they can request more widely as part of the building planning permission process. Planners already have a Local Agenda 21 obligation to progress sustainability on behalf of the local community.
- key developers beginning to recognize the edge that offering sustainability gives them when purchasing land to build on and in assisting with planning approvals.

Conclusion

BedZED seeks to offer its occupants the opportunity to live and work with a completely carbon-neutral lifestyle, making this choice attractive, cost-effective, and appropriate to modern living. It offers solutions to many sustainability lifestyle issues in a practical and replicable way.

One key reason for embarking on the BedZED project was to demonstrate to a sceptical industry how sustainability is possible and can be cost-effective, and how we can really make a difference for society and its future. There is inherently considerable industry inertia to change and improvement. It is through delivering successfully examples like BedZED and proving there is market demand for this kind of product that mainstream developers and construction participants will feel they can seriously take steps towards a more sustainable world. It requires innovation, a strong belief, considerable time input, and the dedication of the complete project team to show how this can be achieved.

The meeting of like-minded people across different disciplines sets in motion ideas for raising the limits of what is possible, instead of what is expected. Relatively rarely do the full range of parties come together to deliver a complete example project without compromise. BedZED is one of these.

The result has exceeded all expectations.

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Credits

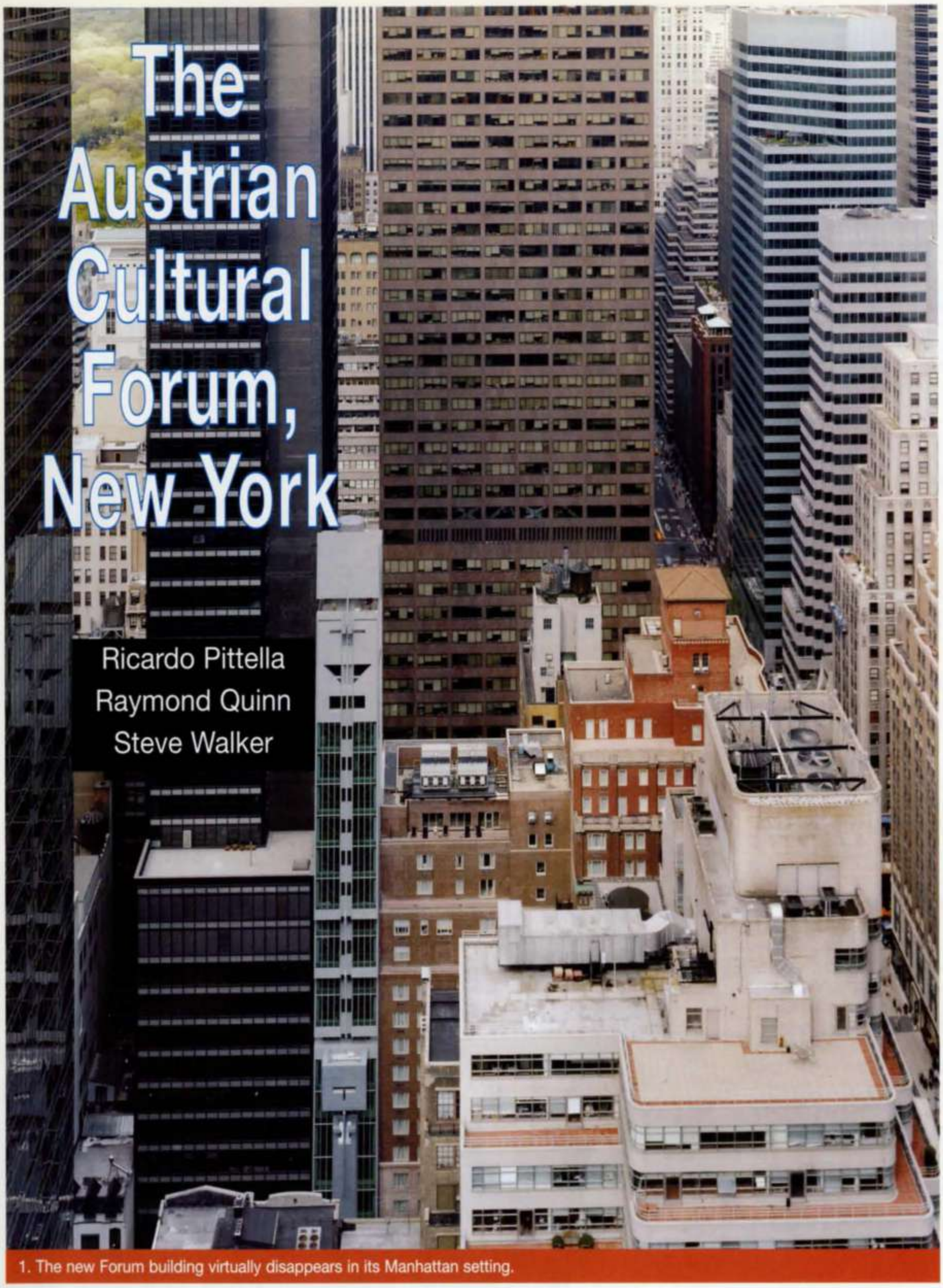
Client:
Peabody Trust
Architect:
Bill Dunster Architects
Engineer: building physics, energy, M&E systems:
Arup Enzo di Enno, Phillip Ellis, Lesley Graham, Gaurav Jain, Jacob Knight, Andy Mace, Frank McLaughlin, Colin Rapley, Ray Sciortino, Les Stokes, Mike Summers, Chris Twinn
Environmental consultant:
BioRegional Developments
Structural & civil engineer:
Ellis & Moore
Cost/site management:
Gardiner & Theobald
CHP supplier:
B9 Energy Biomass
PV supplier:
BP Solar
Wind cowl supplier:
Vision
Specialist water utility:
Albion Water
Illustrations:
2, 3, 5, 6, 8: Penny Rees
4, 7, 10 -12:
© Arup/Graham Gaunt
1, 9:
© Arup/Raf Makda/VIEW

11. Live / work space.

12 right: '... a modern green lifestyle with an innovative approach'.

The Austrian Cultural Forum, New York

Ricardo Pittella
Raymond Quinn
Steve Walker



1. The new Forum building virtually disappears in its Manhattan setting.

2. Architect's model.

3. The shear walls, core, and façade diagonal bracing form the main structural elements; the structure is pushed to the perimeter to maximize usable floor area.

Introduction

In 1992 the Austrian government announced an anonymous architectural competition, open to all Austrian architects, for the design of a new cultural institute in Manhattan; reputedly, every Austrian architect responded.

The design by Raimund Abraham, a Tyrol-born architect resident in Manhattan since 1971, was selected from the 226 submissions.

The Austrian government aimed to replace the quiet town house that the Institute previously occupied on the same site with a contemporary structure, and to update Austria's cultural reputation in the process. Critics hailed Abraham's design, asserting that it would elevate Manhattan's cultural reputation as well with one of the most significant works of architecture in the city for nearly half a century.

None of this would be accomplished with ease.

Austria proposed an ambitious programme, complete with library, galleries and flexible performance space, topped by offices and a residence for the director. All this had to be squeezed into a typical Manhattan town house lot, a mere 25ft (7.6m) wide by 81ft (25m) deep. To further complicate matters, the Austrian government was not initially prepared for the price tag attached to building their selected design in such a restricted site. A combination of financing issues and political struggles delayed the start of construction for over four years. The odds were thus stacked against Austria's project. Nonetheless, this small building conquered them.

'...there has never been a compromise made in terms of architecture': Raimund Abraham

The concept

Abraham told The New York Times that he wanted to show 'the whole city pressing into the narrowness of this site'. His design consisted of a 24-story tower reaching nearly 280ft (85.3m) high with a sloping façade of louvered glass and zinc panels. The jury commended Abraham's use of the sloping façade in response to zoning regulations for set backs and in relation to the conventional 'wedding cake' stepped façades of the surrounding street. The jury also praised his placement of the vertical circulation at the rear of the site, maximizing the full width area available and enabling the narrow frontage to be fully enjoyed. That circulation comes in the form of scissors stairs ingeniously providing the two means of egress called for in the local code. Abraham describes the building as, from rear to front, three elementary towers expressing the counterforces of gravity: the 'vertebrae' (stair tower for ascent and descent), the 'core' (structural tower – support), and the 'mask' (glass tower – suspension). Vertically, the building comprises:

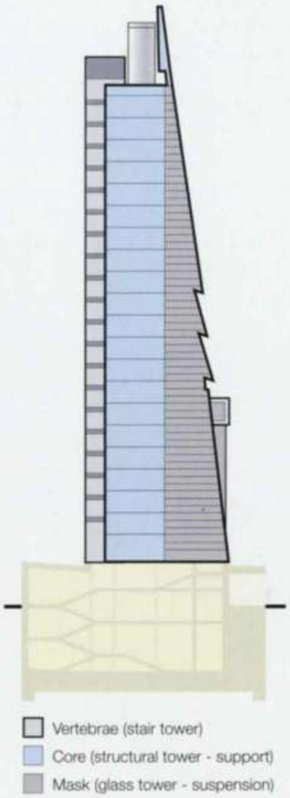
- subcellar: mechanical equipment and storage (level -2)
- main gallery (level -1)
- entry and public atrium (main and mezzanine levels)
- theatre (level 2) and balcony (level 3)
- library (levels 4 and 5)
- offices (levels 6 through 11)
- technical, storage, and forum apartments (levels 12 through 15)
- director's residence (levels 16 through 19)
- outdoor terrace (level 20)
- mechanical equipment (levels 21 and 22)
- rooftop mechanical space.

After winning the competition, Abraham appointed Arup for structural, mechanical, electrical, plumbing, communications, security systems, and acoustics design. Subsequently the firm's role grew even further, to include controlled inspections and commissioning management. Designers had one basic 'mantra': to conserve space lest the building systems occupy the entire floor area! The design that evolved is so integrated there is scarcely a cavity in the building that does not serve a dual or triple purpose.

Structure

The building was designed to be independent of its neighbours and so there is a 3in (75mm) gap on either side throughout its height. To resist the loads faced by the very slender form, Arup developed a largely reinforced concrete system of shear walls in the only possible locations - along the north-south perimeter walls and between the elevator core and the stair in the east-west direction. The resulting group of shear walls has a 'C' cross-section that tends to twist under wind loads, so cross-bracing in the south (street front) façade was introduced to counter this. The concrete structure was designed so that the cross-bracing provides only additional stiffness under wind loading, allowing the structural steel to be exposed without fireproofing. The system features architecturally exposed 7in (175mm) diameter steel members on the sloped, jagged front of the building.

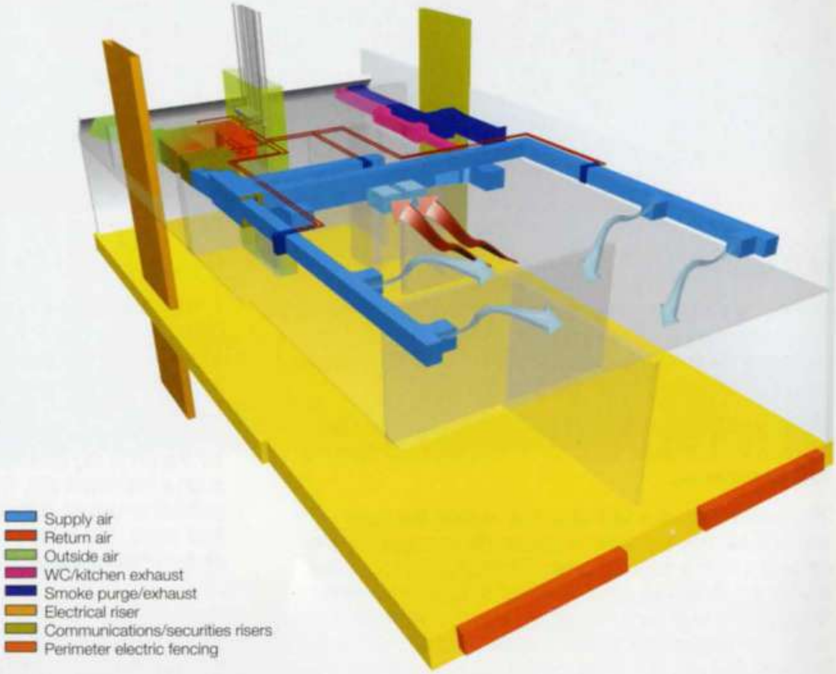
4. View from atrium, looking up through glass roof, of north vertebrae façade.



5. Cross-section showing principal elements.

7. Street façade.

6. Services systems.



Everywhere, concrete construction is as thin as possible. The shear walls average 10.5in (270mm) thick, though in some places columns are built inside the concrete wall, resulting in 16in (400mm) thickness. For the floors, 8in (200mm) thick concrete slabs span east-west to the perimeter shear walls and are supported by beams at the front of the façade and in the north-south direction, adjacent to the service core. Several locations feature architecturally exposed concrete.

Due to the building's diverse programme and its architectural design, there are no standard floors. The sloping (often described as 'slicing') planes that distinguish the façade call for a host of structural features, including sloped columns placed in the outside corners of the building that transfer at several points into the north-south shear walls. Another is the three-storey steel truss cantilever attached to the concrete façade structure to support the library stair; one floor above that, a 10ft (3m) concrete slab cantilever is introduced to support the director's office. The window-washing system at the top of the building features a structural steel bulkhead carried by a concrete slab, in turn supported by a central column.

Mechanical design

The team adopted a floor-by-floor air handling strategy to minimize the size of air handling equipment and ducts while eliminating vertical duct distribution. Each floor has its own ducted air handling system, using one central water-cooled heat pump unit (fan, coil, compressor, and filters) per floor, and its own general and smoke purge exhaust fan. All major system components are fitted into the ceiling void of the corridors to the east and west of the elevator, which barely had the clear heights needed. This location also allowed for easier maintenance (compared to occupied areas), and equipment noise issues could be better dealt with in these less sensitive areas. Also, it allowed ceiling heights in the occupied spaces to be maximized.

Each heat pump unit and exhaust fan has a ducted connection to outside air, threaded through both scissor stairs in fire-rated enclosures to louvres at opposite sides of the rear façade - air intake on one side and air/smoke exhaust on the other. Both of these ducts exit the building through beams carefully notched to allow ductwork passage while maintaining the minimum clear heights at the stair landings. The louvres are integral to the architecture of the building's north façade.

The heat pump units were chosen for two reasons: firstly, they allow energy to move between the different space/usage categories in the building. For example, heat energy extracted from the public/exhibit spaces during the day can be shifted through the heat pump water circuit to the upper floors if required. This allows reduction of the overall system size. Secondly, as a heat pump is a mini-chiller, the building does not have a central chiller, thus realizing another space economy.

The building's heat rejection system uses two open cooling towers on the roof. Several other heat rejection options were investigated in depth, but none was a match for space-take, capital cost, and schedule. The cooling towers are connected to the heat pump water circuit via a plate heat exchanger. Even the heat exchanger approach was controlled to ensure that they could fit in the available area.

The water-cooled heat pump units are fitted with capacity control and supply typically three temperature control zones per floor. Duct-mounted hot water reheat coils are provided for each zone.

Five modular, sealed combustion chamber, condensing gas boilers supply heat, chosen largely to avoid the need for a flue rising above the building. The boilers use a primary-only pumping arrangement to serve reheat coils, stairwell heating, domestic water heating, and the heat pump water circuit via a plate heat exchanger. Each floor is equipped with electric perimeter heating units fitted between the spandrel beams and the curtain wall.

In the theatre, ductwork travel distances were eliminated by locating a dedicated air-handling unit (AHU) in the core area to the rear of the theatre's projection screen wall. An NC 25-30 criterion was specified for the theatre: acoustic testing of the AHU and careful attention to vibration isolation and wall construction were required. The construction difficulties of the project were such that this criterion was marginally exceeded in some areas of the theatre. Air supply to the theatre is from ceiling mounted diffusers with additional diffusers underneath the balcony to serve that space and eliminate any stagnant areas.

The atrium, connecting three levels and topped with a glass roof, is separated from the remainder of the building by fire shutters, with air conditioning supplied by a dedicated system to each of the atrium's levels. Smoke and general exhaust fans are on the atrium roof and use an exhaust plenum formed by the roof's upstanding structural beams. These maximize the clear height of the upper floor without extending the roof of the atrium through the zoning envelope. The fans take the form of ship funnels at the back of the building, as no conventional arrangement of exhaust fans and ductwork would fit inside the building.

Every space in the building is equipped with smoke purge as specified in the code. The atrium, galleries, and theatre employ a complex network of interconnected ductwork designed to assume different functions at different times. For example, fresh air intake ducts can be used as smoke purge ducts in event of emergency.

Every duct assumes at least two roles, with motorized dampers and emergency-only fans to switch the systems from one function to another. The building's water tower is the most visible of the mechanical system's many custom-designed features. (New York's skyline is famous for its cylindrical, wooden water towers set atop buildings on spindly steel frames.)

8. Internal staircase: economy of space.

9. Staircase with water tower above, ventilation louvre at each side, and cooling tower louvred enclosure.

10. The wood-panelled theatre has a removable stage and a hoist to raise the piano to its storage position in the ceiling void.

Awards

New York Association of Consulting Engineers 2003:
Engineering Excellence Diamond Award for Building/ Technology Systems.

American Council of Engineering Companies 2003:
Engineering Excellence Honor Award.

The tank provides water for the fire protection system in lieu of a fire pump that would have taken valuable floor area at the lower levels, with a pressure booster pump to ensure adequate system pressure at the topmost floors. The tank also provides domestic water. The top of the tank reaches 20ft (6.1m) above the highest structural level and brings the building height to its full 280ft (85.3m). The tank is of stainless steel, chosen to minimize the need for maintenance and further decorative cladding.

Electrical design

The building is powered from a Con Edison 208V service with the main switchgear at subcellar (-2) level. An emergency generator at one of the roof levels provides alternative power for life safety systems. The electrical riser is contained with the 6in (150mm) depth of the internal architectural finishes, whilst horizontal electrical distribution on each floor is typically concealed within the floor or wall finishes. The fire alarm system for the building, as mandated by New York codes, has voice evacuation capabilities and was designed with distributed intelligence to minimize interconnecting wiring.

Communications

Recognizing how disruptive a cabling system upgrade would be to such a constricted building, the client decided during construction to upgrade the data and telephone networks to an IT cabling system with the maximum possible lifetime. A system using only the new Category 6 cabling infrastructure in a star topology was provided throughout the building; it provides the client with high-speed data links at all locations. A cable television distribution infrastructure was also included.

Security

Since the building contains public, office and residential spaces, all using the same entrances and circulation, a highly sophisticated security system was designed. An access control system (using proximity readers) permits individual building users and visitors to be granted strictly controlled access to prescribed areas. The elevators are integrated in this system and feature occupancy detection, access control, and CCTV surveillance. In addition, the individual identification principle allows the granting of priorities in elevator use so that key ACF staff or specific visitors can be assured of private usage when desired.

Construction

Constructing this unconventional building in Manhattan proved the most difficult hurdle of all. To fit the programme within the site, engineering systems were integrated in a way not common for traditional towers in Manhattan. The tolerances that local contractors are accustomed to were not available in this building because the constricted site and complex program literally squeezed them out of the design, and so a high level of performance was required from all parties. Construction was scheduled to begin in January 1999 with completion in August 2000. Arup was represented on the site throughout the concrete construction, initially to provide a 'controlled inspections' role.

After basement construction was completed in spring 1999, the original superstructure concrete contractor was replaced. Shortly after the superstructure construction began, serious problems including out-of-tolerance concrete placement and under-strength concrete were identified. All these issues had implications for other aspects of the design, eg space for engineering systems and in particular the curtain wall (then being fabricated in Austria). Problems rapidly multiplied and resulted in work stoppages and remedial works. The replacement of the concrete contractor temporarily halted construction work whilst an alternative was sought Arup's detailed knowledge of the precise state of the building allowed solutions to be formulated to construction deviations that both respected the design and minimized the amount of remedial work needed. This entailed very close co-ordination between all the design disciplines. The structural design specified high strength concrete for stiffness control and not purely strength issues, and this fortuitous choice allowed a certain flexibility when concrete construction problems became apparent: there were instances where concrete work could be retained or modified in ways that would not have been possible had a lower strength concrete been used. When, in December 1999, construction resumed, Arup's site representation role had grown to become full-time assistance to the contractor in executing the work. Concrete construction was completed in May 2000.

Conclusion

In November 2001, Arup was appointed as consultant to assist in facilitating the building's commissioning, as schedule pressures on the contractor had become critical. This enabled faster completion of the MEP systems, since the processes of problem resolution, inspections, acceptance, and owner instruction could be completed concurrently with construction. Raimund Abraham's competition narrative describes the building elements as 'counterforces of gravity'. When the $29M Austrian Cultural Forum officially opened (amidst glowing reviews in the architectural press) on 19 April 2002 it had boldly countered a battery of forces including politics, lack of money, construction difficulties, and a near impossible lack of space. From the design standpoint, the project persevered not because of broad sweeping innovation but from continual, careful, and creative attention to detail. Not only did the project get built but the architect was quoted as saying: 'There has never been a compromise made in terms of architecture'. For those team members who weathered the decade of obstacles set before this project, that is a tremendous statement.

Credits

Owner:
Bundes Immobilien Gesellschaft (BIG)

Occupier:
Austrian Cultural Forum

Owner's representative:
Hanscomb Inc

Architect:
Atelier Raimund Abraham

Engineers:
Arup Leo Argiris, Louis Arzano, Dan Brodkin, Sean Bui, Richard Bussell, Danny Chan, Varughese Cherian, Fiona Cousins, Dieter Feurich, Tania Flavia, Gregory Giammalvo, John Giamundo, Igor Kitagorsky, Al Lyons, Al Palumbo, Ricardo Pittella, Raymond Quinn, Mahadev Raman, Joel Ramos, Ron Ronacher, Yet Sang, Peng Si, Tom Smith, Pete Tillson, Steve Walker, Rebecca Welch, Neill Woodger, Amir Yazdanniyaz

Construction manager:
Barney Skanska Construction Co.

Illustrations:
1, 4, 8, 9, 10:
© Robert Polidori
2: Atelier Raimund Abraham
3, 6: Arup
5: Penny Rees/ Daniel Blackhall
7: © Tobias Klutke

Prada epicenter, New York

Hillary Lobo Gregory Giammalvo Raymond Quinn

1. & 2. (right) The Broadway entrance: the original cast iron façade was retained while the interior of the store was completely re-worked.

Introduction

In the late 1990s, as part of its strategy to protect brand image, Prada, the international fashion house based in Milan, Italy, began to rethink the traditional design format of its retail stores. The strategy, later developed with the chosen architects, came to include the idea that some Prada stores should break away from the traditional model to become 'epicenters' - a reflection of the house's cutting edge products.

These new stores, located in some of the world's trend-setting shopping districts, would sport a dynamic, exciting design and accommodate the latest that technology had to offer, all to enhance and support the shopping and customer service experience. Prada chose New York, Los Angeles, San Francisco, and Tokyo as the locations, and Office of Metropolitan Architecture led by Rem Koolhaas (Rotterdam, Netherlands) as design architect for the USA stores and Herzog & de Meuron (Basle, Switzerland) to design the Tokyo store. While the New York store would be Koolhaas' first retail space, he had long been considering the meaning of shopping in the contemporary urban environment[1,2] and the Prada experiment promised to be an ideal testing-ground for his theories.

Prada decided to locate the New York store in the trendy, downtown neighbourhood of SoHo, already home to outlets of many of the world's fashion elite, and eventually negotiated a lease in a prominent 19th century, cast iron façade, landmarked (listed) building on Broadway at Prince Street. The new store would have 24 000ft^2 (2230m^2) including the street level and cellar, and be the full depth of the city block.

The rest of the New York design team was then brought on board. Architecture Research Office (ARO), New York, was appointed as architect-of-record responsible for the detailed drawings and implementation phase of the project. Arup was asked to participate in the engineering consultant selection process and was awarded the mechanical, electrical, plumbing, fire protection and emergency lighting system design work.

For projects in Los Angeles and San Francisco, Arup's offices there provided structural, mechanical, electrical, plumbing and fire protection system design, and for the Tokyo store Arup Lighting worked closely with Herzog & de Meuron.

Store features

The defining feature of the store is the 'wave', a curving floor that swoops from street level to basement, creating a large volume space and giving shoppers an unencumbered route to the product display areas of the cellar.

Made of zebrawood, the wave functions as flooring, display unit, bleacher seating, and architectural element. During shop opening hours part of this space is for shoe display and fitting, but at other times it can become a performance area, with patrons replacing shoes in the bleacher seating and a retractable stage emerging on the facing side.

3. The wave unites the street level with the cellar. Some shoppers observe from upstairs (street level), while others visit the shoe display on the bleacher portion of the wave (cellar level). The hanging volumes above contain merchandise and audiovisual equipment.

Prada's technology requirement was to support and enhance 21st century shopping. The fitting rooms, for example, are entered through doors with *Privalite* glass that transforms from transparent to opaque at the flick of a switch. Once inside, the lighting is customer-controlled via a dimmer, and the fitting rooms are also equipped with IT features designed to excite. A 'magic mirror' - really a series of cameras and plasma screens - records customers trying on their selections, so that they can see themselves from the front, back and side, with instant replay, if necessary. Upon customers' requests, Prada will store these images electronically for use in future shopping experiences, even online. Also in the fitting room, shoppers can scan product codes for additional product information.

4 left: Shoppers use the wave steps to move between street level and the double and single height basement spaces.

5 above: The wave's steps double as bleacher seating for 'stage' events on the opposite side, and merchandise display.

6 below: The movable, hanging volumes allow many space configurations. The crane system track and the cable raceways can be seen in the polycarbonate ceiling.

One of the store's dramatic features is a series of aluminum mesh cages suspended from the ceiling. Imitating the upside-down skyline of a hanging city, these include hanging bars, shelving, and space for merchandise display, all fully wired for lighting, audiovisual, and IT. And they move: the mobile displays are designed to provide flexibility of floor space and can be aggregated to an area less than 25% of the total floor area. The 'handbag lift', a cylindrical glass elevator, provides access to the 'cellar level'. The cab contains a display of Prada handbags, enabling patrons to browse while on board.

7. The dressing room walls contain a range of IT equipment, all locally lit and cooled to enhance the shopping experience.

8 right: The movable (manual) display units in the basement display area operate like storage compact shelving, allowing different configurations. Walkways cut into the shelving units allow shoppers to pass through the space.

Engineering constraints

In the 1980s, the building was renovated and converted to commercial space. Systems for hot water, chilled water, smoke purge, outside air supply, perimeter heating, fire alarm, and fire protection were installed at that time. Arup worked within the constraints of these existing systems, and the additional constraint of sharing those systems with the other tenants, including a residence and the Guggenheim Museum's SoHo Annex, who required 24 hours per day operations. All reworking of the base building systems had to be carried out without disruption to the existing tenants.

Electrical systems

Realizing the goals of the design required a complex electrical system to serve the ambitious lighting, audiovisual, IT, stage, and even mobile crane systems packed into the store. It comprises a 1200 amp distribution switchboard and multiple separate panels for lighting, audiovisual equipment, data equipment, mechanical loads, etc. The distribution system feeds over 450 branch circuits and uses over 8000ft (2440m) of wiring raceways for power, audiovisual, IT, and security systems wiring. These raceways, located above a translucent polycarbonate ceiling finish, were carefully sized and routed as they would be a visible feature of the store's ceiling-scape.

The Prada epicenter is brightly lit, probably more than most NYC stores. The initial electric demand for the design was 20W/ft^2 (215W/m^2) but this was scaled back to 14W/ft^2 (150W/m^2) after taking cost (a newly reinforced service would have been needed), schedule, and building space conditions into consideration. Designers employed approximately 80 luminaire types with various voltages, integral/remote ballasts, and transformers for each. Eight dimming panels, each with an associated automatic transfer switch, transfer approximately 15% of the retail store lighting to emergency power to provide emergency lighting.

The mobile merchandise displays - 17 hanging volumes at street level and six floor track-mounted units in the cellar - posed their own unique set of challenges. The hanging volumes on the main floor use laser-guided, industrial grade, motorized cranes for mobility (designed and built by Mannesman Dematic).

Each hanging volume is self-contained for lighting, power, audiovisual, and IT, with power derived from four 208V, three-phase overhead busways on the first floor, via power collectors that move with the displays. Lighting is radio-controlled, whilst the audiovisual and IT controls are wireless. The cellar displays are simpler, as they are manually moved. They derive power for lighting and audiovisual from an overhead, single-phase, three-wire bus system.

> *'Prada, the international fashion house based in Milan, located their new New York store in the trendy downtown neighbourhood of SoHo.'*

Mechanical systems

These high electrical demands create high interior cooling loads. The mechanical system designed by Arup provides 200 tons of cooling using a combination of air handlers, fan coils, and computer room air-conditioning units. New and existing air-handling units, seven in total and distributed as space and duct routes permit, provide a total of 63 000ft^3/min (30m^3/sec) to the occupied parts of the store. The lighting control rooms, IT control room, and backstage audiovisual system control room are all independently air-conditioned.

The movable volumes create 'blockages' for air distribution and, given the large air volumes being moved through the space, create the potential for draughts in certain areas while others remain stagnant. The high level, sidewall air supply is designed to allow supply locations to be manually adjusted to the changing (pre-set) positions of the hanging displays. Furthermore, the air distribution system for the main space is designed for a noise level that is low for a retail space but required for the space's other function as a performance venue.

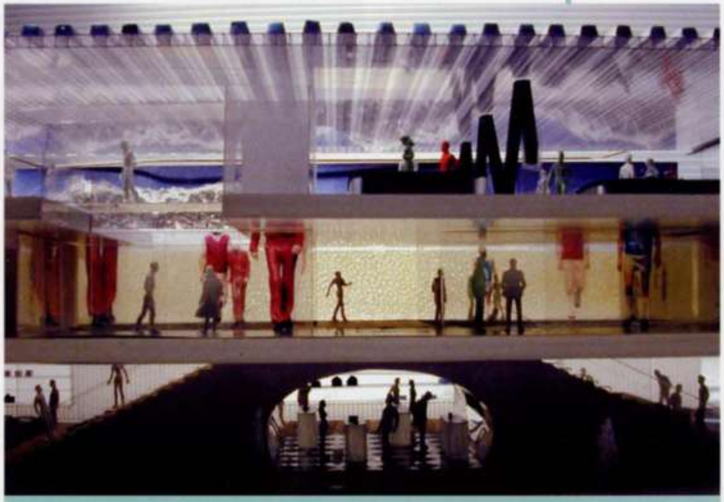
The uninsulated cast iron and single-glazed façade had a history of interior condensation – and even the formation of interior icicles - in the winter. To avoid this in the new use, Arup included low-level trench heating and high level forced air façade heating in the design. Additionally, the building's landmarked status meant that the existing double doors leading to the streets at both ends of the store could not be replaced. Entrance vestibules (which would have provided some protection from freezing New York winter draughts) were avoided in the design, for fear they would disrupt easy customer access. The constant customer traffic means that these doors are often open. Whilst exclusion of draughts is impossible, glass panel handrails at one side and the peak of the 'wave' at the other help to break them up and keep much of them from falling into the bleacher seating of the wave.

On both the cellar and street levels, much of the lighting is mounted behind either vertical or horizontal polycarbonate panels, with some light fixtures and audiovisual equipment built into fully concealed pockets in the walls and ceilings. Various combinations of supply and extract air and local cooling units were used to ensure all the heat from those devices is vented from these pockets. Ceiling voids are used as general return air plenums to remove the heat.

Other Prada projects

Beyond New York, a new Prada epicenter in San Francisco is planned and designed, and Arup also continues to work on another Prada store in Beverly Hills, California.
The scope of services includes the structural, electrical, mechanical and plumbing engineering design of this three storey-plus-basement, 22 000ft^2 (2040m^2) store on Rodeo Drive, of which 18 000ft^2 (1670m^2) is column-free retail space. A steel and glass vierendeel truss roof spans 50ft (15.2m). The main spatial design feature is the 'hill' stair/display form, the inverse of the New York store's 'wave'. Taking advantage of the local climate, the ground floor will open across the entire width of the building, with an 'air curtain' providing climatic separation between interior and exterior. A wall panel will rise out of the basement at night to secure the building. Brand + Allen Architects, Inc, is Arup's client and Architect of Record for both projects, with OMA as design architect for both. In New York, Arup is working with Herzog & de Meuron and Architecture Research Office on the design of a new 15 000ft^2 (1400m^2) multi-media exhibition space for Fondazione Prada, on the ground floor and basement of Prada's US headquarters building, on the west side of midtown Manhattan.

9. **San Francisco:** a 10-storey flagship store providing 37 000ft^2 (3440m^2) of retail and office space with a unique structural system of base isolation and perforated steel shear panels to resist lateral forces.



10. **Beverley Hills:** The lateral system provides column-free spaces on each of the 46ft (14m) wide floors and has a steel vierendeel truss roof diaphragm. The building began construction in January 2003.

Fire protection

Arup also designed the fire protection for this project. One challenge came from the movable volumes, as their design was not initially compatible with standard sprinkler system design. To remedy this, the hanging volumes were lowered slightly, to provide code clearances for the sprinkler heads. The design of the cages themselves was modified to include highly perforated tops and bottoms, allowing water to fall through them. The 'handbag lift' is also fitted with a grating top to allow adequate sprinkler coverage. Consideration was given to sprinkler configuration, in view of the fact that the sprinkler system is permanent while the moveable volume locations are not, and Arup used additional sprinkler heads to 'triangulate' each of the moving volumes.

Additional fire safety measures include an automatic power disconnect to the cages and the Privalite fitting room doors in case of a fire alarm.

Conclusion

After an intense design and construction period of almost 24 months, the store opened to the public on 14 December 2001.

The engineering systems were successfully commissioned and since the opening have performed well throughout the first full seasonal cycle of operation.

Shopper traffic is high, and shoppers seem to delight in the space, both its architectural elements and its high tech wizardry. Critical acclaim has been forthcoming as well. Just two days after the opening, *The New York Times'* architecture critic Herbert Muschamp sang its praises in a review 'Forget the shoes, Prada's new store stocks ideas'. Such diverse publications as *Architectural Record* and *Forbes*, and the technology website *CNET.com* followed - examples of coverage that has gone beyond the architecture and fashion spheres to reach travel, financial, and technology publications as well. The store has become the meeting place that Prada and Koolhaas strove for, the epicenter surpassing the merely commercial to become a public space and a destination as well.

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(1) KOOLHAAS, R, *et al*, *Editors*. Projects for Prada, Part 1, Fondazione Prada, 2001.

(2) KOOLHAAS, R, *et al*, *Editors*. Project on the City 2: Harvard Design School Guide to Shopping, Taschen, 2002.

> *'Forget the shoes,*
> *Prada's new store stocks ideas':*
> *Herbert Muschamp,*
> *New York Times architecture critic*

Credits

Owner:
Prada

Architects:
Office of Metropolitan Architecture / Architecture Research Office

Structural engineers:
Leslie E. Robertson Associates

MEP and fire engineers:
Arup Irina Bulbin, Ash Chawla, Arkady Fishman, Tania Flavia, Gregory Giammalvo, Jonathan Griffiths, Tom Grimard, Hillary Lobo, John Miller, Raymond Quinn, Joel Ramos, Anatoliy Shleyger, Marina Solovchuk, William Stevenson, Gina Wall

Audiovisual:
Shem Milsom Wiklie

Display systems:
OMA

Wallpaper:
2x4

Materials research and development:
OMA, Panelite, Werkplaats de Rijk, Collaborative

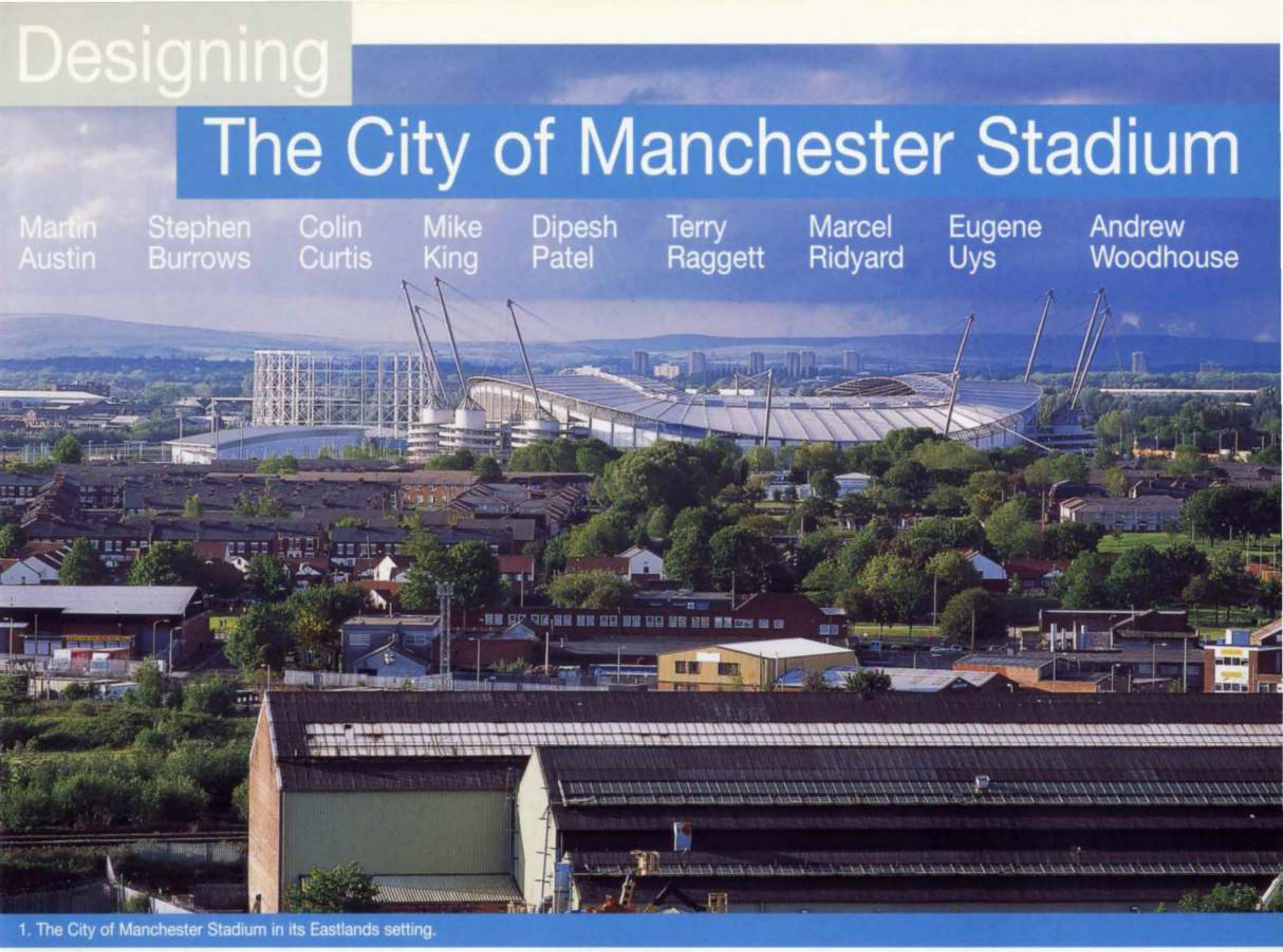
Lighting:
Kugler Tillotson Associates

Elevator:
OMA, Chimetal, Selcom, Edgett Williams Consulting, Thyssen Krupp, Iros

Illustrations:
1: Raymond Quinn
2-10: ©OMA

Designing
The City of Manchester Stadium

Martin Austin Stephen Burrows Colin Curtis Mike King Dipesh Patel Terry Raggett Marcel Ridyard Eugene Uys Andrew Woodhouse



1. The City of Manchester Stadium in its Eastlands setting.

BACKGROUND

History of the bids

The story of The City of Manchester Stadium, from initial sketch to first stone to final touch, has been long and complex - inevitably so, given the background of constantly changing circumstances. Nonetheless, the City Council throughout held to three fundamental principles:

- Manchester deserved a new high-profile sports venue reflecting its status as a major sporting centre.
- The venue should be both a central component of urban regeneration and a catalyst for further renewal.
- The project needed a long-term, sustainable future.

The idea of creating an international stadium dated back to the city's bid to stage the 1996 Olympics. Originally the Manchester Olympic Bid Committee, chaired by Bob Scott, planned an 80 000 capacity venue on a greenfield site in west Manchester. When in 1989 Atlanta secured the 1996 Games, however, Manchester re-evaluated its ambitions in anticipation of a second bid for 2000, and the focus shifted to east Manchester ('Eastlands'), 1.6km from the city centre, derelict and ripe for renewal, as an alternative stadium site. In 1992, Arup was brought in as design consultant for an 80 000 capacity stadium, as the firm had already helped in the selection of the Eastlands site.

At the same time, a working party was set up to review the implications of emerging government legislation on urban renewal, which promised vital support funding and had implications for the final site of the proposed venue. Government became involved in funding the purchase and clearance of the Eastlands site in 1992.

Manchester's bid for the 2000 Olympics was submitted in February 1993, but in October Sydney was declared the winner.

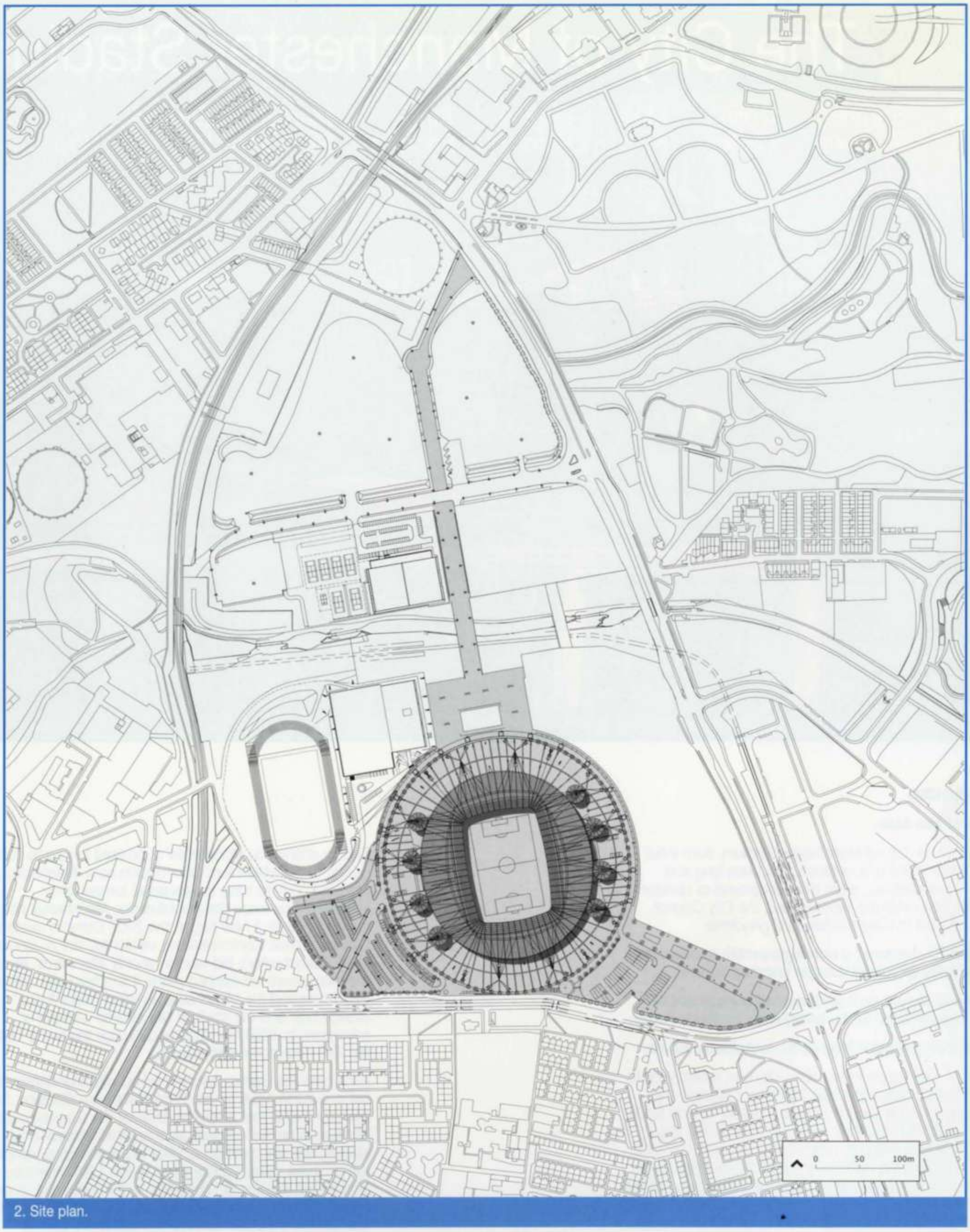
Shortly afterwards Manchester submitted the same scheme design to the Millennium Commission as a 'Millennium Stadium', only to have the proposal turned down. Undeterred by these disappointments, Manchester now looked towards a new target, the 2002 Commonwealth Games, whose Commissioners visited the city in January 1994. Manchester's bid went in shortly afterwards. By now the momentum established made it firm favourite, with a velodrome and the Manchester Evening News Arena[1] already built and the stadium site cleared with plans advanced. In 1995 Manchester duly won the bid to host the XVII Commonwealth Games.

For a time the Games became linked with Manchester's bid in autumn 1996 for the English National Stadium, the intention being that a stadium built for the Games could afterwards be reconfigured as a national football venue. Manchester saw itself as an ideal Northern home competing with or even replacing Wembley. But in 1997 Wembley beat off the Mancunian challenge to be confirmed as the home of the new National Stadium. The final incarnation of Manchester's stadium design was launched, with all energies now concentrated on the 'Friendly Games' of 2002, the biggest multi-sport event ever held in Britain.

One fundamental question remained, however: What would happen to the venue in the longer term?

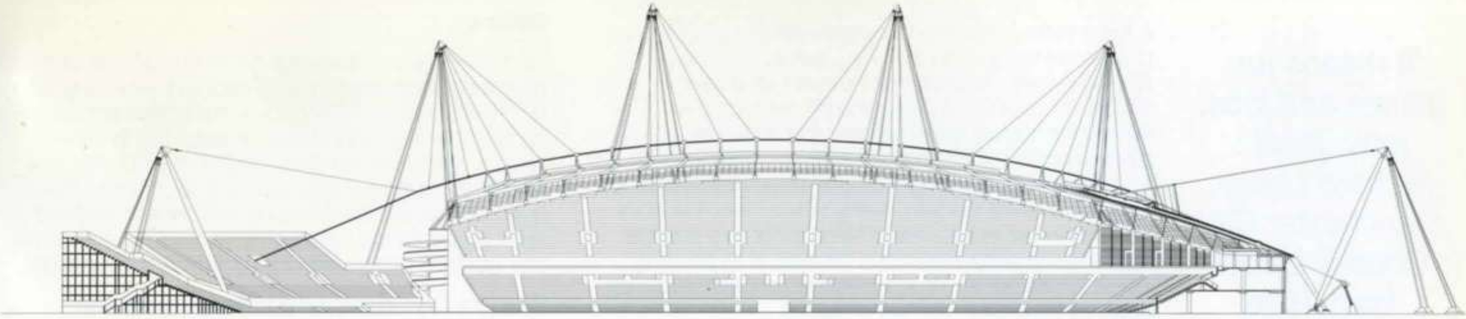
Long-term future

The question of what would happen to the Stadium after the Commonwealth Games was solved when a deal was struck between the City Council and Manchester City Football Club. The Council agreed to take over the Club's old Maine Road ground, with the Club moving to the new Stadium as tenants after the Games.

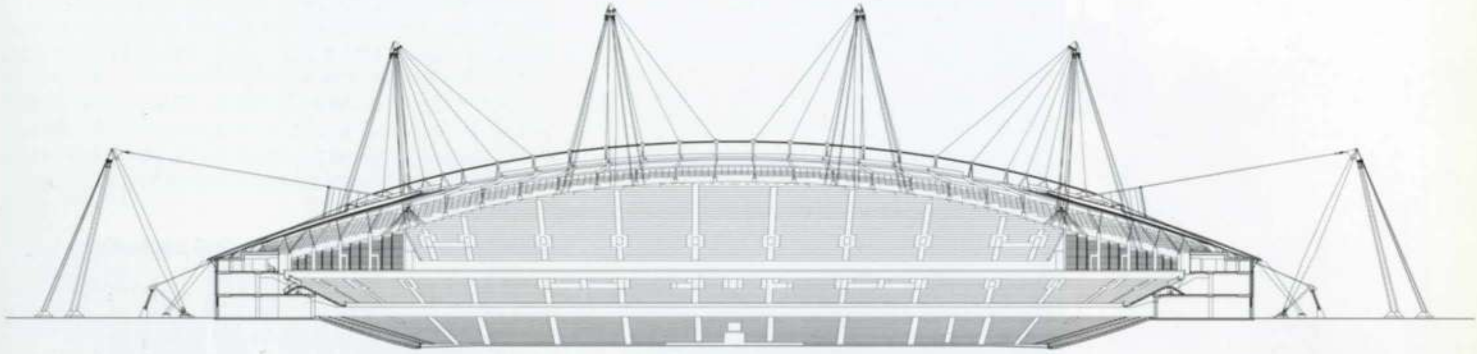


2. Site plan.

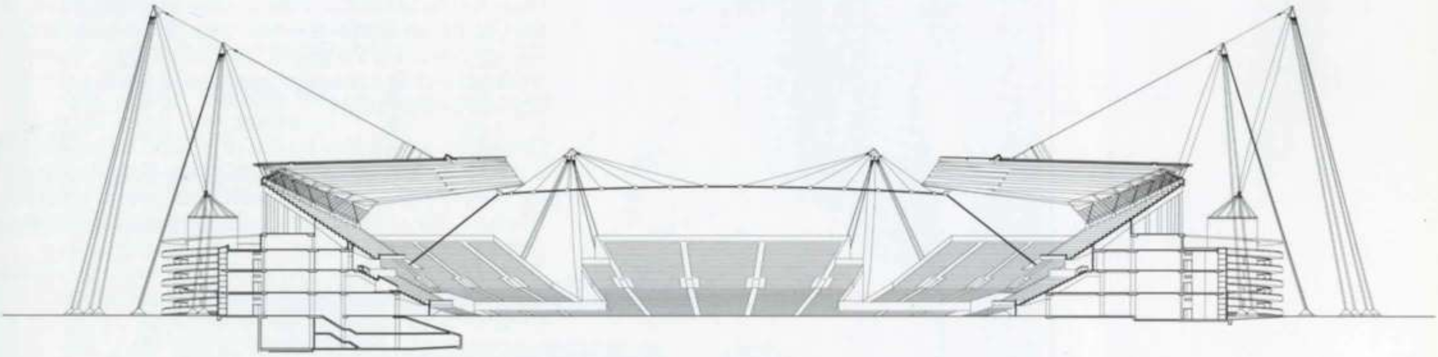
'Manchester deserves a new high-profile sports venue reflecting its status as a major sporting centre, which should be both a central component of urban regeneration and a catalyst for further renewal. It should also have a long-term, sustainable future:' Manchester City Council



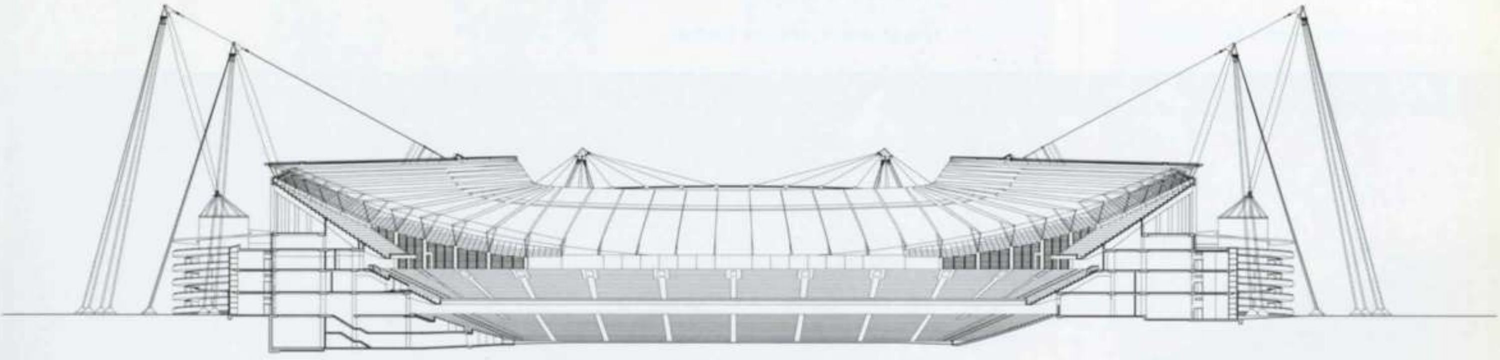
3. Stadium configuration for athletics: north-south section.



4. Stadium configuration for football: north-south section.



5. Stadium configuration for athletics: west-east section.



6. Stadium configuration for football: west-east section.

Manchester City Council, while sharing Sir Bob Scott and his team's commitment to winning the Games, always saw a wider picture. Simply bidding for the Olympics was in itself a statement of intent and self-confidence for Manchester and the North-West. It stimulated publicity for the city and its attempts both to transform its landscape and affirm its growing association with sporting excellence. The publicity, in turn, would attract outside the private and public funds needed for the city to attain its goals.

The concept emerged of the Stadium as centrepiece of a 'SportCity' complex that would transform the area and include a superstore, canalside homes, a hotel, restaurants and bars, plus an extended Metro rail link and pedestrian route along the Ashton Canal corridor north of the site that would link the once-blighted area to the hub of Manchester.

To underline the venue's viability, Manchester City FC was to be joined at SportCity by a branch of the English Institute of Sport and the National Squash Centre, as well as an indoor tennis centre and several other indoor and outdoor facilities, and with the existing and firmly-established velodrome, the National Cycling Centre, as a neighbour.

Alongside all this, other schemes - essentially unrelated but very much interdependent parts of the greater strategic picture - were being pushed ahead in the area by the New East Manchester Ltd urban regeneration company, formed in October 1999. Sport England, responsible for allocating National Sports Lottery Funds, contributed significantly, helping to free Manchester taxpayers from the spectre of a long-term financial burden, the fate of several cities that had staged major international sport events.

> *'It means fun, games and jobs, jobs, jobs!': Richard Leese, Manchester City Council leader from 1996*

A final funding hiccup was overcome in 2001, with the help of Sport England, national government and the City Council. A few months before the Commonwealth Games began, a study commissioned by the City Council from Cambridge City Consultants forecast that the event would secure for the city over £600M in public and private investment. The Games themselves would generate the equivalent of 6100 full-time posts in and around Eastlands, whilst SportCity and the surrounding regeneration could lead to 300 000 extra visitors pa visiting the area. Nearly 30M people, the study also concluded, would look to Manchester as a possible business and visitor destination because of its booming image, broadcast via TV to a massive worldwide audience approaching a billion during the Games.

DESIGN DEVELOPMENT

Outline

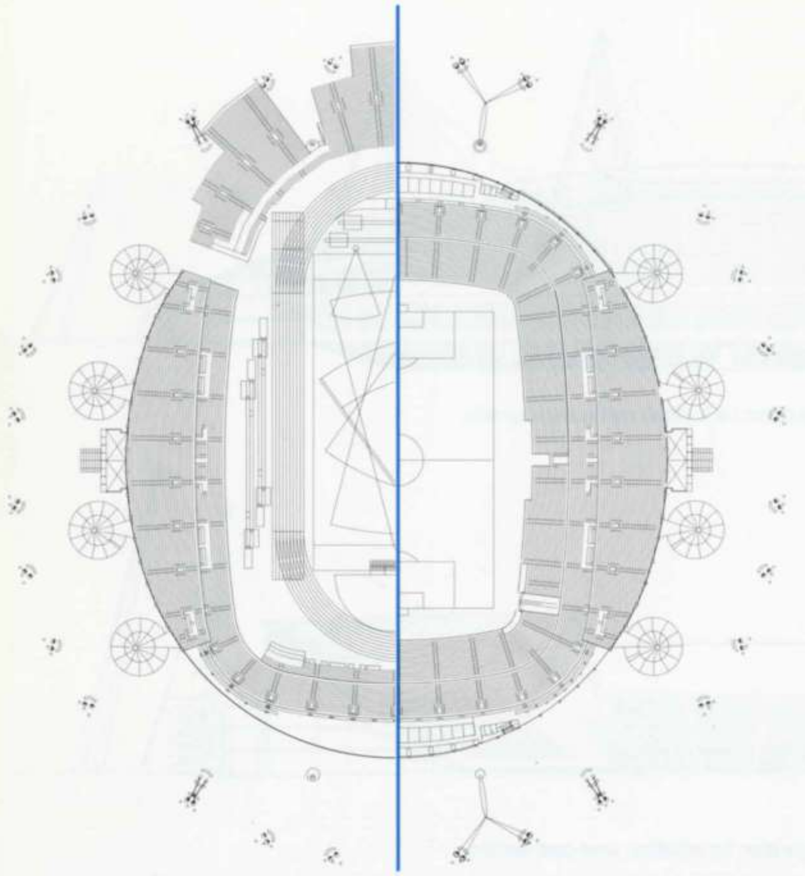
From the original 1992 design for an 80 000-seat athletics-only stadium developed the concept four years later for a 60,000 stadium eventually to accommodate national soccer games. The venue would also be adaptable for other sporting disciplines like rugby league internationals, and major non-sporting events such as pop concerts. Certain basic features like the swooping 'saddleback' roof and the spiral access ramps continued from the 1992 conception into this 1996 design, with the addition of a closing roof.

When the City Council came to its agreement with Manchester City FC, Arup again reworked the design so that the Stadium would be ready to stage athletics for the Commonwealth Games and then be converted for football. The Games capacity was to be 38 000, rising to 48 000 (50 000 gross) after conversion by removal of the athletics track and addition of extra seating (light blue, of course, to match City's colour). This would be made possible by excavating down one level. Almost 40 000m^3 of fill would be removed, the pitch laid, and the temporary 13 000-seater stand erected on the north side of the venue for the Games replaced with permanent structure in time for the 2003–04 football season.

Athletics and football: needs and aspirations

When architects are commissioned to create large buildings likely to add significantly to a townscape, they naturally aspire for them to be iconic landmarks, and objects of civic pride. To satisfy such aspirations cost-effectively is particularly challenging when developing venues for one-off events like the Commonwealth Games. Manchester City Council's vision for this Stadium to have a viable long-term future after the Games, via its role as a new home for Manchester City FC, not only aided the project financially but also meant that it would become a permanent and momentous part of the city's civic infrastructure.

Generically, any stadium is a building for an audience to view a spectacle, the different forms of which dictate the shape of the viewing area. One of the earliest well-known examples, Rome's Coliseum, had a fully enclosed seating configuration enabling events to be viewed all over the display area. The behind-the-scenes organization was extremely intricate and yet functional, to enable the most stimulating and yet smooth-running show.



7a. Overall seating plan for athletics.

7b. Overall seating plan for football.

8. The Stadium in athletics configuration, ready for the XVII Commonwealth Games.

By contrast, the Greek theatre at Epidaurus focused the audience on a very specific viewing area. Current examples mimic the historic: to organize appropriate viewing systems for audiences to enjoy visual spectaculars, with all necessary facilities to hand plus aspects like speedy evacuation for safety.

The principal events at The City of Manchester Stadium were to be athletics first and then football. Athletics has a seating bias skewed towards the home straight, with a particular emphasis on the finishing line. Football is best viewed from the sides, though many fans like to sit behind the goal. The west side is traditionally favoured because most clubs began with just one stand and disruption of the view of the game by low afternoon sun had to be avoided. This is less relevant for large stadia built from the outset with two or more stands, but the west stand is still regarded as superior and is in all cases the 'main' one even though it may be identical to the east stand.

Thus the two sports dictated two ideal seating bowls. Historically, the stature of the buildings housing them had very different origins. From its ancient Greek beginnings, athletics took place in celebrated venues and this tradition continued with the modern Olympics. Architecturally, athletics stadia have always been revered and much thought and effort has gone into their design. In contrast, most football clubs began with very small utilitarian stands, a building type largely ignored by the architectural profession. Most club stands to this day are a seating terrace served by a few toilets and vending areas clad like industrial buildings. Their appearance and building technology is akin to a warehouse, not a civic building.

Visual icon and user experience

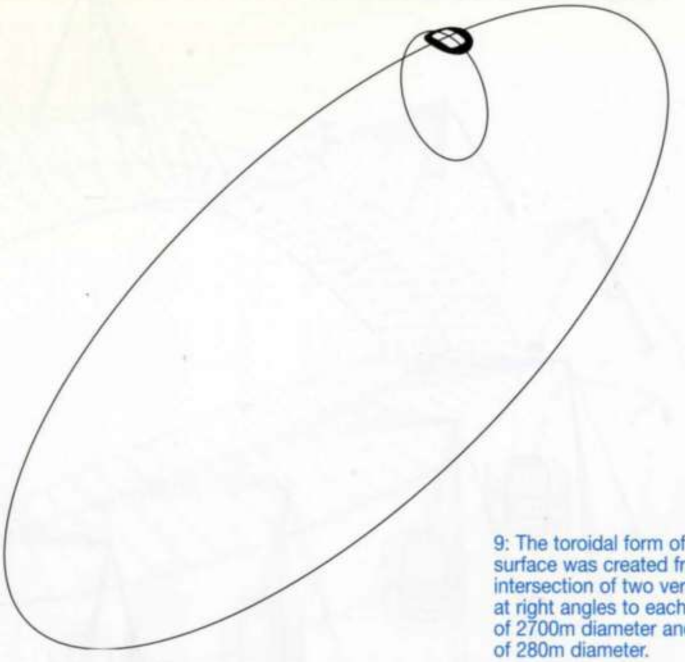
From the outset the objective of Arup Associates as architect was to approach The City of Manchester Stadium as a key civic building. This architectural stature, combined with the significant elements of structure and servicing, also made it a building type particularly suited to the firm's multi-disciplinary practice. Every element in the Stadium is designed to fulfil as many functions as possible, making the design very clear and maximizing use of the available funds.

Two specific goals lay behind the general aim to raise design standards for this building type: (a) to give Manchester a new icon, improving the city and in particular the surrounding deprived areas of Beswick, Chorlton, and Hardwick, and (b) to design a stadium that is a great experience in every way, not just for spectators viewing events. This may seem obvious, but to date no UK stadium has successfully addressed both types of issue. At the urban level many are 'bad neighbours', used only a few times a week at most. Otherwise they are empty shells sitting in a sea of empty car parking. Others are famed for their legendary 'atmosphere', but remain frustrating to get to and away from and become an unpleasant melee during half-time.

Unlike many of its historical predecessors, this Stadium was carefully designed with form, structure, and circulation in mind. The required seating bias dictated a bowl with high sides on the east and west and low ends north and south, allowing a single roof geometry to cover all seating and leaving large open areas in the corners for pitch ventilation and video screens.

This super-geometry comprises two circles, creating a toroidal form (the roof surface) over a circular plan (Fig 9). As oriented, this results in a building that addresses the local context, with the tallest parts in the middle of the site whilst the lower north and south aspects respectively address the sensitive Ashton Canal corridor and the housing area south of Ashton New Road.

Overlaid on this form are the spiral ramps and the masts, the central eight of which sit atop the ramps and together form the Stadium emblems: the distant view is of a low-lying curved form surmounted by 12 masts. These, with the ramps, terminate key view corridors for fans approaching the Stadium. Those coming to Manchester first glimpse these bold new landmarks from various points around the city and then find themselves heading directly towards them, a sequence completed on arrival when they climb up the ramps to enter the upper levels.



9: The toroidal form of the roof surface was created from the intersection of two vertical circles at right angles to each other, one of 2700m diameter and the other of 280m diameter.

> *'The City of Manchester Stadium is a national symbol of how major sporting facilities can contribute to the physical and social wellbeing of a city and country.'*

Placing the ramps externally gives depth to the façades and makes the structure very distinctive, and most importantly adds to the drama of an event. Joining fellow supporters sweeping up the ramp in anticipation of the game ahead and descending afterwards, discussing it, is all part of the experience. The excitement of entering the Stadium is further heightened because fans can see each other and the surrounding city and moors until the very last moment.

This sense of connection begins in the external concourse, the circular public space around the Stadium visually delineated by a grid emanating from the external columns and terminating in a perimeter of trees. Surrounding this plaza will be the sports institute plus shops, leisure areas, and bars - when complete, a truly mixed-use area with the Stadium as centrepiece, and vibrant on both match and non-match days.

The first internal experience of the Stadium continues the human theme of spectator comfort. The space is akin to airport and railway station concourses, unlike other stadia where spectators make do with 'left-over space'.

An innovative fire strategy allowed the creation of continuous concourses - deliberately large, clean, uncluttered, and calm spaces designed to calm the typical half-time scramble for refreshment and relief. The main concourse serving the largest lower tier is also directly behind the last seat. Should UK law on consuming alcohol and viewing the game ever change, the dividing wall could be removed to bring the game's drama right into the very heart of the building.

Enabling works

Site investigation and ground conditions

The derelict 11.5ha Eastlands site reflected the changing face of industrial Manchester. From the mid-18th century it housed coal seams and shafts, and from the 19th century the Ashton Canal, cotton and lead mills, railway lines, and iron and gasworks. It remained fully developed until the 1960s, but the colliery was closed in 1969 and the gasworks flattened to ground level a decade later. Further demolition and clearance work followed. With this history, and the hidden legacy of mine workings and shafts, some contamination was to be expected.

To overcome the shortcomings of previous investigations, boreholes up to 85m deep were sunk, together with trial pits and in situ testing. Landfill gas and groundwater installations were monitored, and samples tested for both geotechnical and chemical properties.

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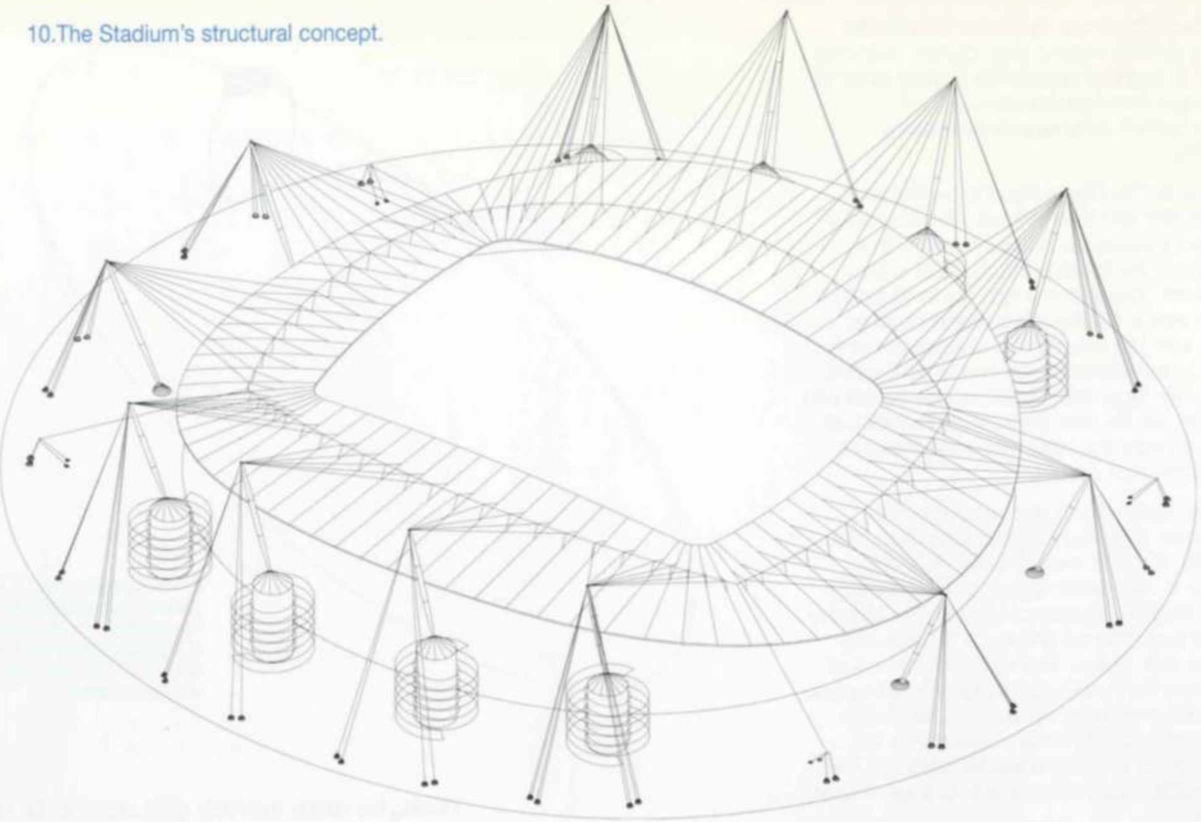
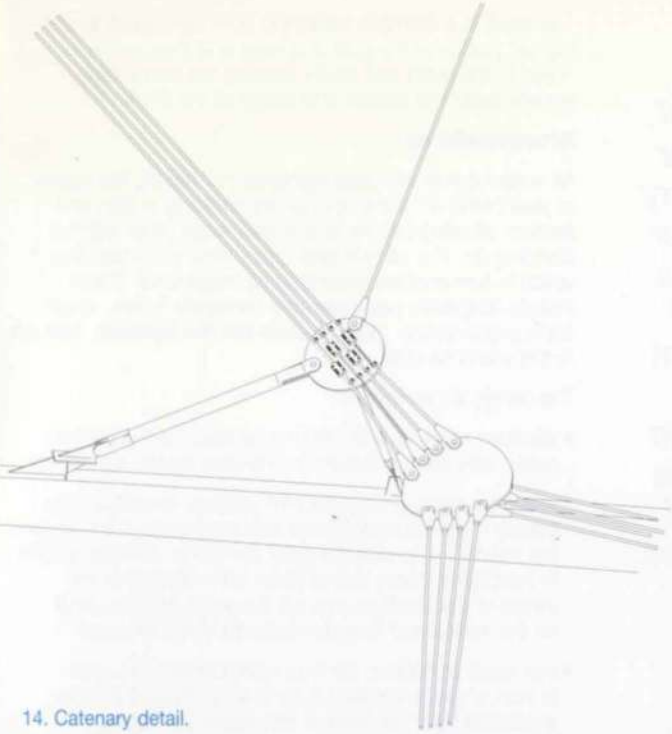
10.The Stadium's structural concept.

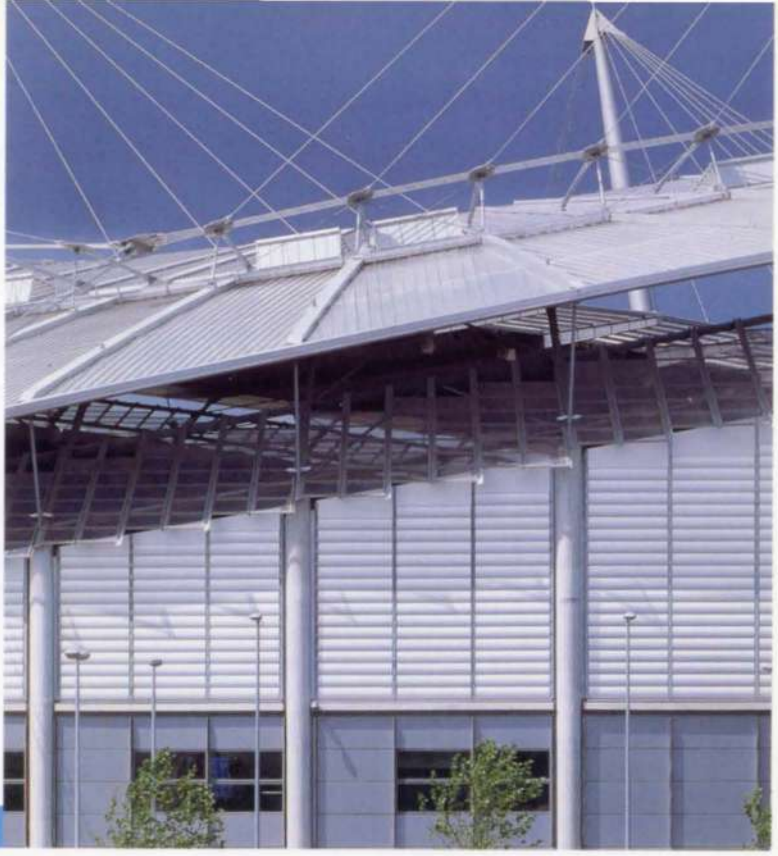


Mast top detail: 11 above: as designed; 12 below: as built.

13. The City of Manchester Stadium illuminated at night.



14. Catenary detail.

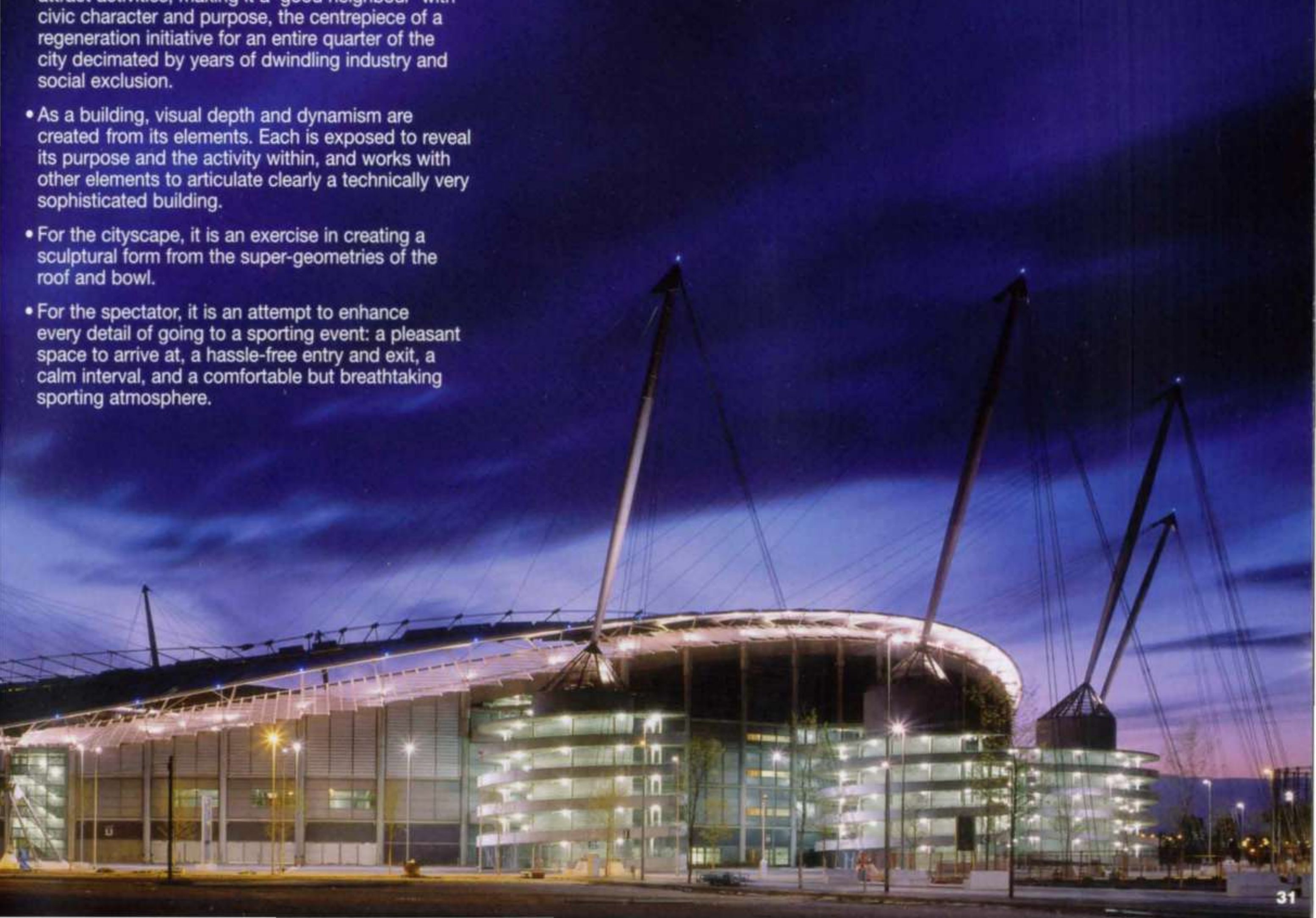


15 right: Façade detail showing louvres.

RAISING DESIGN STANDARDS

Ultimately Arup's main goal was to raise design standards in every way:

- At the urban design level, the Stadium and its plaza attract activities, making it a 'good neighbour' with civic character and purpose, the centrepiece of a regeneration initiative for an entire quarter of the city decimated by years of dwindling industry and social exclusion.
- As a building, visual depth and dynamism are created from its elements. Each is exposed to reveal its purpose and the activity within, and works with other elements to articulate clearly a technically very sophisticated building.
- For the cityscape, it is an exercise in creating a sculptural form from the super-geometries of the roof and bowl.
- For the spectator, it is an attempt to enhance every detail of going to a sporting event: a pleasant space to arrive at, a hassle-free entry and exit, a calm interval, and a comfortable but breathtaking sporting atmosphere.



Enabling works *(continued)*

Geotechnical and technical properties

The geological succession comprised 2-3m of made ground over 7-15m thick glacial clay deposits, in turn above coal measure rocks. The made ground was granular and cohesive, of variable density and strength, and included shallow groundwater. There were also minor water entries in the glacial deposits. As anticipated from the industrial history, the made ground was contaminated to varying degrees with hydrocarbons, heavy metals, and waste-containing obstructions from old foundations.

The coal measures comprised alternating mudstones, siltstones, sandstones, and thin coal seams, maximum 1.2m deep, dipping to the south-west. The coal workings were predominantly collapsed where encountered, probably from longwall mining beneath (in which a cutting head moves back and forth along a coal face). The site had several mineshafts, and in the masterplanning the Stadium was positioned to avoid them (though there was the possibility of old unrecorded shafts). Groundwater was encountered below rockhead. A geological model was prepared which differs from the map by the British Geological Survey, who are reviewing Arup's model for their new Manchester map.

Remedial works

These were designed to mitigate the effects of the abnormal features previously identified, and included large-scale earthworks to form the platform. The strategy was to limit the import of material and disposal offsite by maximizing re-use of excavated material. As for contamination, the levels of chemicals acceptable to be left with respect to end use were agreed with the regulators. Several 'hotspots', primarily hydrocarbons, were identified, excavated and disposed offsite. Of the total 250 000m^3 of material excavated, however, only 10% left the site. The material was either used immediately as fill or processed, with concrete and brick crushed for capping and marginal material treated with lime to stabilize it. The team decided to excavate the made ground to its base under the Stadium footprint to remove obstructions to piling and check for unrecorded mineshafts. Three were found and grouted up.

There was an extensive network of both recorded and unrecorded services, the latter found during the earthworks. New services were constructed and others diverted, the most onerous work involving connections into existing very deep sewers.

Coal workings were treated by injecting grout into a grid of drillholes to different depths relative to each seam. The grout take varied, with more going into an uncollapsed seam than one partially collapsed. The takes also dictated the grid spacing. At the end of the treatment, test holes were drilled to check its adequacy.

Canal Bridge

For pedestrian and emergency vehicle access to the Stadium from the north, a 20m wide bridge was built over the Canal. Its deck was designed to be integral with the abutments, a combination of 1.2m diameter piles supporting the deck with faced reinforced earth infill walls. The bridge was designed to avoid any load being transferred to the Canal walls.

The playing area and seating bowl

Spatial concept

Once in their seats, fans experience the Stadium's principal space, the playing area and seating bowl. The toroidal geometry of the roof combines with the radial plan geometry to create a rising and falling perimeter, with the roof, visually separated from the seating, projecting overhead to create a dynamic space that draws the eye into the field of play.

When full of people this environment pulsates. All spectators are within 100m of the centre spot - as close to the field of play as possible.

For football it is ideal to maximize the number of spectators by the centreline, and to achieve this the 'saddle' bowl configuration was adopted: three overlapping seating tiers on the east and west sides, with two overlapping tiers on the north and south (the lower tier and permanent north end being completed post-Commonwealth Games). The result is a dramatic sweeping bowl curving up to the highest points on the east and west and then swooping down to the north and south, forming the shape that encapsulates the identity and image of the Stadium.

> *'The City of Manchester Stadium story evolved over more than a decade of commitment and co-operation between the public and private sectors.'*

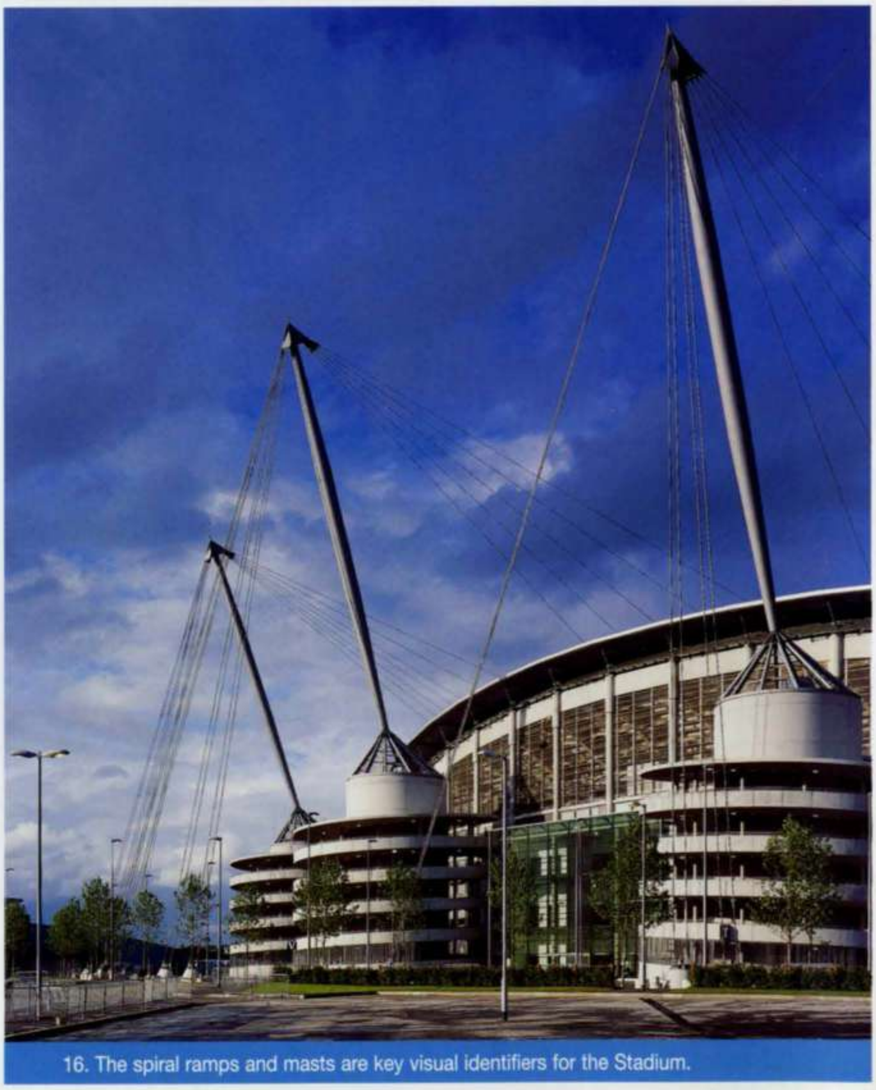
Accommodation

All seats have world-class sightlines ('C' value), the quality of view being enhanced by curved terracing in plan and section, allowing people to look past each other without standing up. The various seat types allow price banding, which in turn enables income to be maximized. These include hospitality packages and corporate boxes, which bring proportionally more revenue into the business, through to the standard seat.

The bands are as follows:

- standard seats at 480–500mm centres, for the general public with season tickets or individual match day tickets
- executive seats at 550–600mm centres, in various price bands; most are upholstered with arms and on the second tier, mainly in line with the pitch centreline. All have access to hospitality suites, two of them with views onto the centre of the Stadium: one on the south and the other on the west stand (the premium restaurant and bar)
- box seats at 600mm centres: upholstered with arms, in front of glass-fronted boxes in a continuous tribune separated from the back of the middle tier by a parapet wall. The Stadium has 69 boxes, averaging 10 persons each.

All seat rows provide an appropriate minimum clearway between folded seats, equal to or more than required in stadium guidance. Generally seat rows vary between 780-800mm in depth. The box seating, a little more luxurious, is 900mm deep.



16. The spiral ramps and masts are key visual identifiers for the Stadium.

17. Executive seating in front of glazed hospitality suites.

The Games' gross seating capacity was 41 000 (a last-minute 3000 increase due to high ticket sales), while the net capacity for football will be 47 500. The Stadium can be used for concerts, and here the total stand + pitch capacity increases to 50 000 -60 000 (dependent on stage position and assuming up to 16 000 spectators on the pitch).

There is, of course, provision for people with disabilities. 226 wheelchair spaces are designed into the Stadium seating at all price bands and levels, each area including seating for those partnering the disabled. Ambulant disabled are also close to these areas so they have either flat or ramped access. Visually impaired spectators are provided with induction loops for match commentary via headsets, and hard-of-hearing spectators can also use these to improve hearing-aid amplification of public address announcements.

Bowl structure and form

The bowl has an in situ reinforced concrete primary structure, on bored pile foundations. Coffered slabs form the floors and precast concrete units create the terracing. A typical radial grid spacing of 7.6m was adopted as this is half the aisle spacing and allows relatively open floor areas below. The secondary circumferential grid, defined by the seating geometry, is translated into a 'faceted' grid for the whole structure. On the outside of the building, the supporting structure of the spiral access ramps also houses toilets, services, and plant, as well as supporting the roof masts.

The exposed structure of the terracing forms the ceilings of the three concourses, with the entrances or 'vomitories' to the seating expressed as ramped or stepped gangways. The concourses allow both mass evacuation and circulation areas to concession units and toilets, which are distributed throughout. Spectators are served speedily in comfortable and pleasant surroundings before returning to their seats, the maximum distance from a vomitory to any facility being just 40m.

Roof structure

Concept and structural systems

A central feature of The City of Manchester Stadium is its distinctive and dynamic form, key to which is the structural solution for supporting the roof. The roof structure essentially comprises two separate structural systems, the first providing primary structural support to the whole roof (the 'cable-net'), and the secondary being a more conventional arrangement of rafters propped from the rear of the concrete bowl and hung towards their leading edges from the cable-net. The mast and cable-net roof primary structure uses a 'grounded tension ring' to create a prestress field against uplift wind loads. 12 cigar-shaped tubular steel masts up to 65m high support a total of 76 spiral strand forestay cables in fan-shaped groups of five or seven cables per mast. Each forestay supports an individual rafter. Just above the roof surface, all the forestay ends are connected by a system of four spiral strand cables that form the 'grounded tension ring' (also referred to as the 'catenary'). Prestress to the catenary and cable-net is provided by four corner-ties anchored to the ground. The top of each column is tied back to the ground by pairs of back-stays comprising groups of Macalloy high tensile steel rods. This mast and cable-net system not only provides a highly efficient structure but also is central to the drama of the building's architecture.

The roof plane structure comprises 300mm wide by maximum 900mm deep box section 'radial' rafters at approximately 7m centres, supporting UB section purlins at 4m centres. The rafters are supported at the rear of the Stadium bowl through integrated V-strut columns on the concrete bowl. The V-struts allow sufficient headroom between the rear seating terraces and roof structure as well as providing for transfer of horizontal thrust from the rafters to the bowl. Towards the inside of the Stadium the rafters cantilever by up to 14m beyond the support provided by the forestays.

Cladding

Most of the roof is clad with an innovative system that typifies how structure, services, and architecture are integrated in the Stadium's design and detailing. 150mm deep aluminium 'liner trays' span the 4m between purlins and rest on the purlin bottom flanges. The liner trays act structurally to support the aluminium standing seam roof sheeting as well as creating a hidden zone for acoustic insulation, wiring, and in-plane roof bracing. The trays also form a visually clean ceiling to the roof where a 'normal ceiling' would not usually be economical.The inside 10m of the roof on all four sides is clad in transparent polycarbonate sheeting, allowing sunlight onto the pitch to assist grass growth and also ample daylight into the seating bowl. Another advantage of this form of cladding at the leading edge is its more gradual transition from full daylight to shadow - particularly beneficial for television coverage.

The roof's geometrical form ensures that its surface always slopes down to the outside edge with an inclination varying from 1.5° to approximately 17°. Along this outer edge an aluminium-clad gutter defines the perimeter and carries all water runoff to two large sculpted downpipes at the northern and southern ends.

Details

A family of fabricated plate connections with a consistent architectural language has been adopted for major details such as the masthead and base, V-strut base, catenary nodes, and back-stay bases. These were developed in consultation with the successful first-stage roof steel tenderer who went on to secure the contract for the roof construction. Where axially loaded elements are visible, pin connections are used throughout except for the base of each mast, which utilizes a series of steel plates and a pot bearing. This detail enabled greater flexibility for rotation in any plane during erection whilst maintaining the capacity to transmit axial compression forces of up to 13 000kN in the final condition.

Back-stay and corner tie foundations

The back-stay rods and corner tie cables are anchored to the ground by an innovative foundation system comprising high strength steel multi-strand ground anchors which pre-compress concrete piles against the underlying rock strata. These anchors comprise 8-15 greased and sheathed 15.2mm diameter steel strands bundled and inserted into plastic ducts. The anchors are installed into bored holes up to 35m deep, with the lowest 10m of the anchor bonded to the surrounding bedrock by cement grout. Each anchor is prestressed so that it is in permanent tension whilst pre-compressing the concrete piles. This system was developed to deal with the local ground conditions where mining had left the underlying bedrock highly fractured. This bedrock can resist permanent tensile loads, but resistance to varying tensile loads is less reliable. The advantage of this anchor system is that the stress on the anchor/bedrock interface remains more or less constant and fluctuations in the back-stay or corner tie forces are accounted for by an increase or decrease in the compression in the concrete piles.

Servicing strategy

A 'clean' form

With some bad precedents in mind, the design team were determined that the public concourses should remain free of distribution services, satisfying the design concept of clear, coherent circulation and amenity spaces designed as 'streets'. The intent is that, unlike many stadiums across the UK, the experience away from the seating area is enjoyable too. Getting refreshments should not be an arduous scramble between events, but a more leisurely experience.

18. The public circulating - amongst the back-stay anchors - during the Games.

During the Games the main concourse level was the Stadium's key operational area and not open to the public. For football, by contrast, it becomes the main entry level and principal concourse, providing ground level access to the top of the lower tier seating and ramp access to all other levels.

The spiral ramp form for spectator access to and egress from the upper level concourses was chosen in preference to stairways for ease and safety of use and improved circulation. As well as being a key feature of the Stadium's image, the ramps are an integral part of the structural and servicing systems. The 10m diameter cores house all major shell and core primary plant, whilst the drum walls ultimately take the loads of mast and Stadium roof. To limit the number of openings through the walls, all ventilation intakes and terminals are at the tops of the towers; ducts thread though the towers to the plant area served. Depressed pile caps allow the piped and electrical main services to drop below ground level and connect into the 'raceway' that distributes services around the Stadium.

Electricity and lighting

An external raceway system was selected on a cost versus risk basis. It carries direct buried electrical communications to powerboards within the Stadium's water, gas, and heating services, linking the primary equipment from the ramp cores to the major building services cores within each stand. Electrical services break out from the towers at two levels, connecting to the Stadium via link bridges. Within the Stadium, cables are routed horizontally at high level and vertically within designated service risers. This enables service-free concourses with all major containment routes behind and beneath seating areas.

For spectators and TV cameras alike to view the action clearly, whatever the time of day, the event lighting needed serious consideration, and was designed to comply with FIFA (Fédération Internationale de Football Association) requirements. Some of the floodlights have hot restrike control gear, backed up by standby generators to maintain 800lux, which is the minimum for television to continue 'live' coverage in the event of a normal mains failure.

The Stadium's electricity needs are served by two 2MW substations, each in towers on the west and east stands. During an event the generators will be run to serve the hot restrike floodlights, but should a generator fail, the supply will automatically switch back to mains. If the mains are not available there is further back-up from the generator in the opposite stand.

Security and ventilation

Still further behind the scenes are the systems that back up the services. For security checks, a CCTV system gives image quality that complies with the required standards for identification and crowd monitoring. 15 fixed colour cameras and 57 fully functional dome cameras monitor the seating, public concourses, and access points. All cameras are run from the event control room where system recording takes place, with a secondary control position in the 24-hour security room.

The ventilation system consists of east and west accommodation air-handling plants at each floor level; outside air is filtered and mixed with recirculated air where appropriate. It is heated with low temperature hot water heating coils, then supplied to the appropriate space via insulated ductwork.

Extract air is drawn from occupied spaces through generally uninsulated ductwork to exhaust fans either at high level in the superstructure or back to the associated air-handling unit for recirculation or exhaust as appropriate. Exhaust ductwork is insulated where it passes through unheated spaces to prevent condensation within the duct and to minimize heat loss where the air may be recirculated. Supply and extract fans have variable speed drives. Exhaust air from general accommodation is discharged from the basement plantroom to the service road.

19. Opening ceremony for the XVII Commonwealth Games, 25 July 2002.

INNOVATORY DESIGN FEATURES

Wherever possible in the design of this building, the team went back to first principles to create the best systems economically possible rather than simply using tried and tested systems as in other stadia. This made for a unique building and enabled its success in both civic and financial terms.

Pitch ventilation

An inherent problem in designing large stadia is to create a roof that not only shelters (with 'drip-line' cover to all spectators) but also ventilates the pitch. Daylight, sunlight, and air movement over the pitch are essential for healthy grass growth but a wind-free and comfortable arena is also needed.

The dramatic roof form and corresponding stand configuration allowed movable louvre vents in the high-level corner voids. These vents can be adjusted to increase or decrease airflow through the Stadium, and thus benefit not only air movement over the pitch but also the spectator environment. Similar low-level vents are also incorporated in the corner exit gates.

Under most circumstances these precautions would have been adequate to ensure good grass growth, but Arup wanted to ensure the very best pitch possible. A further ventilation system was therefore added, this time beneath the pitch as for golf courses. At close centres perforated pipes were laid; these double for pitch drainage and through them air can be either pumped or sucked. Humidity detectors in the root zone of the turf show the groundsmen when the pitch is too humid and needs drying out, or is too dry and requires watering. Another benefit of the system is that air can be pumped direct to the base of the turf, thereby oxygenating the root zone and increasing turf growth.

Turnstiles

After the initial impact of the overall building form, spectators' next impressions of the Stadium are the entrance experience. The design of the turnstiles is a key component of this.

A turnstile capable of increased entry flow rates was desirable to alleviate the inevitable queues from the 20-minute rush before kick-off. To create a more open entry than many current systems, conventional 'off-the-peg' turnstiles were rejected as too unfriendly and unable to give the desired flow rate. Research showed that faster flow could only be achieved by replacing manual inspection of tickets with 'smart card' technology. Passive models - where gates are always open and only close when a 'bad' ticket enters - were looked at, but it was decided that the industry was not ready for such a turnstile yet (although the chosen system can be modified for this). An ergonomically designed turnstile, with increased space standards and a 120° rotor arm configuration, was developed with a turnstile contractor, ensuring comparable security to a conventional turnstile but with the above improvements.

As a result, queuing times and pre-match agitation are cut down and operational costs saved, as ticketing controllers are not required.

The system automatically counts and monitors the speed and location of spectator ingress, allowing stand-fill times to be based on current turnstile throughput.

Recessed gangway tread

Seats with restricted views have practical and financial implications in a stadium, but an unavoidable factor is the safety requirements for balustrades on the gangways of seating tiers, which give partially obstructed views to some seats in every stadium. At Manchester the design of the gangway steps around and above the vomitories was changed from the traditional 'planted-on step' to being recessed into the concrete seating tiers.

Also, there are hand holds on the seating side of the gangways for additional security while exiting the rows. As the height of the balustrade corresponds to its adjacent step, recessing the step results in a lower balustrade around the vomitory gangways, substantially reducing the number of restricted view seats and giving safer and more comfortable circulation around and into vomitories. Implementing this required a small cost increase, but fewer restricted view seats made for far greater added value.

Recessed floodlights and speakers

Floodlights and speakers are normally hung under the roof, with access walkways for maintenance. Additional structural framing and circuitous maintenance routes can create unsightly clutter under a roof; at Manchester this was solved by creating a 'kick-up' in the roof structure and cladding into which the floodlights and speakers are recessed. This integrated solution made for a neat and tidy soffit, free of clutter, with easy and convenient access for maintenance from the rooftop walkway.

Elegance is married with practicality, and both improved.

Fire and safety

Stadia are complicated buildings and do not always lend themselves to solutions based on prescriptive codes. In this Stadium the fire and safety aspects were developed in fire engineering terms in contrast to prescriptive codes. Fire engineering aims for high safety standards, and simultaneously to facilitate design innovation and limit costs.

No credible fire scenario would result in total building evacuation, so the Stadium construction was exploited and areas of fire risk separated so that, in many scenarios, stand occupants would not be immediately evacuated.

An excellent example of the lateral approach arose in the design of the concourse concessions. These areas not only form one of the most significant fire hazards in the building but their location could impact on the stand escape routes.

Awards

British Construction Industry BCI Major Project Award 2002:
High Commendation

Manchester Civic Society Renaissance Award 2002:
Joint Winner

City Life Awards 2002:
Building of the Year

Institution of Civil Engineers 2003:
North West Merit Award

Institution of Structural Engineers Structural Awards 2003:
Structural Special Award

The standard solution is to suppress fire with sprinklers, and either extract smoke directly or allow it to enter the concourse area and extract from there at high level. The Manchester architectural concept was to maintain a clean soffit on the concourses, which ruled out concourse smoke extraction. Direct smoke extraction from the concessions was difficult, as it required large dedicated smoke extractor fans and fire-rated ductwork. Sprinklers were considered undesirable because of the cost and design complications. Faced with protecting the escape routes whilst keeping the architectural design intent, Arup Fire looked for an alternative solution.

The concept developed was the 'sweeper system'. Each concession unit has a double fire-rated roller shutter assembly with the inner (concession side) shutter reaching the floor and the outer (concourse side) shutter stopping short of the floor. An extractor duct connected at high level into the void between the shutters creates negative pressure and ensures that any smoke escaping through the concession shutter does not enter the public domain. 'Cool' concourse air is mixed with the smoke/heat to reduce the extract air temperature, and the smoke extract ducts are connected into the general toilet extract systems. The duct system did not have to be fire-rated, as calculations showed smoke temperatures to be sufficiently diluted by the ambient air drawn from the concourse.

With the aid of computer modelling, the fire engineered approach demonstrated to the statutory authorities that the Stadium is safe. At the same time, costs (both capital and lifetime) were reduced and design aspirations realized.

Structural fin cladding

A final, and fairly simple, innovation developed as a modernization of the standard composite panelling systems used on buildings throughout the world. Panels are usually formed from fabricated layers providing weatherproofing and insulation which are connected on mullions and transoms to create the complete panel, which in turn is hung on a structural framework. Again Arup went back to first principles and looked at extruding aluminium mullions into structural fins that would combine the tasks of fixing panels and being the framework.

This relatively simple invention contributed in several ways to the scheme development. Not only did the idea save money but it also gave an extra dimension of detail by producing relief lines to increase the interest on the façade.

CONCLUSION

These key innovations contributed to the Stadium's success and ensured not only its stature as an architectural landmark building for Manchester and the UK, but also its lead in integrating technology and architecture.

The City of Manchester Stadium story evolved over more than a decade of commitment and co-operation between the public and private sectors. The XVII Commonwealth Games was universally deemed a huge success, and that it coincided with HM The Queen's Golden Jubilee added an extra shine to a very successful event. The re-opening of the Stadium for football is scheduled for mid-August 2003.

Reference

(1) BURROWS, S, *et al*. The Nynex Arena, Manchester. *The Arup Journal, 36*(1), pp38-43, 1/1996.

Credits

Client:
Manchester City Council

Design team:
Arup and Arup Associates Carolina Aivars, Martin Austin, Michael Beaven, Angela Bennett, Jane Bennison, Polly Bentham, Helen Bladen, Gavin Blakemore, Mark Boyle, Tony Broomhead, Peter Brown, Mike Buckingham, Peter Budd, James Burland, Stephen Burrows, Peter Caller, Graham Campbell, Tristram Carfrae, Eddie Carmichael, Glen Carney, Richard Carroll, Jonothan Carver, Steven Clarke, Pat Clowry, Adrian Collings, Jane Collins, Kevin Connaughton, Peter Connell, Chris Cowell, Colin Curtis, Russell Cutts, Theo Devaney, Mike Devriendt, Anthony Dolan, John Edgar, Jeremy Edwards, Julie Ellis, Paul Entwistle, David Ferguson, Frank Ghaidan, Russell Grayson, Enamul Haque, Ben Hargreaves, Dennis Harrison, Peter Hartigan, Rob Hartshorne, Paul Holder, Rick Houghton, John House, Alastair Hughes, David Hughes, Paul Hughes, Ian Humphreys, Naushad Islam, Andrew Jefferson, David Johnson, Rich Johnson, Lindsay Johnston, Oliver Jones, Lee Jordan, Ulkem Karaca-Buckley, Mike King, Chris Lambell, Chris Lantsbury, Andrew Law, Simon Lay, Tim Leadbetter, James Leahy, Anna Liu, Peter Llewellyn, Carl Lowe, Charles MacDonald, Caroline Marklew, Mike Marr, Teresa Marshall, Dave Maunder, Sean Macintosh, Luke McAdam, Patrick McCafferty, Fergus McCormick, Vivien McCullough, John McDonald, Peter McDowell, Brian McLoney, Roger Milburn, John E Miles, Cathy Milligan, Mark Moppett, Richard Morris, Paul Murphy, Phyginia Okoli, Donie O'Loughlin, Tsuyoshi Oya, Darren Paine, Ajay Parag, Richard Partridge, Raj Patel, Dipesh Patel, Steven Pearson, Neil Phipps, Rachel Pickford, Roger Pickwick, Duncan Platt, Adrian Popplewell, Judith Quinn, Terry Raggett, Reuben Ramelize, Stuart Redgard, Roland Reinardy, Marcel Ridyard, John T Roberts, Craig Robinson, Jon Sandford, Mark Scull, Stephen Setford, Gopi Shanmuganathan, Martin Simpson, Ben Slee, Caroline Sohie, Dave Spencer, Charles Stanton, Alexandra Stevens, Callum Stewart, Anthony Sumner, Craig Taylor, Jeffrey Teerlinck, Patricia Thorpe, Michael Tite, David Twiss, Eugene Uys, John Waite, Lisa Walker, James Ward, Trevor Wheatley, Gary White, Brian Wilcox, Tanis Williams, Darren Willis, Michelle Wilson, Michael Wilton, Joanne Wolbers, Colin Wood, Andrew Woodhouse, Jason Yi, Keith York

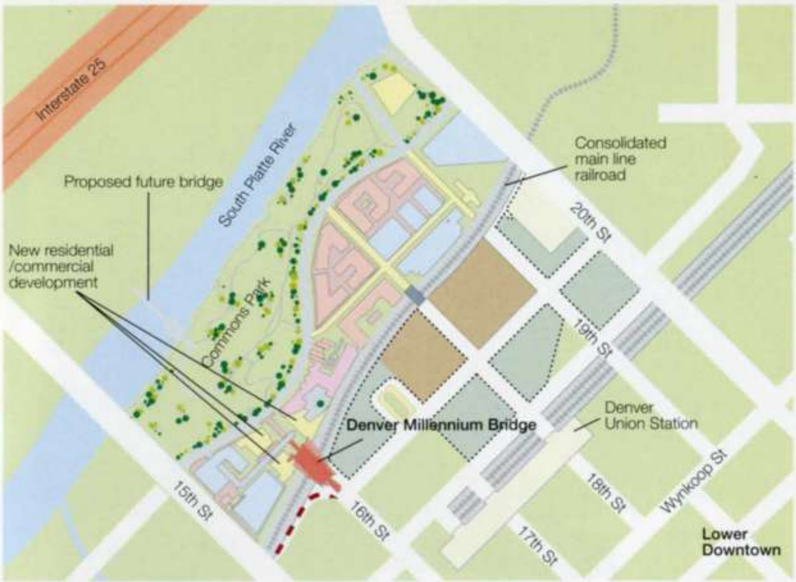
Design team collaborators:
AMEC Developments Ltd
Gillespies
HOK / Lobb Sports Architecture
KSS Sports and Leisure Design
Manchester Engineering Design Consultancy
Sinclair Knight Merz
Sports Turf Research Institute
Davis Langdon & Everest
Poole Stokes & Wood Partnership

Main contractor:
Laing Construction Ltd
Steelwork subcontractor:
Watson Steel Ltd
Illustrations:
1, 8, 12, 13, 15-17: ©Dennis Gilbert/VIEW
2, 3-6, 7a-b, 9-11,14: Arup Associates
18: Caroline Sohie
19: Dipesh Patel
20: ©Grant Smith/VIEW

20. The Stadium in athletics configuration, ready for the XVII Commonwealth Games.

Denver Millennium Bridge

John Eddy Steve Kite



1. Location plan.

Introduction

16th Street, Denver, Colorado, is a pedestrian mall, originally designed by IM Pei in the city's Lower Downtown (LoDo) district. Pedestrian connectivity to development parcels and existing neighbourhoods west downtown created a strong desire by developers and the city to extend the mall across the Platte River Valley to Commons Park, and this extension required a major obstacle to be overcome: the consolidated main line railroad tracks and corridor for the future Regional Transportation District (RTD) light rail system.

To celebrate overcoming this barrier, a landmark pedestrian structure to bridge the 130ft (40m) was conceived, and to maintain the 'mall quality' of 16th Street, this new Denver Millennium Bridge was designed with a varying deck width of roughly 80ft (24m). No mere point-to-point crossing, it is a central marker and icon for the new residential and commercial development where it is situated, and indeed for the whole city.

Arup and ArchitectureDenver worked very closely with the City and County of Denver and East West Partners to arrive at a design that realised their desires, and continued to work with the Central Platte Valley Metropolitan District to provide a scheme that was robust and buildable. Working to an extremely short design timetable (to complete the bridge concurrently with the surrounding buildings), construction documents were produced within six months of starting the project and issued in August 2000.

Minimizing the vertical pedestrian movements, with minimum structural depth below the walking surface, and the desire to provide a major sculptural element, all led the designers to a single-mast, cable-stayed structural solution.

'Arup's contribution to the Denver Millennium Bridge project ensured the provision of a scheme which was both robust and buildable.'

2 above: Architect's concept, viewed from the city and 3 right: viewed from the park.

Bridge description

The main feature is the 200ft (61m) high, tapered, tubular steel mast, located on the city side of the Bridge to one side of the 16th Street thoroughfare, and inclined towards the city and away from the centreline of the street. Steel deck members are suspended on 20 cables, 65mm in diameter, connected to the top part of the mast, whilst five 110mm diameter back-stay cables anchor it to the ground. The back-stay anchors are located along a circular arc defined by a concrete berm protecting people from the nearby light rail lines, and the resulting twist in the back-stays creates a distinctive aesthetic appearance for the structure.

The deck is raised 25ft (7.5m) above the surrounding ground level so as to cross the railroads, with staircases and bicycle ramps providing the primary access from both the city side and the park side. Access to the bridge is also provided by glass-enclosed elevators at both ends, connected to the bridge via walkways with wooden decking.

The steel deck members are laid to form a grillage, longitudinally forming a fan shape with transverse members spanning between the fingers of the fan and aligning with the railroad tracks below. On the walking surface of the deck this grillage is topped with a sealed concrete 'carpet' - as it is described by ArchitectureDenver. The 'carpet' intentionally does not completely cover the full width, but leaves the outermost primary girders exposed on each side of the bridge. Large planters, benches, and other urban features help to enforce the sense of destination for the people of Denver on this 'floating piazza'. Sculpted connection sockets, where the cables terminate on the deck and at the back-stays, further add to users' visual and tactile pleasure.

4. Side view from the north, showing the bridge crossing the consolidated main line railroad tracks.

Design

The design team used detailed 3D modelling in MicroStation to study the relative positioning of the mast, cables, and deck within the site constraints. This led to a very tall mast to make the most efficient use of the cables for strength and stiffness.

Both linear and non-linear analyses were performed to account for the effects of the construction sequence as well as the behaviour of the completed structure.

Bored piles of 36in (900mm) and 60in (1500mm) diameter and up to 62ft (19m) long were used to carry both tension and compression forces, with narrow ground beams linking back-stay and abutment pile caps to counter the lateral loads on each pile group. The pin-ended steel mast tapers from 18in (450mm) diameter at the top to 7ft (2.1m) at the centre, and back to 42in (1m) at the base to provide the necessary resistance to buckling. The wall thickness is a constant 1.25in (32mm) with internal ring stiffeners at the cable connection points.

Optimizing the cable tensions to balance the deck forces was a huge analytical task. The nature of the structure led to extremely complex interactions between all the cables, with no direct solution possible. The aim was to maximize the use of the bending capacity of the deck by stressing the cables against it, which would position the bending moment range to make the best use of the hogging and sagging deck capacities at different stages of construction and under different loading cases. Each cable also had to account for a 10% force variation to give the contractor some tolerance.

The geometry of the connection details made the design and fabrication of these elements quite complex. A combination of stiffeners and increased plate thickness was used to ensure that loads could be transferred appropriately.

5 above: Architect's model, showing the width of the deck.

6 right: The width of the deck gives the impression more of an open space than a bridge.

7. Detail of cable termination.

Construction

Components were fabricated in many locations: the mast by Mississippi Tank in Hattiesburg, Mississippi, the mast bearing by Cosmec, Walpole, Massachusetts, and the deck structural steel by Colorado Bridge and Iron, Grand Junction, Colorado. The cables came from Wire Rope Industries, Montreal, Canada, and the cable terminations from Texas Steel, Fort Worth, Texas.

Erection sequence

One of the most challenging aspects of the Bridge was the erection sequence. The main girders were placed over the railroad on a line of temporary supports at mid-span, and the secondary supporting beams were then attached. Once the deck members were in place, the mast - shipped to site in one piece from the fabricator - was erected and the deck cables connected. With the mast tilted forwards from its final position, the deck cables were attached to the deck fin plates, already cut and adjusted to the desired lengths. The five back-stay cables were then jacked backwards one at a time, moving the mast into its final position. Nine separate jacking operations were required to achieve the correct force in each cable without overstressing any component of the bridge in the process.

At each stage the deck cable forces were monitored and minor adjustments made to ensure they were on target to achieve the correct final forces. Finally the metal decking was placed and the 6.5in (165mm) thick lightweight concrete deck poured.

Opening

The local press followed the construction with interest as the Bridge took shape, and turned out in force for the opening ceremony. Denver's Mayor Wellington Webb presided over the ceremony on 22 April 2002.

Awards

New York Association of Consulting Engineers 2003:
Engineering Excellence Gold Award

American Institute of Architects Denver Chapter:
Urban Design Award 2002

8. The bridge viewed from the city.

Credits

Client:
Central Platte Valley Metropolitan District

Architect:
ArchitectureDenver

Civil and structural engineers:
Arup Ignacio Barandiaran, John Beckwith-Smith, John Eddy, David Farnsworth, Steve Kite, Tsuyoshi Kobayashi, Lynn Pang, Richard Prust, Mark Roche, Ian Schmellick, David Scott, Darren Sri-Tharan, Paul Summers, Chris Taylor, Craig Wiggins

Main contractor:
Edward Kraemer & Sons

Illustrations:
1: Sean McDermott
2, 3, 5: ArchitectureDenver
4, 6-8: Frank Ooms

Engineering Marsyas at Tate Modern

Cecil Balmond   Chris Carroll   Brian Forster   Tristan Simmonds

How it all began

Each year since opening in 2000, the Tate Modern[1] gallery in London has commissioned an installation sponsored by Unilever for the Turbine Hall, a vast interior space over eight storeys high and 150m long. In January 2002 the Tate approached the Turner Prize-winning sculptor Anish Kapoor to undertake the third in the installation series. The brief was entirely open, the only constraints being budget and that the work had to be completed by 8 October 2002, less than nine months from commission to unveiling.

Kapoor, aware of the work that Cecil Balmond and Arup's newly-formed Advanced Geometry Unit were doing with such architects as Toyo Ito, Daniel Libeskind, and Shigeru Ban, arranged a preliminary meeting in late February 2002. At this time the artist was still wrestling with the immensity of the Turbine Hall as an art space. His predecessors, Louise Bourgeois and Juan Munoz, had elected to use only the eastern end, but Kapoor concluded that 'to tackle the verticality of the space one has to paradoxically take on its entire length'.

The offer was thus open for Arup to collaborate on a very special project. From the outset it posed huge challenges to both artist and engineers, but given the nature of Kapoor's organic curved forms and the sheer scale of the Turbine Hall, it was an offer the Arup Unit could not refuse, and they threw themselves into designing and delivering a piece of work that broke boundaries between architecture, art, and engineering.

Developing the concept

Arup explored many ideas (Fig 1) with Kapoor, ranging from a solid bean-like form that cantilevered outwards from the central mezzanine bridge, to a mirrored form stretching from one end of the Hall to the other, to the final choice of a complex membrane shape stretched between three steel rings. Within these primary concepts many sub-ideas were explored, such as the effect of air inflation, and of hydrostatic pressure created via the use of tonnes of polystyrene beads. Many material options were examined including plywood, PVC, expanded metal mesh, aluminium, GRP, and glass cloth laminated with metal films.

It was essential to developing the work that these ideas could be explored and visualized effectively and rapidly. A clear methodology was required. Complex 3D analytical models were built using software such as the in house, non-linear, form-finding program Fabwin, which was reprogrammed specifically for the project to help create the highly curved organic forms desired by Kapoor. The geometry of tensile membrane structures is based on that of a soap film stretched between boundaries, with the software simulating the behaviour of a natural soap film. Through the reprogramming the Arup team was able to push the form way beyond the soap film envelope of normal membrane structures and into new engineering territory.


a. Ellipse


b. Stretch


c. Peanut


d. Steel


e. Cleft


f. Double

1a-f. Some ideas explored during scheme development.

It was also apparent from the start that communicating the design ideas was paramount to the project's success, and so to visualize the forms as they developed, wax prototypes were built using the team's Thermojet printer (Fig 3). Thus complex geometry, not easily conveyed through conventional two-dimensional drawings, could be examined and more easily understood by Kapoor and the Arup team.

Finally, to demonstrate what the various forms would look like within the Turbine Hall space, Arup developed a '*Realtime*' virtual reality engine (see panel on right) using the latest 3D gaming technology. Models developed initially using analysis software were transferred directly into a virtual Turbine Hall, allowing Kapoor to 'walk' around the piece at his leisure using 3D glasses. Thus colour, texture, and lighting, as well as form, could be studied in detail. (The *Realtime* system proved such a useful and intuitive tool that it is currently being developed for use throughout Arup for all types of design projects.)

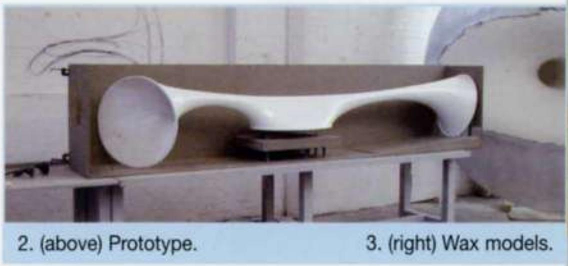
Using an iterative process of analysis, prototyping, and virtual reality, plus scale models from Kapoor's studio, the artist and engineers arrived at an optimum form.

The final design

After three intense months of developing and refining ideas, the team arrived at a final concept and outline geometry. In essence this was a membrane stretched the entire length of the Turbine Hall and anchored at each end to massive 30m diameter steel rings in turn anchored and propped by the fabric of the Hall itself. In the centre, hanging 2.5m above the central bridge, was to be a third steel ring, its weight and shape being used to contort the membrane and give more scope for defining the overall form (Fig 4). Removable panels were detailed into the central ring so that sand bags could be added for further ballast and to allow horizontal tuning of the ring's final position.

Engineering the membrane

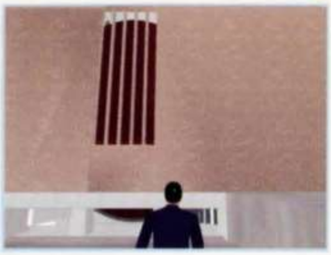
Simply speaking, FABWIN treated the membrane surface as a net of node points connected by triangles. Each triangle tried to pull on its three corner nodes with a constant force (prestress), which in turn moved the nodes. This iterative process was carried out for every triangle and every node many hundreds - even thousands - of times until each node stopped moving because it was being pulled equally in all directions. Because the triangles pulled with the same amount in all directions, similar to a soap film, the resulting surface developed an equal amount of curvature in all directions. By varying the amount and direction of prestress within specific parts of the surface, the curvatures could be precisely tailored to create the forms desired by Kapoor, resulting in the dramatically long drawn-out 'backbone', 'necks', and steeply curved funnels of the final sculpture (Fig 5).


2. (above) Prototype.


3. (right) Wax models.

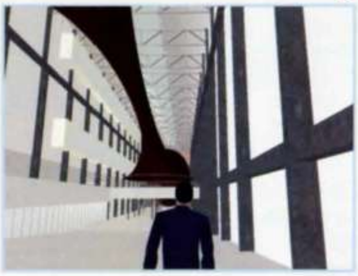
Arup *Realtime*

a.



a-d Frames from the Marsyas *Realtime* 'walk through' sequence.

b.



Realtime is a novel capability being developed by Arup to allow non-3D specialists to visualize, interact, and evaluate 3D models of proposed designs or 3D worlds in real time, in an easy, intuitive way on current Arup specification hardware and without the need for expensive visualization or CAD software.

In the collaboration with Anish Kapoor on Marsyas, the novel technique allowed the artist and design team to quickly and effectively visualize and evaluate the complex sculptural forms being developed on a nearly daily basis. Moreover, it allowed them to 'experience' the proposed designs in the context of their final surroundings.

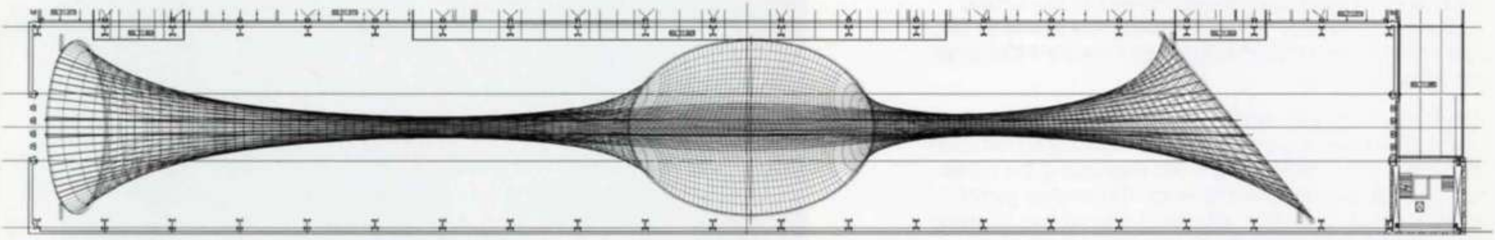
A 3D model of the Turbine Hall was created in AutoCAD from existing 2D CAD drawings and subsequently imported into 3D *Studio Max* for a basic makeover of textures to match the real building. The iterative process involved:
(1) importing sculptural forms created in *Rhino* or *Form-found* in Fabwin/GSA into the Turbine Hall 3D model;
(2) exporting the *Max* scene to the *Realtime* engine;
(3) running the 'walk through' to assess the design in an accurate and realistic setting.

Realtime uses cutting-edge 3D graphics technology developed by the computer games industry, allowing the navigation and interaction of large, high polygon count, 3D worlds in real time requiring only a standard specification PC with a £100 ($/euro150) worth of 3D graphics card. Also, *Realtime* software and the 3D world files can be burned onto a CD and distributed to internal and external parties without the risk of 3D design content being copied or edited.

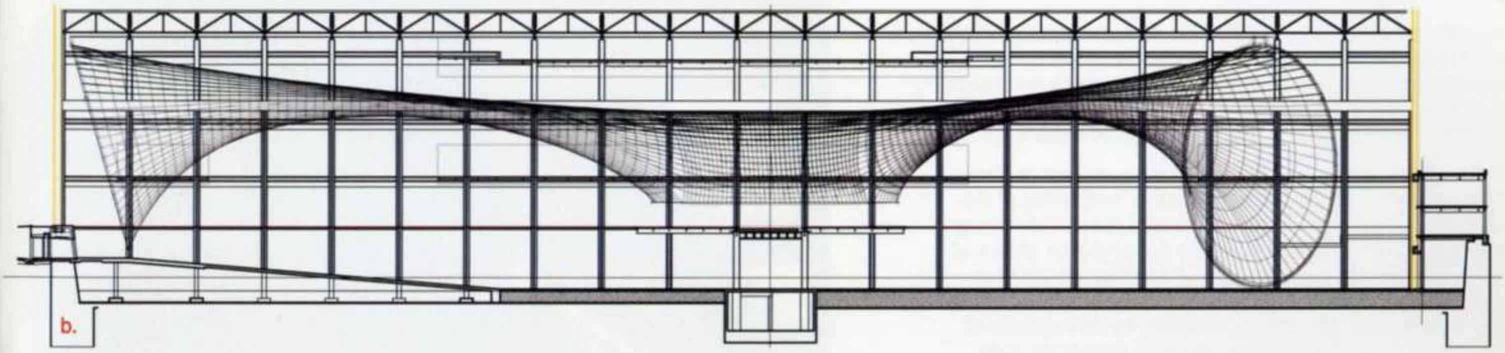
The *Realtime* development project, now funded by Arup's Innovation Fund, is currently under way to provide *Realtime* technology and services to the rest of Arup as well as external clients.

c.

d.



a.

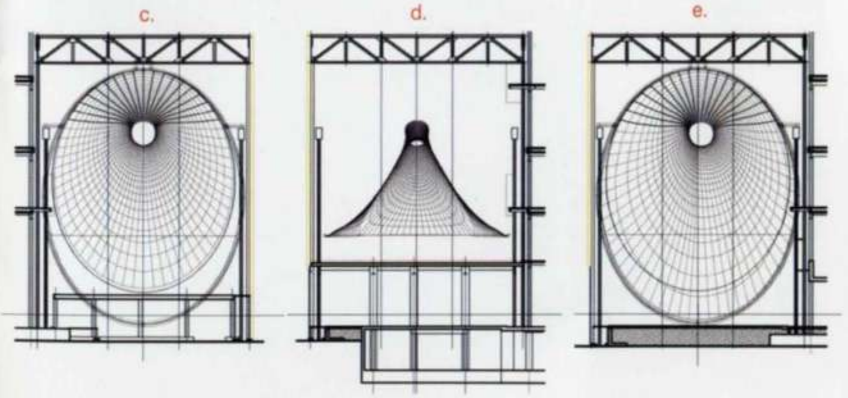


b.

c.

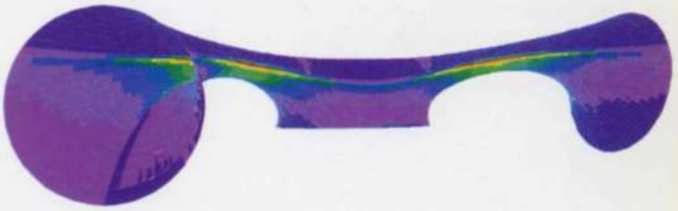
d.

e.



4 Plan (a), elevation (b), and west end, central, and east end sections (c-e) of the final design within the Turbine Hall.

5. FABWIN stress plot.

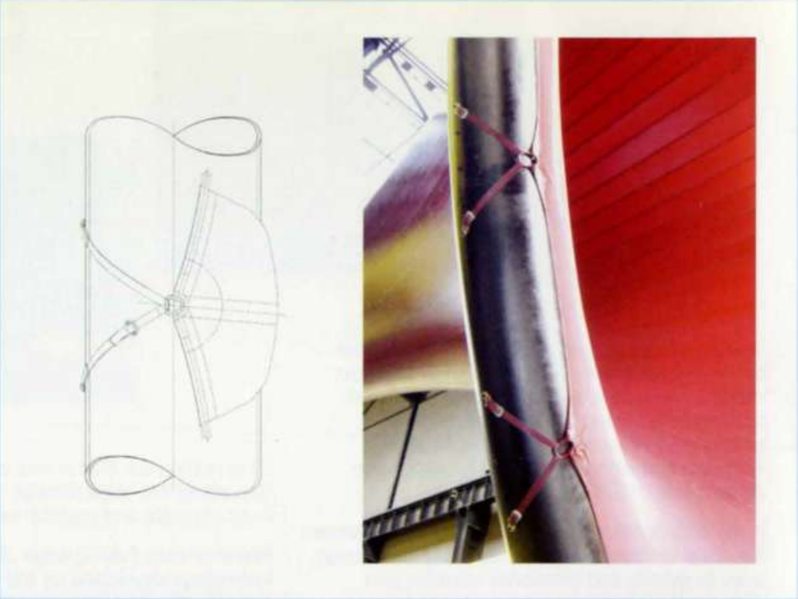


When the real fabric structure was eventually cut from panels of fabric, prestress was added by cutting each panel too small, essentially shrinking the membrane so that when it stretched to its correct shape it had the correct prestress and remained stable and taut. The enormous 140m span, combined with the particularly shallow catenary and narrowness of the sculpture's 'back', resulted in extremely large membrane prestresses along the top of the structure. To limit the potential for wrinkling between adjacent fabric panels that this large prestress range could cause, 19 high strength polyester belts were introduced along the back of the structure to help share the load.

PVC-coated polyester membrane was the natural choice of material because of its strength, robustness, cost, and ability to be coloured to the artist's particular requirements. The form's extreme shape meant that the material's behaviour had to be predicted as accurately as possible. This led to the selection of a specific 1.8m wide PVC Type II fabric manufactured in France, woven and coated under tension, to provide consistent and predictable properties. Some 5km of it were needed.

Connection details were integral to the process of introducing prestress into the membrane - and had to be aesthetically acceptable to the artist.

Details able to deal with the tolerances of working over such a large span, and with an ever-changing angle of incidence with the steel rings, were developed in conjunction with Kapoor and the membrane contractor. The splayed belt detail that emerged minimized the use of metal parts and maximized the flexibility to allow for standardization across all connections (Fig 6).



6. Membrane connection details.

The steel support structure

A particular ambition for this structure - the two end rings and their connection into the existing building - was that it effectively became part of the building fabric. With its 'language' of simple industrial components, the membrane form had to appear wedged or jammed into the Turbine Hall. Aside from these artistic ambitions, the steelwork also had to resist very large tension forces from the 140m span membrane structure.

The final solution was simple, utilising as much of the existing building structure as possible and so reducing construction costs, but much work was put into engineering the details to be unobtrusive and easy to erect. The existing gantry crane support structure (designed to support two 50 tonne cranes) was clearly a candidate to support some of the loads that would be generated via the tension membrane both vertically and horizontally.

As built, each end ring is of 508mm diameter circular hollow sections (CHS) that span effectively between five points, transferring all the tension applied by the membrane structure to these points primarily via bending, with some torsion due to the eccentricity of the membrane support system.

In turn these five points are resisted via compression struts spanning between the similar five points on the ring at the other end of the Hall. At three of the five points the existing building provided these struts - the two crane rail girders at each side and the concrete slab at the base. At the other two points, two lines of 168mm CHS were inserted into the plane of the roof. Despite compression loads in excess of 15 tonnes in each of the lines, relatively slender sections could be used as they are designed to be restrained by the existing trussed roof structure against buckling.

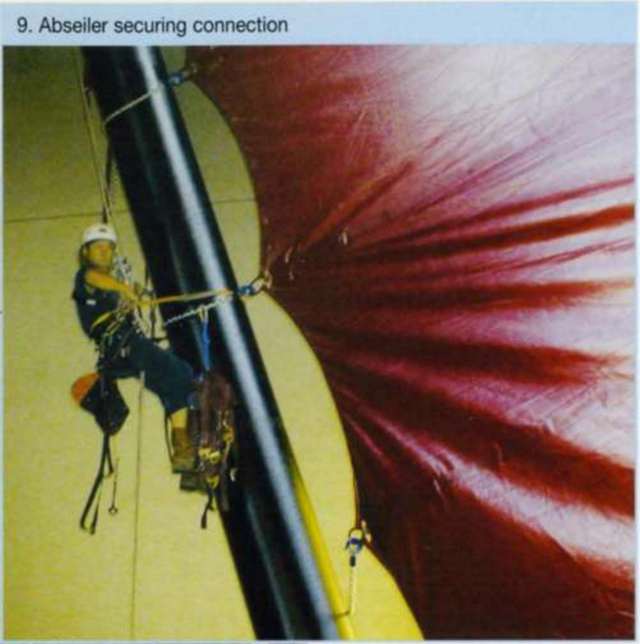
The self-weight vertical load of the membrane and the steel itself - some 45 tonnes - is resisted by only the support points attached to the crane rail girders, thus avoiding overstress of the existing Turbine Hall floor slabs.

The steel rings were designed in transportable sections and bolted together on site using internal end plates. As well as allowing for easier erection, the bolted connections also enable the sculpture to be de-installed - an integral part of the design requirements.

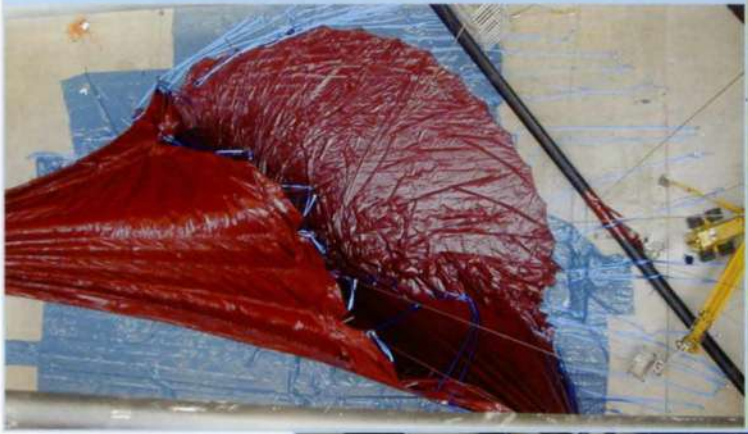
7. Commencing erection of east steel ring.

8. Raising membrane at east end.

9. Abseiler securing connection



10. Membrane at east end viewed from above prior to erection.



11. Fabric at east end.

12. Membrane prior to stretching around central ring.

13. Membrane close to final position.

'It is jammed into the building so as to not allow anything but a partial view. The work must retain its mystery and never reveal its plan': Anish Kapoor

Fabrication

Arup advised the Tate to make a direct appointment with the specialist contractor Hightex because of the shortage of time. A price was agreed very promptly and Hightex became an integral part of the team. There was full co-operation and the team did everything necessary to make the project happen. Hightex employed a sub-contractor, Tensys, in Bath, to produce the cutting patterns for the membrane - bringing to bear their own considerable skills to solve some tricky issues. In retrospect that was an important decision. After Arup had finalized the surface form, the 3D geometry data was sent to Tensys. Their complex digital process involved slicing the form into panels, shrinking them according to prestress, and finally squashing them flat so that they could be cut from lengths of fabric off the roll. The patterns were then sent to for printing at full size in Belgium prior to arriving at the workshop in Hungary for fabrication by Hightex. Here the panels were cut and welded together along seam lines, using a high frequency welding technique - somewhat like tailoring but on a giant scale.

The final arrangement of panels and seams attempts to balance the aesthetic need for the sculpture to be a monolithic piece, with seam lines flowing unbroken along the entire length, with the practical constraints of the 1.8m roll width and the difficulties in manhandling and guaranteeing the workmanship on such a large piece of material.

The resulting seam arrangement allowed the monolithic piece to be fabricated initially in three sections and then joined, producing the 'petal' effect seen at each end of the suspended ring (Figs 14 & 15).

The steel rings were curved to their required radii via a process called induction bending. CHS sections are passed through an electric induction coil that generates an area of very local high heat (about 50mm wide) via electrical currents induced through the coil's powerful magnetic field. The steel sections are clamped at their leading end to a pivoted radius arm that is adjusted to controlled radii, centimetre by centimetre, until the required geometry is achieved. Once bent to the correct radii, the six segments of each ring were cut to length and end plates were cut out, drilled and welded in place. All the ring connections were trial-assembled in the fabricator's yard to ensure perfect fit-up before delivery to site.

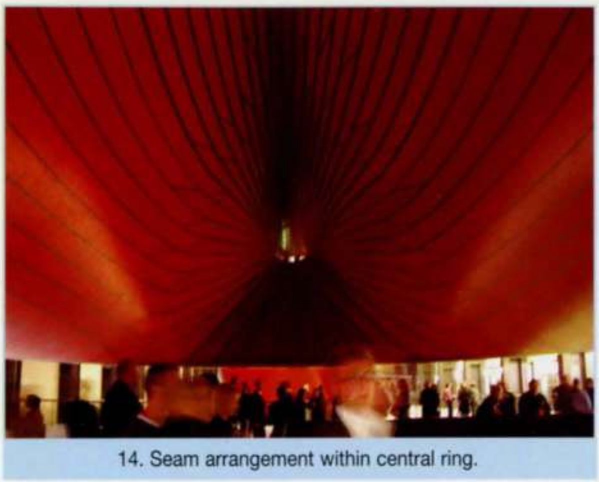
Given the tight programme a just-in-time fabrication schedule was adopted. As the first pieces were delivered to site for assembly, the final pieces of the central ring were leaving the induction bending works for fabrication. Simultaneously the final seams were being welded on the membrane prior to crating up for transportation from Hungary.

Installation

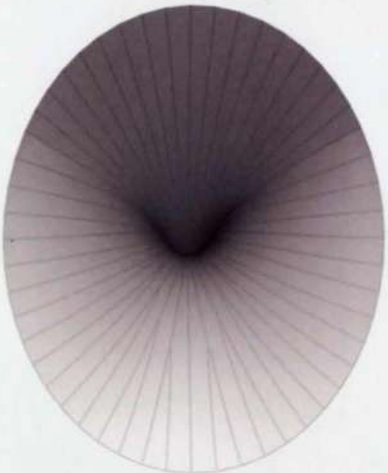
To meet the opening date deadline and to minimize disruption to the operation of Tate Modern, less than a month was available for the complete installation. The entire Turbine Hall was closed to the public for the installation period.

With only two weeks programmed for the steelwork erection, followed by a further two weeks to install the membrane, meeting the launch party deadline proved to be a real race against the clock. For Tate Modern late delivery was not an option: invitations had already been sent out, champagne and canapés ordered, airline tickets paid for. Sheer dedicated hard work from everyone involved delivered the project on time. The whole team bought into an effective 'no-blame' culture, where instant problem-solving and a co-ordinated team response enabled effective trouble-shooting of any hitches during erection.

Given this commitment, the team finished a 'comfortable' two hours before the first guest arrived!

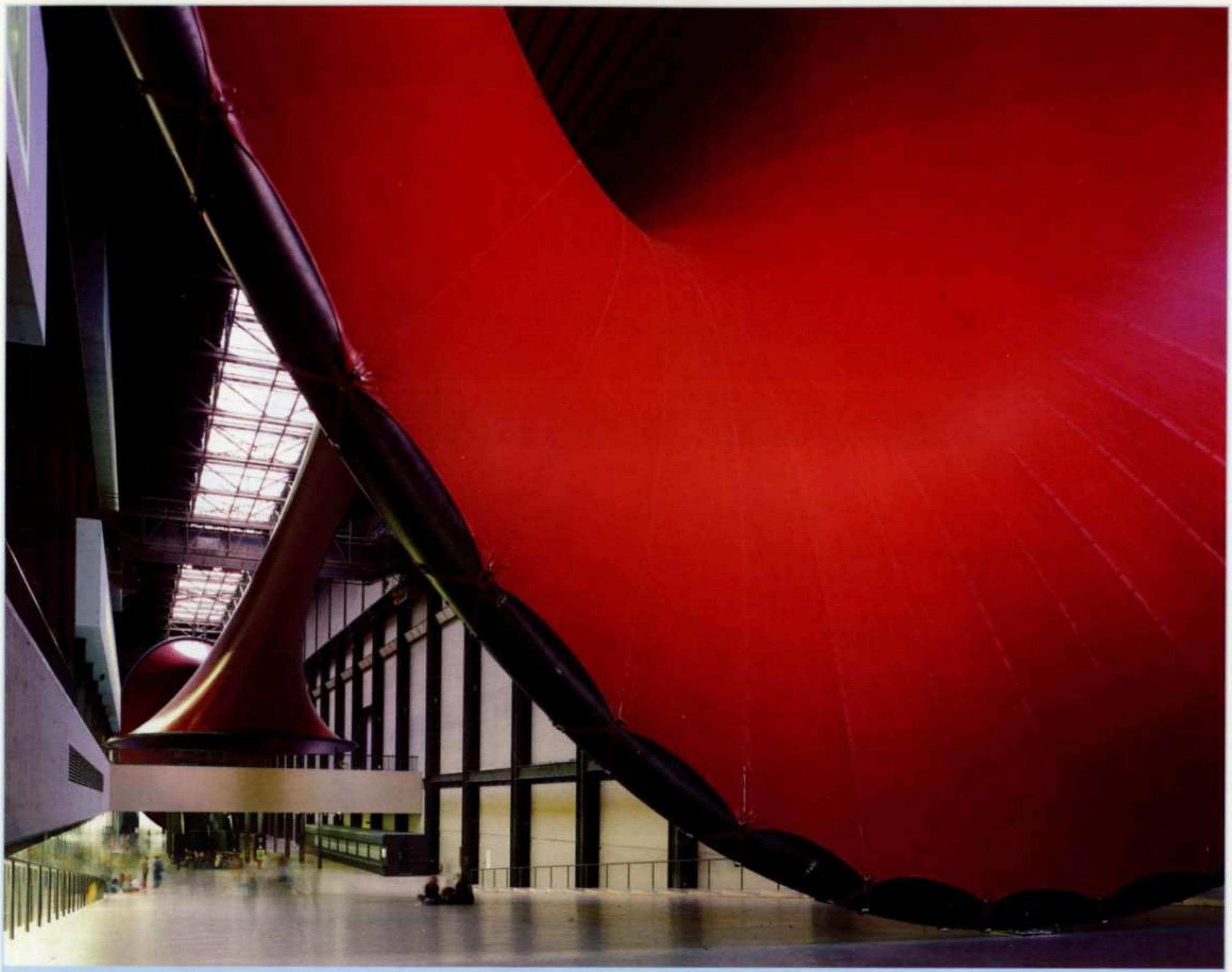


14. Seam arrangement within central ring.



15. Seam arrangement at west end.

16: Marsyas complete, the west end viewed from the central bridge.



17. Marsyas complete, viewed from the east end of the Turbine Hall.

Project facts

- Fabric membrane: PVC-coated polyester woven type 2 fabric, manufactured and coloured in France
- Fabric colour: unique and specially developed for Marsyas
- Fabric area: approximately 3500m^2
- Structural span: approximately 140m
- Form fabrication: from precisely derived patterns seamed together in Hungary
- Maximum fabric tension: approximately 1.5 tonnes/m
- Total length of fabric strip: approximately 3km
- Steel ring construction: induction-bent 508mm diameter circular hollow sections
- Quantity of steel: approximately 50 tonnes
- Fabrication duration: approximately 10 weeks
- Installation duration: four weeks
- The installation's title is from Greek mythology: Marsyas was a satyr who, having lost a musical contest with Apollo, was flayed alive by the god.

Conclusion

Marsyas showed what can be achieved when a collection of bright, imaginative, and enthusiastic people are brought together and given the opportunity to create something special. Already the Tate has published a superbly illustrated book about the design, construction, and installation of Marsyas[2], and two films have been made. One, focusing primarily on Anish Kapoor, was produced by Illuminations for BBC4's EYE series, whilst 'Engineering Marsyas' was made for Arup by Steph Harris.

For further information on Thermojet 3D prototyping, contact Martin Self (+44 (0)20 7755 2093; martin.self@arup.com), and on Arup *Realtime* virtual reality software and Arup Fabwin software contact Tristan Simmonds (+44 (0)20 7755 3543; tristan.simmonds@arup.com).

References

(1) HIRST, John, et al. Tate Modern. *The Arup Journal, 35*(3), pp3-11, 3/2000 (Millennium Issue 4).

(2) THE TATE. Anish Kapoor: Marsyas. Tate Gallery, 2003.

'To tackle the verticality of the space one has to paradoxically take on its entire length': Anish Kapoor

Credits

Client:
Tate Modern

Artist:
Anish Kapoor

Structural engineer:
Arup Cecil Balmond,
Chris Carroll, Brian Forster,
Ray Ingles, Sharon Nolan,
Martin Self, Tristan Simmonds,
Charles Walker

Membrane contractor:
Hightex

Patterning and compensation analysis:
Tensys

Steelwork fabricator:
SHStructures.

Illustrations:
1, 3-16: Arup
2: Studio Kapoor
17: Dennis Gilbert
©Arup/Dennis Gilbert/VIEW

Zayed International Cricket Stadium roof, Abu Dhabi

John Abbott   Linda Ness   Rui Rodrigues

Introduction

The roof structure of the new Zayed International Cricket Stadium near Mussafah, just outside the centre of Abu Dhabi, Arab United Emirates, was an exemplary fast-track structural steel project that brought together the skills of engineers and contractors from three continents.

The steelwork tender was keenly competitive, and the design-and-construct team that won the contract included Arup South Africa as structural engineers. The structure was designed to British Standards in South Africa, with specialist advice from Arup's London-based Advanced Technology Group. The steelwork was shop detailed in South Africa, procured internationally, fabricated in Dubai and Abu Dhabi, and erected by Malaysian-based specialist contractors.

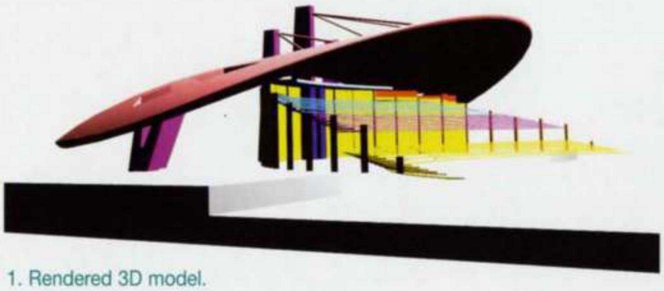
Generating the geometry

On the tender drawings the architectural concept was shown in outline as a crescent-shaped roof over the south stand. Unusually, the curve of the crescent opposes the curve of the stand, giving the appearance of the peak of a cricket cap suspended above it. The roof's free-flowing leading edge extends over the back of the stand to sculptured concrete abutments, the roof structure being tied back by hangers from three concrete masts, 30m and 40m high, behind the stadium (Fig 1).

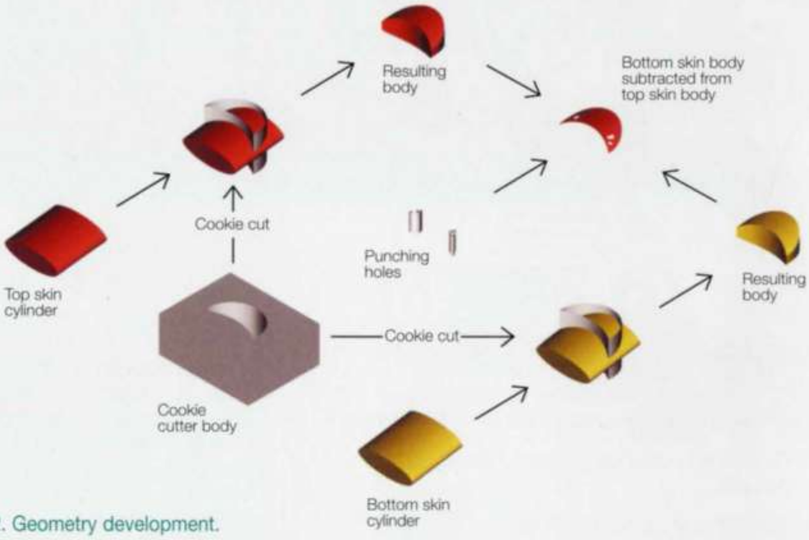
This concept had to be formalized into a defined geometry, and this was achieved by developing top and bottom surfaces that would allow a repetitive flat-panel composite aluminium cladding solution. To avoid bi-directional curvature, these surfaces are cylindrical, and also elliptical in section to achieve the required shading and stand clearance. Separate cylinders of different diameters and slants, defining the top and bottom 'skins' of the roof, went through a process of 'cookie cutting' to fit onto the given footprint. The resulting solid bodies were then subtracted from one another to form the roof body, which was then punched for holes near the ends (Fig 2).

A final CAD exercise filleted the leading edge with a pair of complementing radii to form the final shape. The resulting solid body of the cladding envelope was the basis for the structure's geometrical design, and was subsequently used at every stage by all parties. This electronic information trail extended from the GSA modelling to the cladding installation.

After considerable discussions with the steel contractor, and using the member sizes resulting from preliminary design GSA models, a set of rules was formulated for the structural skeleton offset and relative orientation from the cladding skins. A precise centreline model was then drawn in AutoCAD 3D, incorporating the structural members required for both a final full GSA analysis model and for importing into the shop detailing software. The shop detailing by Genrec using STRUCAD was awarded second prize internationally and first in Africa in a competition organized by the software suppliers.



1. Rendered 3D model.



2. Geometry development.

Structural arrangement

The primary structure comprises a grillage of full depth latticed trusses. A series of seven continuous trusses run parallel or near parallel, increasing in depth from the leading to trailing edges. The three central trusses are connected to the three concrete masts, as fixed end connections. Seven chunky tubular hangers fan out from the mast tops to pick up the overhanging roof shape.

These hangers were designed with 'in-line' pin bearings, hidden within the hanger tubes, to allow the hangers to hinge under conditions of wind uplift. They also have spiral strakes to prevent wind excitation.

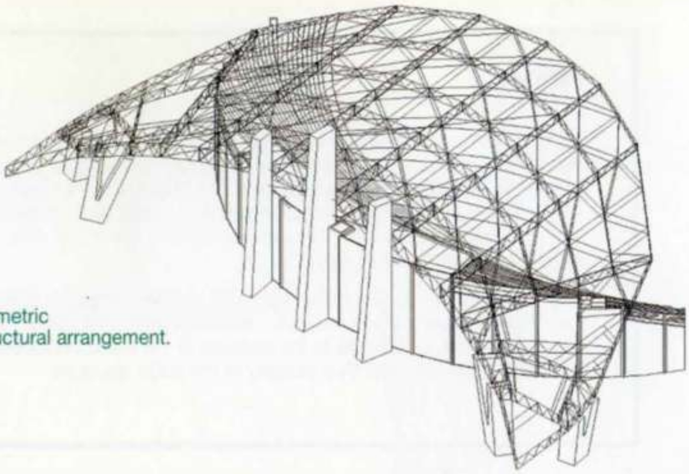
Six 'arch' latticed trusses span the canopy from end to end, forming a series of generally evenly spread lines emanating on plan from the canopy tips. Each truss is continuous over the full arch and the two outside arch trusses define the leading and trailing edges of the canopy. Four of these arch trusses merge to fix to two sculpted concrete abutments at each end, again with a condition of interface fixity.

A secondary grillage of diagonal bracing members covers the entire roof plate on both the upper and lower surfaces, forming a triangulated 'diamond net' of bracing. This ensures an interaction between the arching action over the curve of the canopy down to the abutments, and the support provided by the masts and mast hangers (Fig 3).

Fabrication and erection

Structural continuity, structural dead weight, and potential lack of fit all helped to define the final solution. This involved a limited series of temporary latticed prop towers, towering 30m above the field level at the leading edge, a single tower crane reaching over from the trailing edge, and a precisely monitored and systematic jacking procedure.

Working outwards in both directions from the centreline of symmetry, the prop towers were positioned to support the parallel trusses near splice points, which were bolted up in the air. The reach/capacity ratio of the cranes prohibited these trusses, 55m long at maximum, from being lifted in a single piece, but more importantly the prop towers all but eliminated dead weight deflection of the trusses, so holding the critical inter-connection points with arch trusses true in space (Fig 4).



3. Isometric of structural arrangement.

Once sufficient parallel trusses had been erected, the arch trusses were installed in single bay segments, again working out both ways from the centre. To minimize the cost of the temporary structure, there were less prop towers than required prop points, so a system of 'leap-frogging' the prop towers outwards was developed in close collaboration with the erection sub-contractors.

'The roof of the new Zayed International Cricket Stadium was a fast-track structural steel project that brought together the skills of engineers and contractors from three continents.'

4. Cladding in progress, closely behind erection of fhe steel.

5. One of the concrete abutments to the roof.

Nodes

By rationalizing the structure into a grillage of planar faceted trusses, the connection complexity was intentionally concentrated at the primary truss intersection nodes, where truss chords framed into a single node on the upper and lower surfaces. These nodes were finally detailed and checked in a 3D environment in close collaboration with the shop detailers and fabricators (Fig 6).

The result of this was a precise fabrication process adopted by the two independent fabricating companies, resolving quality and tolerance issues that were paramount to the success of the erection procedures, structural continuity, and thus integrity of the entire structure.


6. Truss intersection node.


7. The completed roof in position.

In addition, a series of sequential erection status GSA models was formulated to allow for an optimum procedure and to estimate the prop tower reactions and jacking down distances for their removal. The hangers were discretely propped from the canopy structure along their length to prevent a dead weight catenary uplift effect on the partially constructed grillage.

Conclusion

Commissioning the structure was epitomized by the single moment at the end of June 2002 when the design engineers and erection specialists stood on top of the vast semi-clad roof expanse and gave the 'thumbs up' for the final towers to be de-propped.

Project facts

- total seating capacity: 20 000
- number of seats shaded by roof: 9000
- roof dimensions: 140m tip-to-tip; 60m maximum width
- roof area: 7000m^2
- quantity of steel: 900 tonnes, mostly standard UB and UC sections
- design output: 5000 shop drawings from 15 initial design layouts and a 3D Autocad file
- construction time: from steelwork tender award to completion in 15 months, April 2001 to June 2002

Credits

Clients:
Abu Dhabi Cricket Council

Architect:
Godwin Austen Johnson

Engineers for stadium concrete works:
Maunsell Group
WH Hussein and Partners/LC Consulting

Design engineers for steel canopy:
Arup John Abbott, Andrew Allsop, Gaye D'Alton, Liz Du Plessis, Graham Gedge, Graeme MacKenzie, Linda Ness, Geoff Plant, Yolandi Pretorius, Rui Rodrigues, Radivoj Sendic, Alistair Usher

Project manager:
Mace International Ltd

Stadium main contractor:
Al Habtoor Murray & Roberts

Roof sub-contractor design-and-build:
Al Habtoor, Murray & Roberts, Genrec JV

Structural steelwork fabricators:
Al Habtoor Engineering Steel Workshop, Headline Engineering,

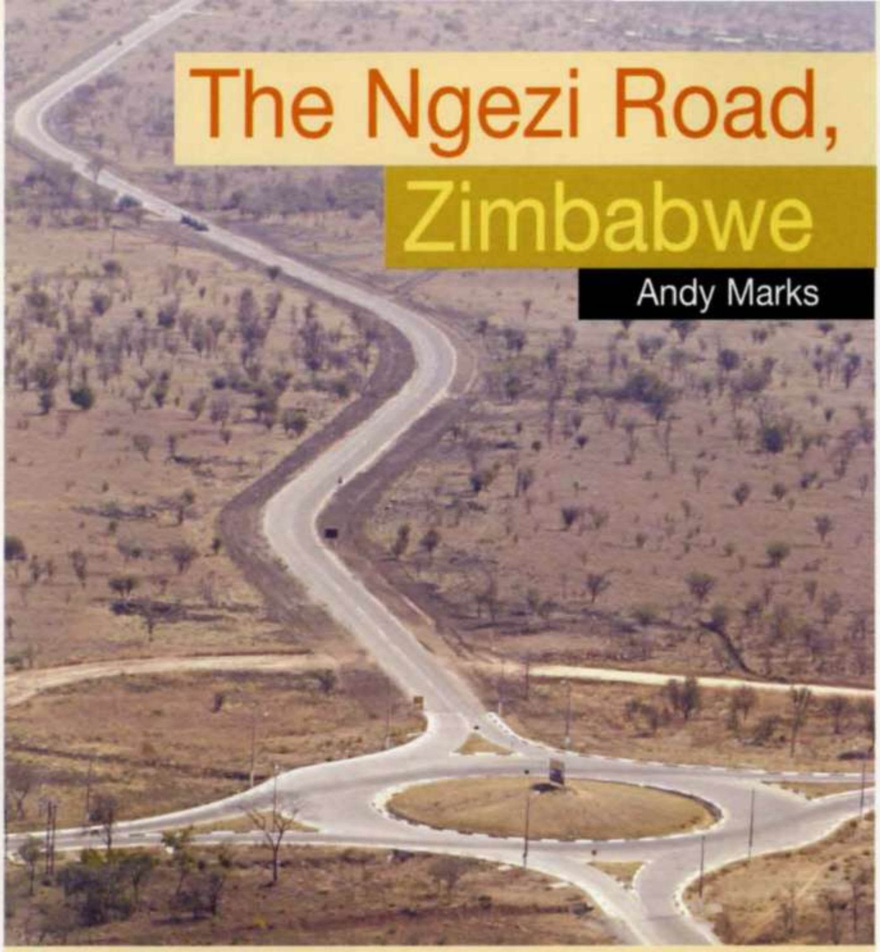
Steel erection sub-contractors:
Eversendai Engineering LLC

Cladding sub-contractors:
Arabian Profile Co Ltd, Sharjah, UAE

Illustrations:
1-3: Radivoj Sendic
4, 5, 7: John Abbott
6: Linda Ness

The Ngezi Road, Zimbabwe

Andy Marks



1. Final leg of the haul road from the Harare-Bulawayo roundabout over the Seruwe River Bridge to the Selous Metallurgical Complex (SMC).

Introduction

In 1999 Zimbabwe Platinum Mines (Zimplats) bought for a nominal value the Selous Metallurgical Complex (SMC) from another mining company which had been making a venture into Zimbabwe. Platinum mines and their complex metallurgical processing plants are normally next to each other, but in this case Zimplats' opencast mine was 77km south of SMC.

Thus began the search for the most cost-effective way to transport the ore from mine to processing plant. To meet this challenge, Arup initiated and was involved in pulling together much of Zimbabwe's construction industry in the unprecedented Ngezi Road Joint Venture. NRJV went on to design, refine, and innovate the first road train haul road in Zimbabwe, constructing the 77km with three major bridges in seven months.

Project creation

Arup's introduction to Zimplats came through the Environmental Impact Analysis of the Ngezi opencast platinum mine in January 1999[1]. The company was investigating how to transport the 2.2M tonnes of ore annually from the mine to SMC; it became clear that they saw the haul method as a major part of the development. Though their energies were primarily focused on mining, they also wanted the lowest capital and operating cost for transportation. Rail fulfilled the former, but had the highest operating cost, due to rolling stock. Crushing+pumping was considered, but road was finally selected as it could also double for the necessary access to the mine.

Another consultant had been asked to undertake a pre-feasibility study on a possible haul road, but Arup at its own risk, simultaneously undertook a scheme design and bill of quantities for a similar haul road. This was costed by contractors Tarphalt Paving and submitted to Zimplats as a lump sum design-and-build proposal.

Ngezi Road Joint Venture

Zimplats were impressed by Arup's proactive approach but wanted transparency and assurances on deliverability through an international tender. The haul road was more than half the total mine investment (US$35M), and would have a tight (seven-month) construction programme on the critical path.

This led to the formation of the NRJV with Zimbabwean contractors led by Costain and including Tarcon (Tarphalt Paving and GT Earthworks), Bitumen Construction, and Arup as consulting engineer. This was a large contract in lean times for Zimbabweans, and if successful would go a long way to sustaining the NRJV member companies and their subcontractors; the NRJV motto: 'formed to save the road construction industry' was coined.

Before tender documents were released further investigations were made, mainly into the naturally occurring gravels that formed the bulk of the road costs. This plus local knowledge gave an edge over NRJV's competitors, all of them large South African contractors. NRJV's was not the lowest tender, but after negotiations focusing on NRJV's innovation in design and construction and local knowledge, Part A for design only was awarded in February 2000, with Part B to follow once full project finance was in place.

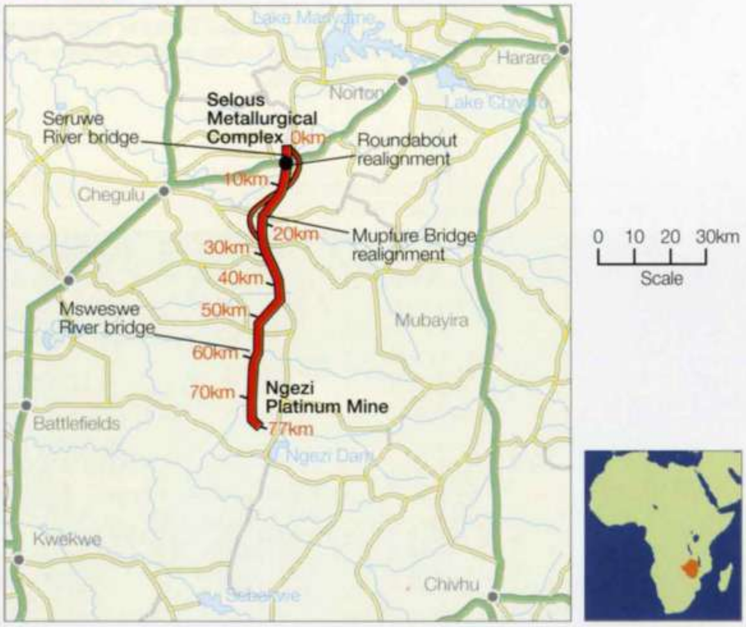
Design

Route alignment

This basically followed the Great Dyke south from SMC at Selous to the mine near the Ngezi National Park. The Ministry of Transport as controlling authority undertook the initial route alignment, which mainly followed existing gazetted road reserves. The team thus had little flexibility for change, but during the design walked and inspected the whole route, in various locations proposing realignments that were accepted by the client and the MoT.

The first and most significant was Mupfure River Bridge. Initially the route deviated 5km from the straight to an existing low-level bridge, to be widened to accommodate the road trains. This was the cheapest solution, but there were flood risks and significant embankment cuts were needed to accommodate the existing low bridge level. NRJV proposed a direct route straight through an existing dam. This saved 3.2km (at US$220 000/km = US$700 000), but required a high level bridge (costing US$700 000). This 'cost neutral' solution saved 3.2km on haul costs and gave a much safer alignment. However as it would cross the existing dam, careful backwater calculations were needed to ensure the bridge would not be flooded. Building a 112m bridge over a 5m deep dam was an interesting construction challenge.

2. Location plan.



'Arup initiated the Ngezi Road Joint Venture, which produced the first road train haul 77km road in Zimbabwe in seven months.'

3. Road train en route from Ngezi to the SMC.

4. Roundabout crossing with main Harare/Bulawayo road raised centrally to prevent glare from oncoming vehicles. This requires street lights for 24-hour operation.

> *'The traffic roundabout on the Bulawayo-Harare road has operated well, with minimal delays to the road trains.*
>
> *The public are still awed when they encounter one of these enormous, 40m long road trains. each weighing 152 tonnes.'*

The second realignment was to bypass Selous village, including an alternative junction with the main Harare/Bulawayo Road. Initial concepts included upgrading and signalizing the existing junction or building an overpass, but the client favoured neither of these due to haulage delays and expense. NRJV therefore proposed a skew roundabout, which was accepted by both the client and the MoT and saved 1.2km of both capital and final operation costs.

Road trains

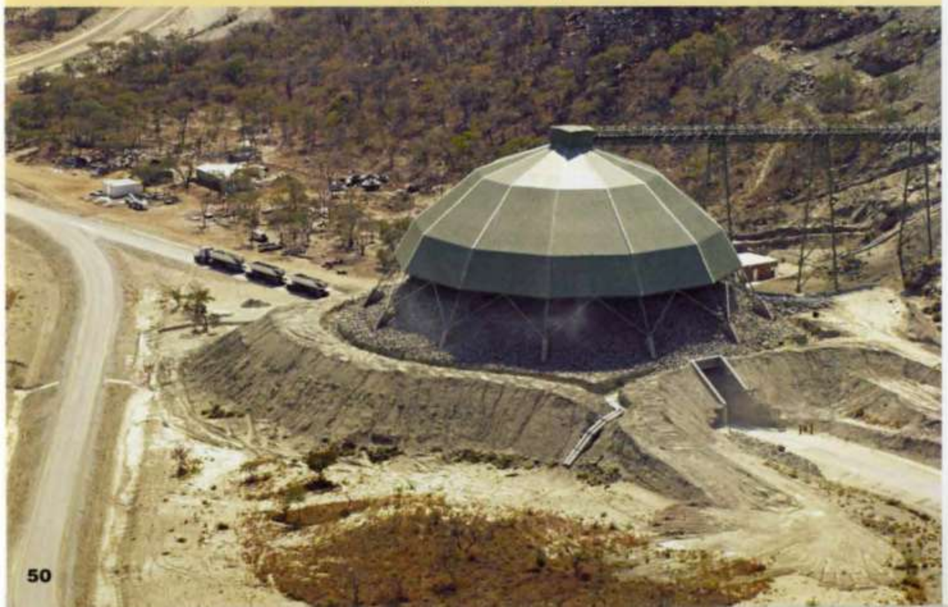
The road trains are 40m long and weigh 152 tonnes, with three side-tipping trailers. As they are classified as restricted access vehicles, approval was required from the MoT for their use. They are new to Zimbabwe, and special signage was installed to educate other road users about their large size.

Environment, topography and materials

In parallel with its design, Arup Environmental undertook an EIA for the proposed new haul road in accordance with the World Bank, Ministry of Environment and Tourism, and MoT guidelines. Various sections were re-aligned according to the EIA recommendations.

Advanced Planning Systems undertook a topographical survey in association with GPS Africa. Control pegs were surveyed in from the national grid as this central section of Zimbabwe was previously unsurveyed. A strip survey of the pegged alignment at 50m intervals was produced using a digital terrain model in the Civil Designer road design software. A more detailed survey was undertaken for road junctions and the bridges.

5. Ngezi mine load out dome and tunnel, with crusher to the right. A full 152 tonne road train on the left begins its 77km trip to the SMC.



The alignment traverses the Great Dyke of Zimbabwe with its significant mineral wealth, of which chrome and platinum are mostly mined; the road's setting was described as 'a geological Smartie box'! The greenstones/serpentines and dolorites produce plastic soils - and poor road foundations - so they had to be excavated between 150mm and 600mm depending on their expansivity. The excavated roadbed was then filled with imported selected subgrade as a foundation for the road pavement, the materials for which were sourced from borrow pits in the adjacent granites. To accommodate the design traffic's strength requirements, the base 1 material needed to be a crushed stone, and a new quarry was proved and opened approximately midway along the road.

Traffic

On completion, the Ngezi Road became State Road Number 928, combining several previous roads - mainly gravel, though in some sections with thin sealed surfaces. Traffic counts at major junctions revealed low volumes for the mainly rural agricultural areas. The traffic projections based on haulage for the mine were as follows:

- years 1-5: 2.2M tonnes of platinum ore per annum
- years 6-15: 200 000 tonnes of concentrate per annum
- years 16-20: local traffic only.

For the first five years, approximately 124 road trains per day (62 in each direction) were predicted, running 24 hours a day, seven days a week. Various users, including tourists, freight, farm machinery and draught drawn vehicles were included as the future beneficiaries of the improved road from SMC to the mine.

The road and its environs

The design speed for the road is 80km/hr, as specified for a secondary road with a minimum horizontal radius of 750m if curve widening is to be avoided. This was reduced at approaches to the Harare-Bulawayo roundabout and at the major river bridges. The vertical alignment was particularly flat and the maximum start ability of 9.8% for the road train was not encountered.

Initial analysis gave a design figure of 3M 'standard axles' across the pavement's 20-year design life. After considering the tracking effects of the road trains' concentrated loads, and following expert consultations, this was factored up by an additional 50%. By employing a mechanistic design approach to analyzing the pavement layers, using stiffness values and Poisson's ratios to calculate the life of the various pavement layers, the thickness of the expensive base was reduced to one layer of crushed stone and the cheaper cement-stabilized base increased to two layers, to produce a more economical pavement. The surfacing was a double seal spray and chip with a 19mm stone tack coat. The tar binder was locally produced in Zimbabwe and hence cost-effective, but susceptible to deterioration from ultra-violet rays. Accordingly the seal coat used a 7mm stone with a more expensive imported bitumen binder.

6. Seruwe River Bridge: 36m long, cast in situ solid slab deck.

Stormwater drainage was designed from 1:50 000 maps, with smaller areas from 1:12 500 aerial photos. Large stream crossings used corrugated steel pipes or Armco structures for speed of construction, despite being more expensive, with relief culverts and small stream crossings using local concrete pipes, relatively wide with a minimum 750mm diameter for maintenance purposes.

The whole length of the road is fenced on both sides to prevent cattle and animals straying onto it, with farm gates at minor side tracks and cattle grids at roads. Scotch-cart paths were constructed along the road's outer edges where there is high population, particularly near resettlement areas, to minimize any conflict between the local population and the road trains.

As road trains operate 24 hours per day, 365 days a year, NRJV proposed the use of high quality red and orange cat's eyes for the entire length of the road. This has been successful in maintaining driver alignment at night (even though it can look a little like a runway with landing lights!).

Bridges

Three major rivers cross the road route, all at new locations. The 112m Mupfure River Bridge was relocated about 1km upstream from the existing low level bridge, and 0.5km upstream from the existing Seigenery weir. The chosen method of construction - a composite deck of 17.8m prestressed, precast beams, 1.2m deep in a 200mm thick reinforced concrete slab - avoided the need for shuttering the deck, which could have proved difficult in the weir basin. The bridge hydrology was designed to accommodate a 1:100 year flood for the 4300km^2 catchment; backwater calculations for this confirmed that it would just rise to the bridge beam soffits. The 53m Msweswe River Bridge has a channel where shuttering could be used fairly easily, enabling the use of a concrete twin beam and slab design. This was a difficult final choice due to the large boulders and poor founding conditions, and a large triple corrugated steel pipe solution was seriously considered.

The costs were virtually the same, but with the large 700km^2 catchment, the possibility of blockages due to trees and durability considerations swung the decision towards concrete. The 35m Seruwe River Bridge has a catchment of only 45km^2, and so a simple concrete solid slab option was selected.

Construction

January 2001 started with good rains and a series of negotiation meetings between the NRJV and Zimplats, with the contract being finally awarded on 23 March 2001 for US$18.8M. Due to Zimbabwe's political uncertainty, financial arrangements were difficult to conclude, and Zimplats were only able to give notice to proceed with the work on 19 April 2001. Road building in Zimbabwe, with its heavy rains, can be precarious, but fortunately the finance came through at the end of the rains and the beginning of the seven-month dry winter. This was a large, fast-track project with a construction programme of only seven months and a penalty of US$18 000 per day. Further, Zimplats could not start up their newly acquired platinum processing plant until the road and the Ngezi Mine were in place, and so the road was on the critical path.

To ensure this programme was achieved, the NRJV drew on the Zimbabwean construction industry's large but under-utilized resources. This was co-ordinated by the NRJV board and supervisory team, with each joint venture partner responsible for the construction of a specific section:

- Bitcon - the first 20km, the roundabout, and the SMC loop
- Costain - the middle 17km plus the bridges
- Tarcon - the last 40km to the mine
- Arup - supervising engineers.

The impossible

Many thought it impossible to complete 77km of national road, plus three major bridges, in seven months. The key was teamwork and focusing on completion. This started at the top, with the supervisory board's commitment to the NRJV rather than to the individual companies. NRJV shirts and teambuilding helped, but ultimately a common goal and a serious penalty, with team spirit and the philosophy of solving the problem between the consultant, contractor and client, won through.

The critical path was clearly through the Mupfure River Bridge, which was to be built through the Seigenery weir with a water depth of 5m. However what initially seemed a huge challenge was skilfully resolved through the providence of a good rainy season, full dams, and permission granted by the water authorities to dewater the weir. The project manager solved this dewatering by blowing a hole in the weir wall, allowing construction of the bridge to proceed on the dry riverbed. The weir was repaired just before the onset of the November rains.

Construction was not all straightforward. Work on the Msweswe River Bridge was brought to an unceremonious stop when the local N'anga (witch doctor) announced that there was a 'Njuzu' water spirit in the pool being filled to create a platform for the piling rig. No one would work until this most powerful of ancestral spirits had been appeased. The N'anga said a black bull would have to be sacrificed and beer brewed for the ceremony. After a week of negotiation over the impasse, the contractor bought a black goat, which was said to be acceptable, but the N'anga still had to brew the beer - another seven days' work - and only then perform the ceremony.

The situation became untenable when a second N'anga appeared with a new set of requirements, and there seemed no way to get the labour back to work. Then Langton Gatsi, a pastor who understood and had experience in dealing with ancestral spirits, was introduced into the equation. The design team with the pastor visited Chief Mupamombe at his kraal, and in front of a crowd of villagers, the pastor outlined the Christian alternative to belief in ancestral spirits. Amazingly, the Chief and his family fell to their knees and gave their lives to Jesus. After prayers, the next day the workers started construction and the bridge was finished on programme without further problems. There are now three thriving churches in Chief Mupamombe's village.

Project management

Arup undertook the project planning, using the program Suretrak as the planning tool due to the project's complexity. An overall master programme was established for all activities, and the contractors' resources allocated.

7. Surfacing unit with chip spreader about to lay the seal coat of 10mm stone.

8. Six-bore Armco multiple culvert.

9. Cement stabilization using mechanical self-propelled reclaimer with water bowser connected for moisture conditioning during mixing.

10. Compacting rock fill layer and hand screening of oversized rocks.

11. Typical line of balance chart for rock fill activity.

12. Mupfure River Bridge: 112m long with precast concrete beams and cast in situ slab. This method cost more than the traditional cast in situ beam and slab, but was faster and did not require staging in the potentially flooded river bed.

13. Road trains unloading platinum ore at SMC.

This immediately demonstrated where shortages of plant and resource lay, and enabled Arup to advise how best to share equipment amongst the various contractors to satisfy outstanding work.

With such a short construction period, monitoring progress was critical, and a simple system - taking dates from the programme and preparing a spreadsheet that was updated weekly by each contractor- was found to be most practical. These actual dates were then put into the programme to reshuffle outstanding work and resources accordingly. A weekly line of balance chart was then produced for each major activity for each contractor, demonstrating their weekly progress against their required output from the programme. This allowed the contractors to see at a glance their progress and was an enormously useful management tool.

Completion

The road was completed on time and budget, but due to its magnitude this is best seen through a few key statistics, mainly taken from Zimplats' congratulatory plaque, as follows:

- Haul road length: 77.1 km
- 1km completed every 2.61 days
- 9m of road with double seal surfacing
- Three major bridges
- Peak manpower: 1471 employees
- Peak equipment: 591 units
- 2 393 496 man hours worked without a 'lost time injury'
- Total volume of earthwork: 700 000m^3
- Time to completion: 200 days.

Operation

The road was complete two weeks early, and the first ore hauled from Ngezi Mine to SMC in late December 2001. The first road trains started operating in January 2002, and in the first year, 10 road trains hauled 1.2M tonnes of ore. There was an unexpected increase in the chrome mining haulage trucks which initially travelled on only a portion of the road, and then cut across to Kadoma. They have now built smaller versions of the road trains and use the higher quality haul road, travelling an additional 70km to Kadoma.

At design stage it was felt that agricultural development would increase significantly, but the 'war veterans' from President Mugabe's land reform programme form the only significant increase in agricultural activity. They have cut down trees and constructed thatched pole and daga huts, but generated minimal additional traffic.

The road has performed well, the only signs of weakness being a few longitudinal cracks in an area of deep fill. These were sealed and are being monitored by the NRJV who have a two-year maintenance requirement as part of their contract. The traffic roundabout on the Bulawayo-Harare road has operated well with minimal delays to road trains and no negative feedback from the Ministry. The public are still awed when they encounter one of the enormous road trains.

Activity and date

Ngezi Open Cast Mine EIA complete: June 1999

Haul road scheme design and build lump sum undertaken at risk: August 1999

NRJV formed: December 1999

Tender for haul road: February 2000

Design only awarded to NRJV: 23 March 2000

Design, survey, soil testing, realignments, MOT and client approval: 30 September 2000

Haul road EIA complete: November 2000

Construction awarded to NRJV: 19 April 2001

Seigenery weir blasted to drain water for Mupfure River Bridge: 2 May 2001

Start date of contract: 14 May 2001

First pre-stressed beams to Mupfure River Bridge: 3 August 2001

First prime coat: 18 September 2001

Practical completion: 3 December 2001

First ore hauled: Mid-December 2001

First road train operational: Early January 2002

Conclusion

Zimplats' management was impressed by the completion and two-week-early opening to traffic of the road - 'an amazing feat'.

There is no doubt that through the combined design and construction teamwork, the NRJV lived up to the motto 'formed to save the road construction industry'. It brought together a significant part of the industry in Zimbabwe at a time of despair in the nation and gave a sense of purpose in achieving what many said was impossible. It certainly went a long way to 'shaping a better world' in Zimbabwe.

A key follow-on opportunity arose in January 2002, when Corridor Sands Limitado, a Mozambique titanium mining company, invited Arup and the NRJV to advise and design for feasibility their 66km haul road near Maputo. Arup in Harare has also developed a skill in heavy vehicle pavement design, and was commissioned in December 2002 to design Zimplats' Phase 2 roads. Each company involved in the Ngezi Road has grown in strength and capability and Arup continues to look forward to further follow-on work as a result of this success.

Reference

(1) CARTER, Chris. EIA study: Ngezi opencast platinum mine, Zimbabwe. *The Arup Journal, 35*(1), pp9-12, 1/2000 (Millennium Issue 2).

Credits

Client:
Zimbabwe Platinum Mines Ltd (Zimplats)

Ngezi Road Joint Venture:
Costain Africa Ltd
Tarcon Pvt Ltd
Bitumen Construction Services Pvt Ltd
Arup Neil Bradshaw, Shake Chambati, Josephine Chigamba, Shelter Dube, Blessing Farirai, Douglas Favtini, Chris Furukia, John Hanlon, Graham Hill, Shaun Landman, Pioneer Madaro, Moses Makuruvi, Andy Marks, Farai Mavia, Mudzviti Mudzviti, Stuart Perry, Fred Smith

Sub-contractors:
Civil Planning Partnership Zimbabwe
Hart Frost Consulting Engineers
Ascon
Soil Test Laboratories
Northern Testing Laboratories
Advanced Planning Systems
GPS Africa
Grinaker
B & E International

Illustrations:
1, 3, 5, 6. 12, 13: Cameron Corporate Sean Herbert
4. 7-10: David Brazier Wide Angle
2, 11: Arup (Daniel Blackhall)

Merrill Lynch

John Hirst Roger Olsen Alan Pepper

Introduction

When the American finance house Merrill Lynch merged with the former Smith New Court Bank in 1996, it became clear that pressure of space on their existing offices in the City of London would need to be addressed. They were keen to bring the various elements of the business together on one site, so a comprehensive search for suitable premises was mounted. This revealed no existing and available building stock to meet their exacting requirements, which included dealing floors of not less than 3700m^2.

Merrill Lynch appointed the design team, including architects Swanke Hayden Connell and Arup as engineer, in 1997. Arup worked with the architects to provide a comprehensive multidisciplinary service on the project, covering archaeology, geotechnics, structure, building services, lifts and escalators, security, acoustics, audio-visual, fire engineering, IT strategy, and transport planning.

It became apparent that any existing building would require extensive and costly remodelling, so the decision was taken to search instead for a suitable construction site. The team created a theoretical model of Merrill Lynch's requirements and all available sites were assessed against it. The search covered much of Greater London, but the location eventually selected was in Newgate, close to the financial heart of the City. Over the centuries the plot had been progressively occupied by a mediaeval friary, from the 1550s by Christ's Hospital school (Christ Church), and from the beginning of the 20th century by the Post Office. Although ideally located, this complex site presented several significant challenges to the design team. It encompassed not only several listed buildings, but also a fragment of the Roman/mediaeval City wall, which as a Scheduled Ancient Monument had to be open to public viewing.

1. The main building glimpsed beyond the surviving remains of Christ Church.

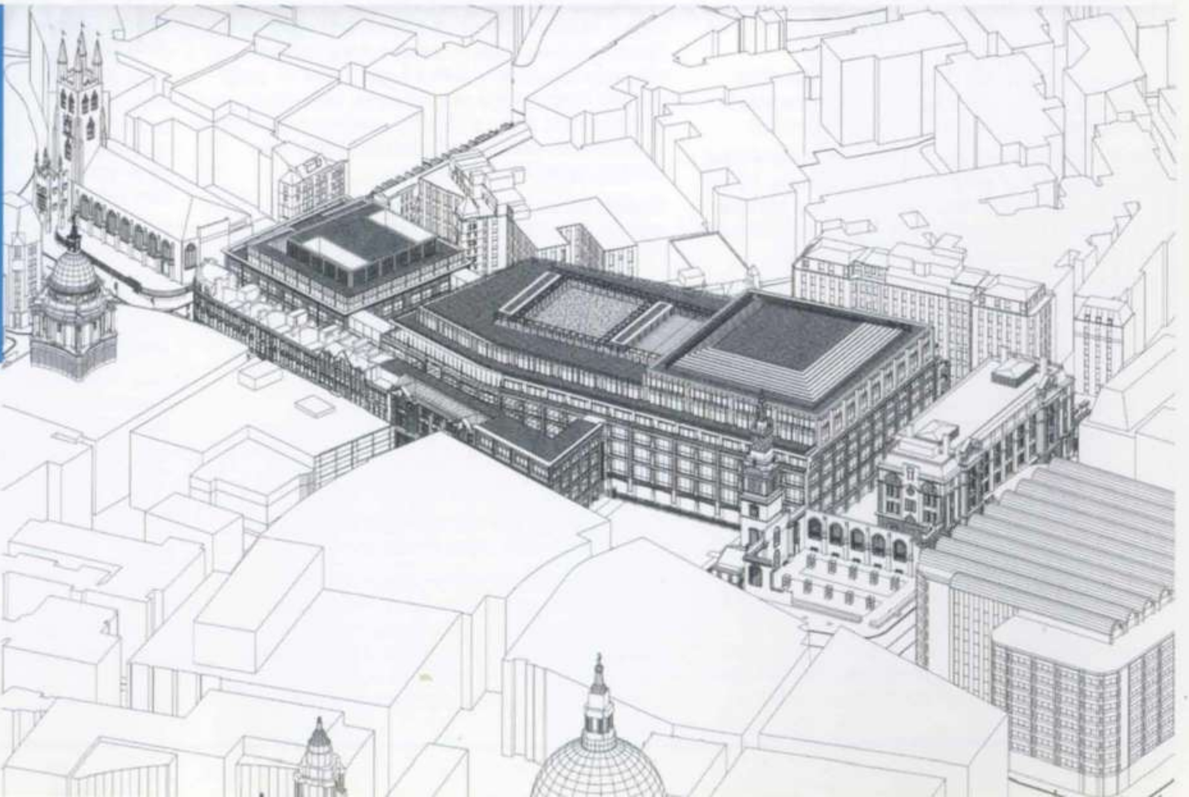
Building form and construction

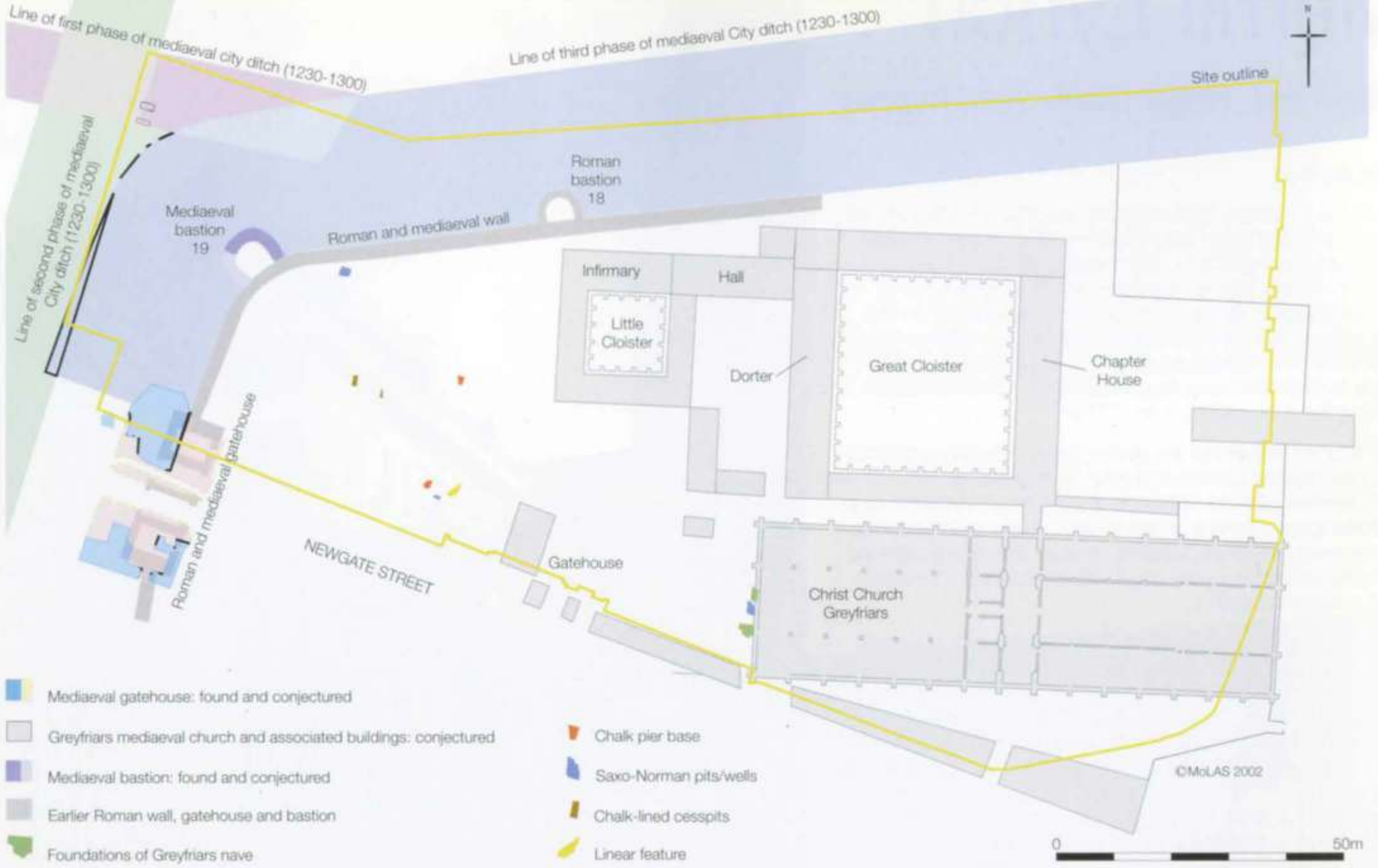
The strict rules governing sightlines to St Paul's Cathedral determined the buildings' overall height. The main block rises to seven storeys on its eastern side and six on the west, while a separate building further west again is of five storeys (Fig 2). Designed to reflect the client's vision of a sense of solidity, timelessness, and stability, the structures are clad in brick and stone so that the frame, rather than the glazing, dominates visually.

The buildings enclose several green spaces, with a glazed galleria running east to west through the site to provide a focus for those who work there. A public route runs behind a restored (and now profitably rented) parade of Victorian shops bounding the south side of the site on Newgate Street. More restoration, in this instance to the retained Post Office building at the eastern end of the site, has provided elegant conference and client presentation space in its colonnaded hall, now known as King Edward Hall.

2. Axonometric of the whole project. On the left is the west building, separated by lawn from the main building, which is in turn separated from the retained and restored Post Office (King Edward Hall) on the right.

In front, the restored Victorian terrace faces onto Newgate Street as do, in the right foreground, the remains of Christ Church, Greyfriars.





3. Archaeological features on the site.

Archaeology

Richard Hughes

The extensive archaeological remains within the site footprint are of national value. The Roman and mediaeval City wall and associated external ditch and internal bank and related structures, the Roman/mediaeval Newgate Gate entrance to the City, and the ruins of the mediaeval/Wren's Christ Church are protected Scheduled Ancient Monuments. Other remains, including Roman buildings, early Saxon 'Dark Earth' formations, the 12th century Greyfriars monastic complex later to become the famous Christ Church School), and a late 18th century 'Compter' (a debtors' prison) were also regarded as of considerable value to the heritage of the City of London.

Sadly the development necessitated the demolition of the Grade II Listed main Post Office building – a fine and very early example of Hennebique reinforced concrete construction.

Arup's comprehensive desk study established the heritage value of the site, and was followed by an archaeological site evaluation integrated with the engineering site investigation. This required the first of many Scheduled Monument Consents.

The site's status required the key archaeological elements to be preserved in situ, not archaeologically excavated and not removed by new groundworks. The aim here is to preserve archaeological deposits for the future: some 50% of the total resources within the City have been destroyed over the last 40 years. This requirement imposed constraints on the development and greatly limited the extent of the proposed new basement in the west building and the location and sizing of piles and service locations there as well. In the western yard the archaeological deposits started from just below the tarmac surface, as here there had been no long tradition of building – it was still substantially the cloister area of Greyfriars.

Fortunately for the development, the former Post Office building had no archaeological development constraint as it already had the equivalent of a three-level basement set well into natural gravel soils. One key element was the preservation and enhancement of the 'Bastion Chamber'. In 1909-1911 the Post Office developed the site as their western loading yard and found there the north-west corner of the Roman City wall with, at the angle, an external mediaeval horseshoe-shaped bastion. This complex was preserved by the Post Office within an underground concrete chamber, and since then had been accessible to the occasional visitor. Despite regular flooding and the dank, musty conditions, it had survived well. Basal decay necessitated the structure being underpinned in the 1950s, but only a nominal amount of conservation has had to be done.

Clearly, the new west building and the landscaped setting required new groundworks, and much of Arup's early work was in designing the heritage mitigation measures – with a large output of 'early' detailed design of the groundworks, excavation specifications, and construction method statement - and all with associated Scheduled Monument Consent application documents.

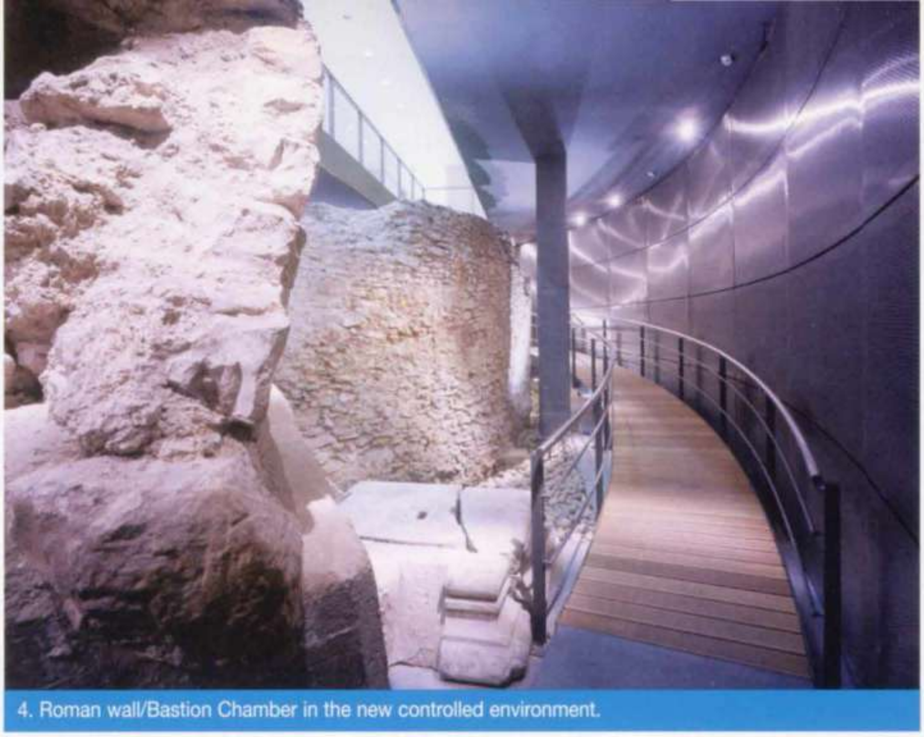
Outside the protected areas there were similar requirements for satisfying Corporation of London Planning Consent Conditions.

The strategy

- maximum in situ preservation, by construction being set above the top of proved archaeological levels
- maximizing of spans between piles and minimizing their diameter
- pile caps and ground beams formed above ground level or in soils proved to be modern
- establishment of maximum gaps between piles and the City Wall (always more than 1m)
- archaeological excavation of many of the larger diameter piles, based on modelling the archaeological potential of each location and an excavation research agenda that linked piles to act as boreholes for mapping archaeological sections. One pile passed through a Victorian basement backfilled with human skeletons, found in the City Ditch in 1909. The remains were carefully excavated and reburied with appropriate ceremony at the local Greyfriars monastery. Many of the piles disclosed Roman remains, and the well-honed digging techniques significantly contributed to understanding how the Romans originally developed this part of London. Evidence of quarrying and pottery-making was found, followed by land preparation for constructing simple wattle-and-daub and earth structures, these then being replaced in the 2nd century with stone-walled houses and other light industrial works.
- full and large-scale excavation over three months of the main part of the 'Compter' that had fronted Giltspur Street, and where a new basement was approved.

  Here, the massive brick walls and basements were found precisely in the predicted locations, as well as a timber piled foundation and some superbly-constructed brick drains. The many other interesting finds include a watertank lined with Dutch 'blue and white' picture tiles.
- watching briefs on the replacement of old ground surface with a new engineered one externally and internally to the west building; this exposed the top of the archaeological levels and allowed, for example, mapping of the City Walls orientation without any need for archaeological excavation.
- local archaeological excavation relating to inserted new construction within the retained Victorian buildings along Newgate Street
- watching briefs to surface landscaping in Christ Church churchyard gardens.

Finally, a new environment and display setting was created for the Roman wall/Bastion Chamber complex (Fig 4, facing page). The natural environment was monitored for humidity, temperature, and wind movement for over a year, and the data was then used for derive new conditions that would allow for viewing down onto it from within the west building foyer and for visitors to walk around it.



4. Roman wall/Bastion Chamber in the new controlled environment.

With their large and densely occupied trading floors, the first and second storeys of both the main and west buildings have electrical and cooling loads around three times that of a standard back-office floor. In response to this they have a higher floor-to-floor height and a deeper than normal raised floor void. The fabric of the building was selected and tested to provide high thermal performance, with double-glazing and internal blinds to reduce glare.

Structure and geotechnics

A desk study of the site revealed that the principal buried man-made features included important archaeological artefacts in the western part – one of the Scheduled Ancient Monuments on the site - and several tunnels beneath and adjacent to the proposed development. The most significant of these tunnels was for Mail Rail, including a figure-of-eight tunnel layout and station complex which served the existing Post Office building.

A detailed ground investigation confirmed the site geology as superficial deposits (made ground, alluvium or brick-earth) overlying River Terrace deposits, London clay, Harwich formation, Lambeth group, Thanet sands and chalk.

The foundations were a particular challenge to the design team and several options were evaluated, taking into account the presence of the archaeology and the tunnels as well as the basement of the existing Post Office building. Limits on working hours and noise levels, particularly due to the proximity of St Bartholomew's Hospital to the north, were a further important parameter in developing the foundation strategy.

The selected solution was a combination of bored piles, principally for the western part of the site, in order to substantially preserve in situ the archaeological resource at shallow level and a raft foundation for the main building in the area of the original Post Office premises, where the archaeological remains had already been removed.

The adoption of a raft for the main building was both technically superior to fully piled foundations with respect to movements of the tunnels, and realized a significant cost and programme advantage.

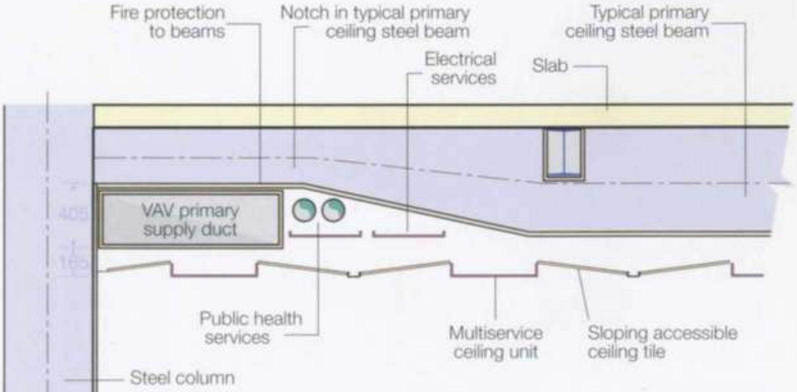
To minimize disturbance to buried archaeological artefacts, the bored pile layout comprised a minimum number of deep piles, with generally single piles per column. However, this still necessitated some piles having a minimum clear distance of less than 1m from the edge of the tunnels. Their design thus took into account the effects of boring and subsequent loading on the adjacent tunnels, and finite element analyses of the soil were used to establish that the effects on the tunnels were satisfactory.

The raft was designed with Arup's Oasys computer program GS Raft to model the soil-structure interaction. This analysis included for both, the short and long-term effects of unloading, due to demolition of the existing Post Office building and the deeper excavation, and reloading of the ground from the new building. The results indicated the maximum long-term settlement to be about 75mm. The deformations and stresses in the tunnel lining were also analyzed, and shown to be satisfactory.

Displacements of the Mail Rail tunnel, the buried section of the Roman Wall and the raft itself were monitored before, during, and after construction; the measurements were within the predicted and agreed limits.

Effects of archaeological and other ground constraints also affected the superstructure design. Many of the available foundation locations were somewhat eclectic. The floor plates of the buildings obviously had to be rational however, so this challenge was met with a combination of long-span steel floor framing and the use of steel façade frames as four-storey vierendeel girders.

The structure of the main and west buildings is largely of conventional structural steel construction with composite slabs and beams, on a 12m x 12m grid for the main building. The beams are notched adjacent to supports to accommodate service distribution (Fig 5).



5. Section of column and notched beam showing structure/services integration to minimize building height: this saved 100-200mm of height on each floor.

However, a somewhat novel approach was adopted for the provision of tender and construction information for the steel frame in the form of a 3D XSTEEL computer model issued electronically. This program is widely used in the steelwork industry for producing fabrication information. Conventionally the XSTEEL model is produced by the fabricator on the basis of 2D framing plans provided by the designer. The normal process is therefore to communicate information on a 3D frame in a 2D format, which is then converted into a 3D computer model (Fig 6). The advantages of representing the 3D frame directly as a 3D model are clear.

In addition, the information is provided in a format far more useful to the fabricator. For example, material requirements can be obtained directly which assist in tendering, ordering, and making a rapid start to the fabrication process. This approach reduces the number of links in the supply chain for the benefit of all. The Merrill Lynch project is believed to be the largest steelwork contract to have been procured in this way at the time of construction.

6. Extract from XSTEEL 3D computer model of the atrium structure, without atrium roof details.

Mechanical and electrical engineering

As well as planning and aesthetic considerations, the project had to both satisfy the critical business needs of a major financial institution now, and had to be suitable for future use by other types of occupier. It incorporates the latest developments in international financial buildings, and in operational terms is unusual for the way the owner has encouraged integration of the business IT systems with the control and monitoring of the many M&E systems.

As noted earlier, the buildings are a mix of new and old, with restoration of two major areas to create both modern useful office areas and museum space. For all areas, however, the high power and cooling loads and high density of occupation dictated an air-conditioned building.

The height restrictions imposed by the closeness to St Paul's Cathedral, and the presence of underground railway tunnels to limit deepening of the existing basement, had a big influence on the location and form of the M&E plant. The structural and services systems had to be carefully chosen, and many alternatives were considered before deciding which to use. Plant space was a key issue in the system selection, with maximum use of the existing basement - deepened wherever underground tunnels and archaeology would allow. The new-build areas use a conventional overhead variable air volume air-conditioning in the office spaces and a through-the-floor system in the trading areas.

The refurbished areas were mostly listed and have restricted floor-to-floor heights, which necessitated the use of fan-coil units with minimum outside air.

7. Office areas, showing ceilings with multi-service units incorporating lights, swirl diffusers, smoke detectors, and sprinkler heads.

'Everybody loves the building. We commissioned a facility to bring together our various business functions but the team has achieved much more - they have created a home': David Komansky, Chief Executive, Merrill Lynch

Reliability and resilience of the power and cooling systems is vital to firms in the financial sector, and this need required the building to be able to operate independently of the external power network. Six diesel-driven rotary UPS/generator sets are used, plus seven air-cooled chillers with N+1 capacity. The rotary diesel UPS/generator system was selected for its simplicity and to save space and installation time, and the six sets are capable of cleaning the power supply under normal conditions, and providing generator and UPS backup in an emergency.

The plant runs constantly and so noise attenuation was a key issue. The 300 tonne roof-level plantroom housing the sets was therefore positioned on six anti-vibration spring supports, effectively isolating it from the building frame.

All business critical systems are dual-fed from separate sub-stations, while different electrical risers serve alternate trading desks. A no-break changeover to an alternative sub-station can be effected in the event of a fault. The electrical and lighting systems have been installed on a modular basis, providing significant savings in installation time and – crucially - enabling future changes with minimal disruption.

Seven roof-mounted air-cooled chillers, each of 1.2MW capacity, meet the building's cooling needs.

IT strategy

Working closely with the client, the design team developed the IT strategy at a very early stage in the project design.

The objective was an adaptable building that could accommodate rationalized and upgraded IT systems (from three locations into one), and allow for future expansion of trader numbers (from 1100 to 2000+) and future technology developments (video to the desktop, greater use of fibre optic cables, etc). Allowing sufficient space but not over-designing was key.

A fully resilient 2000m^2 main communications room was incorporated in the basement, with IT equipment placed to minimize quantities of cable runs and crossovers. Security and riser distribution issues determined the location of the secondary communications rooms, all of which were sized with future expansion in mind.

From the outset the design and layout of the trading floor was heavily influenced by flat-screen technology, which had a major impact on the space required on desks, the electrical power, and the heat dissipation needed. The result was one of the largest integrated communications cabling systems in the world, with the potential to support telephony, IT, building management systems for heating and air-conditioning, lighting control, load shedding, power management, and security systems. Thus, for example, a security camera can be positioned anywhere in the building in a matter of minutes and connected to the nearest communications cabling outlet. The building management controllers are similarly connected to the nearest outlets with networking hardware, and configuration carried out in the IT secondary communications rooms. This integrated approach saved significant time and costs during construction and is proving its worth in subsequent operations.

8. Typical trading floor.

9. King Edward Hall.

Transport planning

The redevelopment required major improvements to the local highway layout, which in turn enabled the footprint of the 13th century original (and long-destroyed) Christ Church of the Franciscan Grey Friars to be restored by building new boundary walls to match those remaining in the south-east corner of the site.

The new vehicular route bounding the north edge of the site, linking Giltspur Street to King Edward Street (respectively the east and west site boundaries) is wide enough for two-way traffic, but all delivery vehicles must operate on a single through movement, west to east. Staff traffic (cars, motorcycles, and bicycles) descends down a straight ramp to the basement car park, whilst delivery vehicles proceed along the service road to the central delivery area.

The junction of Newgate Street with King Edward Street at the south-east corner was redesigned as a fully signalized junction incorporating facilities for both pedestrians and cyclists. Footways around the perimeter of the site have been repaved in York stone, as has the restored rose garden in this south-east corner on the site of Christ Church. The access road leading to the rear of the restored Post Office building on King Edward Street has also been reconstructed with a granite sett surface.

As for the internal circulation within the new buildings, pedestrian movement studies were undertaken at existing Merrill Lynch offices to establish the number of lifts required.

Added value by Arup

- *Foundation design resulted in three months' saving on programme, with a benefit of £1M.*
- *Modular wiring systems significantly reduced installation time in ceiling voids.*
- *Integrated use of IT structured cabling created significant time and cost savings.*
- *Gas-fired humidification plant resulted in significant running cost savings.*

Acoustics

As already noted earlier, noise and vibration control of the substantial rooftop plant installation was crucial. The priorities were to achieve low noise levels in the client centre meeting rooms on the floor below, and to avoid disturbance to St Bartholomew's Hospital to the north. Throughout the buildings, the interface between the slab-to-slab drywall partition and building structure allows for building deflections without causing a weak noise transmission path to degrade the overall sound insulation.

Audiovisual

The audiovisual facilities mark a radical change in Merrill Lynch's use of presentation and conference systems. Arup helped to define the requirements for each space and designed the network that links them together, to broadcast links to and from the British Telecom tower 3km away in London's Fitzrovia district, and to the television distribution system that feeds PCs via the computer network and numerous plasma screens around the building.

There are two auditoria, one in the centre of the ground floor of the main building and the other in King Edward Hall. Both bring together state-of-the-art presentation technology with video and telephone conferencing and with near broadcast quality video recording and relay. The rooms are technician-driven – one technician assists on basic presentations, whilst the most complex can require three or four. Alongside in King Edward Hall is a multimedia museum showing the history of Merrill Lynch and of the financial sector in the Corporation of London.

The sixth floor accommodates the client centre and the boardroom, the former a mixture of rooms for dining, presentation and video conferencing; much effort was spent integrating the technology into the fabric of each room. The boardroom seats 26 people at a custom-designed table that conceals microphone and laptop connections when not in use; full height wooden screens hide the rear projection screen and video conferencing cameras.

The financial community regularly contributes to television and radio programmes, and Merrill Lynch has two broadcasting points on the trading floor that hook into the building-wide broadcast network to be sent to the British Telecom Tower and on to broadcasters.

All in all, Merrill Lynch's integrated audiovisual facilities have set the standard in the London financial community.

Fire engineering

The architectural and client ambitions for the building set several fire safety challenges:

- incorporating existing buildings into the design
- integrating the west building with the main building, but so that the former can operate independently if required
- open links via escalator voids and atria from basement level to the fifth floor
- minimal business disruption from fire or false alarms, particularly to the dealing floors
- negotiating acceptable levels of fire risk and fire prevention between the client and their insurers.

Arup Fire's contribution to the design began at concept stage with strategic issues agreed early in the design process. Several aspects of the design required a fire engineering approach to gain acceptance from the local authority.

The large central floorplate to the dealing floors made travel distances to the escape stairs greater than prescribed in the codes. Single floor evacuation also allows business to continue on non-affected floors with minimized disruption.

Atrium roof structure

Keith Jones

10. Atrium showing glass roof.

The structural system of the main building atrium roof is 3m by 1.5m double-glazing panels supported on 6m long glass beams at 1.5m centres. These glass beams - at the time of construction thought to be the longest constructed in Europe - span between steel box girders and consist of two vertical layers of toughened laminated glass, 450mm high by 19mm thick.

Each of these layers of glass was designed to resist the full design load (up to 3kPa snow drift) in the event that the other layer fails. If this happens, the vertical interlayer acts as a bond to hold the shattered pieces of the failed layer in place. In the unlikely event of the second layer of glass also failing, however, a third structural system is brought into play. A catenary wire spans each side of each glass beam between the steel box girders, offset approximately 50mm from the centreline of the beam.

The wires pass through steel eyelets at right angles to the glass beam, welded to steel U-plates bonded onto the top of the glass beam. These catenary wires are designed to support both the failed glass layers of the beam and the glazing panels above, with the interlayer bonding both the failed layers together.

A full-scale glass beam and catenary system was tested on site at 1/3rd design load to ensure that the failure support mechanism would behave as predicted.

The glass beams were designed to the Australian Standard *AS1288-1994, Appendix H,* 'Glass in buildings - selection and installation'. This was subsequently incorporated into the Institution of Structural Engineers publication: 'The structural use of glass in buildings', December 1999.

The mode of smoke extract lessened risk to the business. Office atrium smoke management allowed open-sided floors and the glazed roof to be flush with the roof finishes instead of using a traditional upstand reservoir as required by the British Standard for atria.

King Edward Hall was linked to the main building by horizontal fire compartmentation at ground level and with fire-protected circulation stairs penetrating down to the basement level. This was a significant departure from local regulations, the application of which would have restricted the design severely. A performance-based approach was used on parts of the existing structure, eg the car park and the staff dining area, to show that an alternative approach to prescriptive guidance could be adopted.

Many of the demands by the project's original insurers were unacceptable to the client and design team.

One requirement for increased fire resistance to the floor slabs would have involved thickening them, thus increasing floor-to-floor height and in turn raising the building's height.

As this was restricted by local regulations, the demand for greater fire protection to the structure could have resulted in the loss of the top floor to satisfy the building height requirement. By presenting calculations on the effective fire resistance for the building, Arup was able to assist the insurers in reducing their demand and a more reasonable fire resistance standard was established.

The fire engineering approach also allowed the use of timber surface finishes like walnut. In addition, Arup Facilities Management in Bristol developed a very successful operational fire safety manual for the building operators, thus complementing the design manuals prepared by the architect and Arup.

Awards

City Heritage Awards 2002:
Commendation

Civic Trust Awards 2002:
Winner, London Region

American Institute of Architects London Chapter Design Awards 2002:
Finalist

New City Architecture Awards 2002:
Special Commendation

Society of American Registered Architects:
Professional Design Award 2002

Office Agents Society Award 2002:
Winner, Best Central London Office Development

British Council for Offices 2002:
Winner, London Region Corporate Workplace

> *'The integrated approach which Arup and the other design team members applied to this project achieved significant time and cost savings.'*

11. Main building façade.

12. Reception area within the internal 'street' between Newgate Street and the main building.

Security

Teamwork characterized the efforts made to provide Merrill Lynch with an effective and flexible security solution that provided them with a launch pad into the 21st century. Their own security team worked closely with Arup specialists to establish a strategy resilient to project changes throughout the design and construction. A fundamental element of the design was the use of a common cabling infrastructure for CCTV, access control, intruder detection and video intercom systems to provide control and monitoring facilities. This solution comprised a combination of IT hubs, routers, data cabling, and fibre backbone cabling. As described previously this was part of the fully integrated solution. Not only did it allow for the business operations' future churn, it also enabled Merrill Lynch to deploy early on temporary CCTV and access control devices to monitor and control goods in, and safe storage areas during the fit-out of the building easily and effectively. This was a great benefit to them as they rely heavily on IT for their core business. Other aspects with which Arup was involved included threat and risk strategy development, project management of the security system design, and advice on specific counter-terrorism measures, including a dedicated mail screening installation.

Official opening

HRH the Prince of Wales officially opened the building in July 2002. Merrill Lynch's commission provided an ideal opportunity for Arup to bring the firm's multidisciplinary expertise to bear on a complex project. Working closely with other design team members, this integrated approach enabled the Arup team to make significant time and cost savings, while delivering a leading edge facility.

David Komansky, Chief Executive of Merrill Lynch, described the completed project: 'Everybody loves the building. We commissioned a facility to bring together our various business functions but the team has achieved much more - they have created a home. In real estate terms, the decision to own and occupy our own premises has reaped enormous savings in occupation costs and allowed for flexibility in post occupancy real estate and financial planning. The quality of the design and the sophistication of the technical provision have become a benchmark for similar organizations and provoked competitors to consider similar approaches.'

Credits

Client:
Merrill Lynch Europe Pty Ltd

Architect:
Swanke Hayden Connell

Construction manager:
Mace Ltd

Multi-disciplinary engineer:
Arup Paul Anderson, Gert Andresen, Nigel Annereau, Peter Bailey, Lloyd Bair, Mike Banfi, Simon Barden, Darren Barlow, Anita Batterham, Fergus Begley, Andrea Blackie, Dave Bosher, Jonathan Brecknell, Simon Brimble, Alexis Brown, Andrew Butt, Vaughn Campbell, Adam Chodorowski, Mark Collier, Richard Coveney, Kenneth Cox, Martin Crichton, Robert Dagnall, Paul Davenport, Daniel Davis, Steve Davis, Brian de Mello, Anthony Dunnings, David Eastland, Salim Esmail, George Faller, Ian Fellingham, Carlos Fernandes, Chris Field, Ian Fowler, Mark Fyson, Andrew Gardiner, Savvas Georgiou, Jeff Green, Lee Greenwood, Mike Greisen, Bill Grose, John Haddon, Stephen Hill, John Hirst, Martin Howell, Roger Howkins, Richard Hughes, Rebecca Hutt, Alan Jefcoat, Keith Jones, Tony Jones, Sam Jordan, Vince Keating, Leonard Kgathola, Felix Lai, Mark Lay, Gordon Lland, Gerry Loader, Beccy Lock, Chris Marrion, Tom Mason, John McKay, Bruce McNaughton, Chris Moore, Doug Moulton, Avtar Muker, Graham Naylor-Smith, Peter Nono-Bwomono, Paul Nuttall, Alan Ogden, Roger Olsen, Lee O'Rourke, Leigh-Suzanne Parratt, Val Pavlovic, Jonathan Peats, Alan Pepper, Graham Pitman, Dean Podesta, Caroline Ray, Andrew Reeves, Ricky Reynolds, Mark Richards, Anis Robinson, David Satchell, Julian Saunders, Duncan Steel, Jim Stewart, Sasi Suresh, Vaughan Sutton, Gavin Taylor, Ross Taylor, David Trelease, Jean Paul Velon, Cesar Villavicencio, Zoren Vulovic, Keith Wake, Paul Wellman, Catherine Wenger, Simon Willoughby, Gregory Wright, Malcolm Wright, Ray Young

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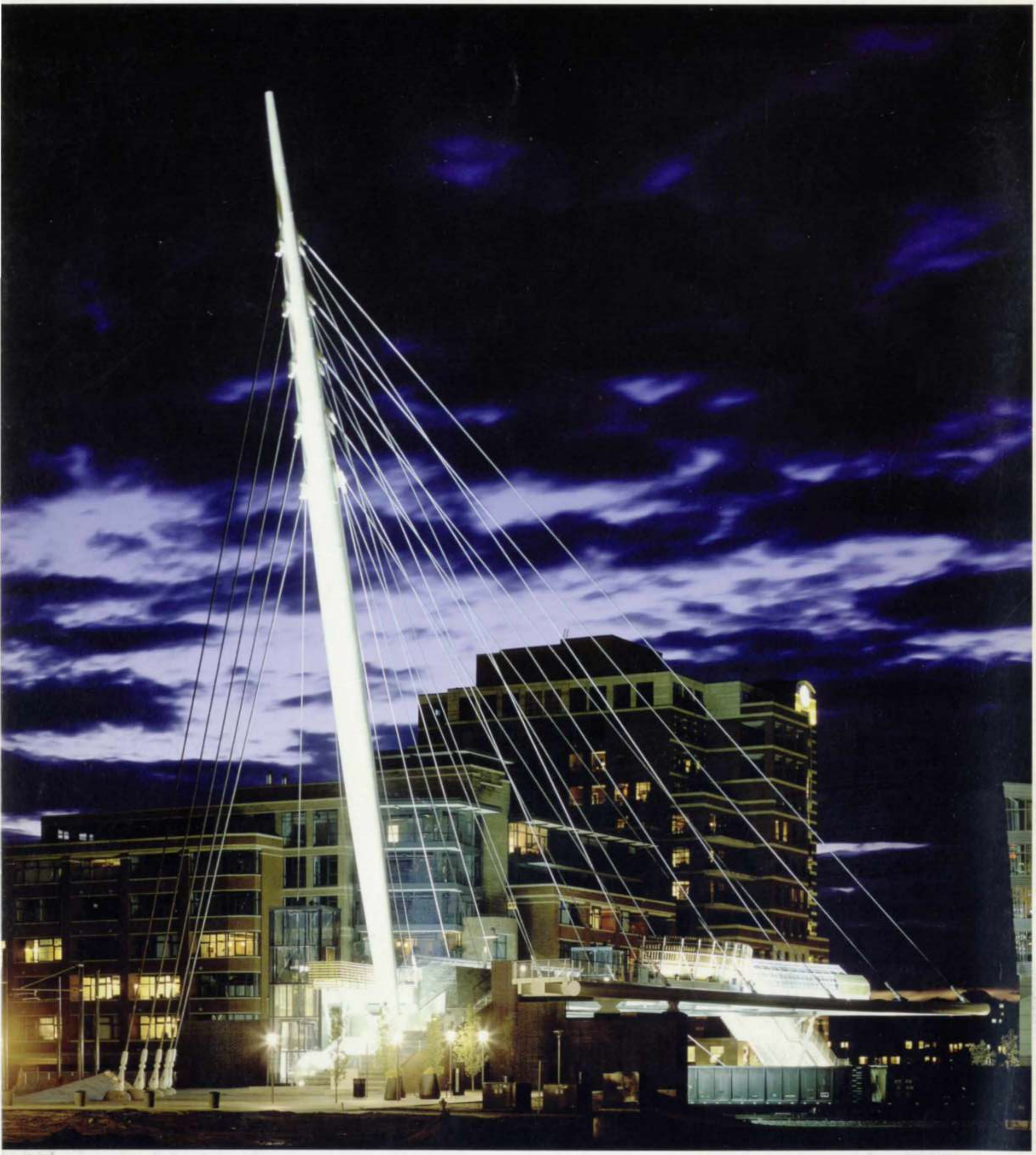

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