THE ARUP JOURNAL

4/1996

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Vol. 31 No. 4
4/1996

Published by
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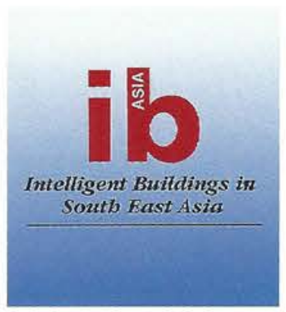
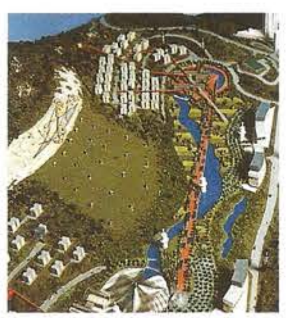
Front cover:
Phoenix Central Library (Photo: Bill Timmerman)
Back cover:
San Miguel Brewery, Hong Kong (Photo: Colin Wade)

The City of Phoenix, Arizona, wanted a 'library for the 21st century', to accommodate fully the needs of information technology as well as traditional printed sources. Ove Arup & Partners California carried out the building engineering design for this distinctive landmark building, which meets its complex brief within a tightly-controlled budget.



Arup Communications formed part of a joint venture to carry out a research project in South East Asia to identify characteristics of 'building intelligence'. This article summarises its findings, defining levels of computer-integration in buildings, and analysing the benefits and costs of integration.

Transport projects tend to carry significant risk, which in turn leads to funding difficulties. Arups' experience has shown how essential expert patronage forecasting and economic/financial evaluation are to delivering the funding that will get transport projects built. This article summarises arguments for the use of these methodologies, and discusses their use on projects in Thailand, Singapore, and the UK.

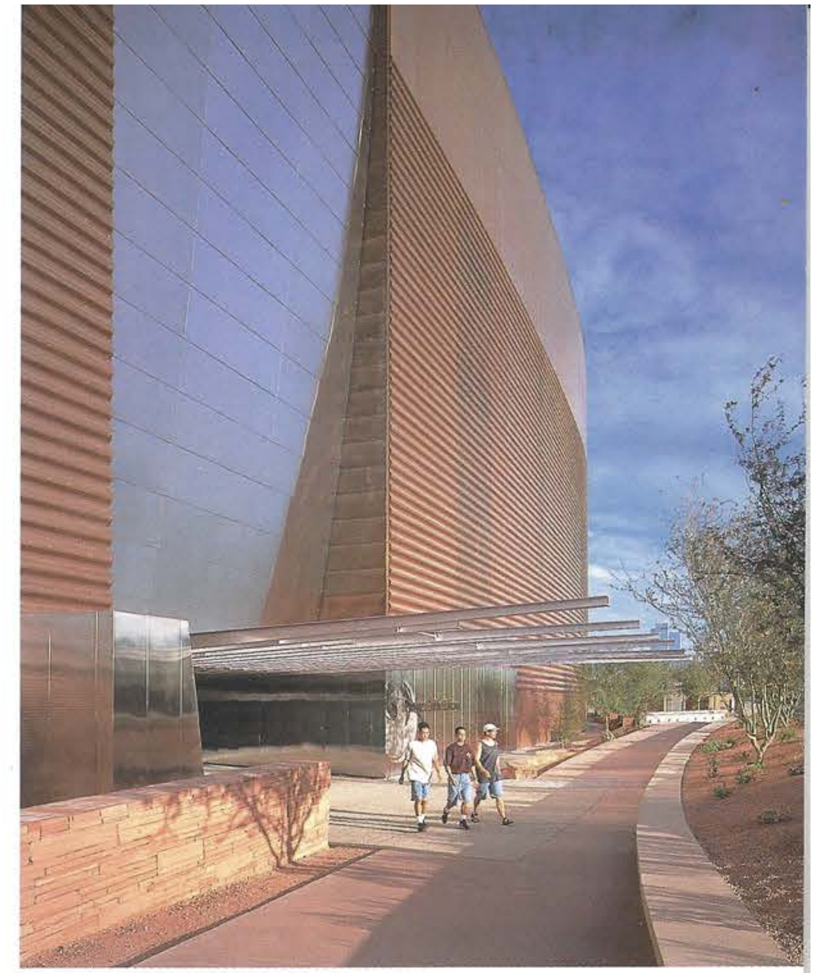


Quarrying on the hillside overlooking East Kowloon has left a major landscape scar. Ove Arup & Partners were commissioned to carry out a comprehensive study for its rehabilitation, embracing quarry development planning and land formation, engineering design, infrastructure assessment, and traffic impact. Work on implementing the study's proposals begins in January 1997.

In 1994 San Miguel commissioned two new breweries for fast-track completion in Baoding, China, and the New Territories, Hong Kong. Arups have provided co-ordinated design services for the former - plus full design responsibility for some areas of the project - and project management and construction management in addition to full design and design co-ordination for the latter. This article describes the completely different challenges for two Arup project teams in Hong Kong, supported by colleagues in London, Manila, and Nottingham.

Phoenix Central Library

Rob Bolin Nancy Hamilton



1. The polished stainless steel skin above the entrance resembles a canyon cutting through a Monument Valley mesa: an example of Bruder's use of 'functional metaphors'.

Introduction

Phoenix, Arizona, has been one of the United States' fastest-growing cities over the last decade. This growth has made it aware of the need to expand its cultural and community base, which in turn triggered plans for a new state-of-the-art cultural/arts centre to revitalise a declining downtown area. Several commissions are currently in design or have recently been completed, notably the Phoenix Art Museum, designed by New York architects Tod Williams and Billie Tsien, and Richard Meier's New Courthouse Building, for which Arups in New York has a critical role in the design of the façades and atrium.

The first new civic building to be completed was Phoenix Central Library, designed by architect Will Bruder in collaboration with DWL Architects. Bruder knew of Arups by general repute, and discovered virtually by chance that the firm had offices in California. He immediately made contact and, after a number of meetings and a successful interview, the project and the relationship were born. Arups played a major role in the realisation of both Bruder's and the City's visions for a 'Library for the 21st century'.

Will Bruder is an architect trained as a sculptor, with a studio in the desert just outside Phoenix. Having recently completed a series of innovative branch libraries for the City, he was ideally placed to design the new Central Library. The Arup team quickly realised that he and his collaborator Wendell Burnette believed in teamwork, bringing to the project great talent for investigating, examining, making decisions, and re-examining, all very quickly to meet not only schedules and budgets, but also ideals. This resulted in a cost-effective and, above all, a truly integrated building of great pragmatism and poetry.

The brief

Having outgrown their existing library, the City was looking for new premises in which all of its collections could be available, with room to expand for the 21st century. Technology played an important role in their vision, which realised that the library of the future will integrate information technology with traditional printed sources. Offices for the librarians, special collections spaces, a public reading room, and children's rooms were also part of the brief for the library as a space the public would enjoy. Initially a 240 000ft^2 (22 300m^2) building was called for, with a $28M (£20M) budget. The design team's examination of the brief discerned inefficiencies in the existing library design and, through discussions and agreement with library staff, were able to provide a total of 280 000ft^2 (26 000m^2) for the original $28M, or $100/ft^2.

The issue of energy efficiency was critical. The brief underlined the need to design for the extreme desert climate conditions of Phoenix, with summer daytime temperatures reaching 110°F to 120°F (43°C to 49°C), and that maintenance and operating budgets, as with many cities, are under strict review and are almost always reduced. For the building to be successful throughout its life, it needed to be efficiently maintained and have low energy consumption. The project also had site challenges: a quarter of its area extends out over the I-10 freeway, where the previous design of the freeway tunnel had envisaged supporting a much lighter building than a library.

The building had to be designed for future expansion, and still give flexibility for change in the meantime. It was important to avoid errors of past public building design, when structures served single functions and had limited growth or change potential, resulting in the need for early replacement or major renovation.

The solution

Will Bruder believes in total team collaboration, and in the early design phases, not a single idea or suggestion passed unexamined. Many alternatives were considered and rejected before the final solution was agreed. The critical issue was always to provide a building that mirrored and respected the desert environment. One early strategy was to emulate the traditional Southwestern adobe house, using heavy, dense concrete walls that allowed little light to enter and provided a time lag that moved heat gains from the harsh, daytime sun to later in the day. But it was agreed that the users might not have been happy with that solution.

Many of Bruder's concepts were based on his use of 'functional metaphors'. Reflecting Arizona's unique natural beauty, the building image was to resemble a Monument Valley mesa. The polished stainless steel skin above the entrances looks like a canyon cutting through the mesa, and the façade's corrugated copper panels recall the grain silos, barns, and railroad cars common to local history (Figs 1 & 2).

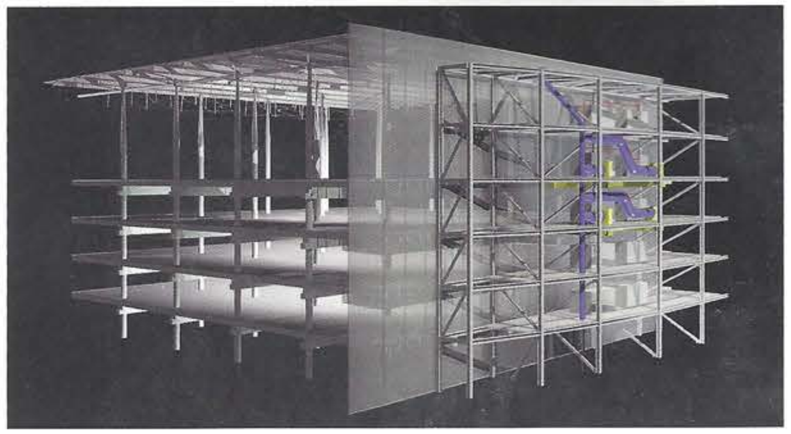
2. North elevation and entrance.

The key to the solution lay in the organisation of the library floor plan. Early schemes gravitated to the typical central core, with limited glazing on all perimeters, and mechanical equipment on the roof. However, such schemes proved cost-ineffective, energy-inefficient, and did not give the flexibility that a 'Library for the 21st century' needed. The breakthrough came during a team design meeting when a plan emerged for a service zone on each side of a 'warehouse for books'. The western metaphor was the saddlebag, where a cowboy keeps everything he needs at his side (his support space), while he rides his horse. The 'saddlebags' for the library hold the fixed service functions, like service elevators, exit stairs, and rest rooms, as well as spaces for all of the mechanical and electrical rooms and the lateral framing for the structure (Fig 3).

The 'saddlebags' embrace the east and west façades, and combined with heavyweight, dense concrete walls, reduce heat gains.

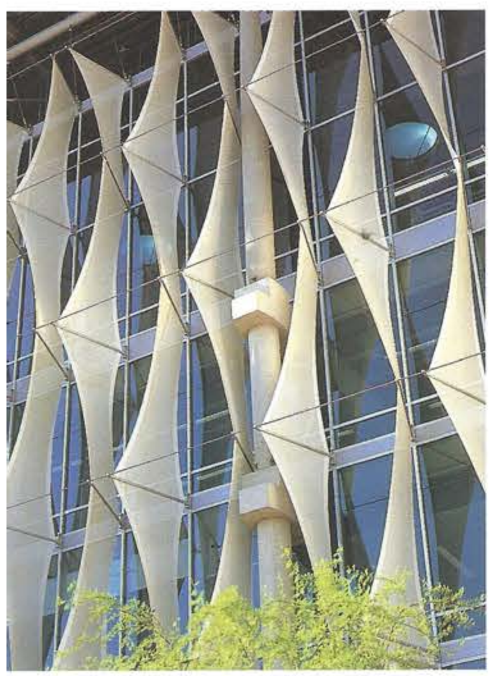
More importantly though, glazing on the north and south walls open the library to views of Phoenix, bringing in the necessary daylight for reading. Again addressing the need to minimise heat gains, the glazing on the south side incorporates external movable aluminum louvres to mask direct sun, while maintaining views and natural daylight (Fig 4). The north façade has external vertical shade sails to avoid northeast and northwest summer solar heat gains reaching the space (Fig 5).

The concept also allowed for floor-by-floor air-conditioning units, which minimised cost through limited duct distribution, and increased library flexibility. The 'saddlebags' also kept lateral structural support to the building perimeter where it is most effective, leaving relatively open areas in the interior where changes can easily be made.



3. Structural form showing braced frame 'saddlebag'.

4. Aluminium louvres at roof level on the south façade.



5. Vertical shade sails on the north façade.

Another critical issue was the desire to place the main reading room and non-fiction collection at the top of the building (level 5), which would provide the best views and ensure that users experience the library as a whole as they are drawn up through its central full-height atrium in glass elevators or onto the grand staircase (Fig 6). The reading room created the opportunity for a double-height space topped by a lightweight roof system (Fig 7).

Building engineering systems integration

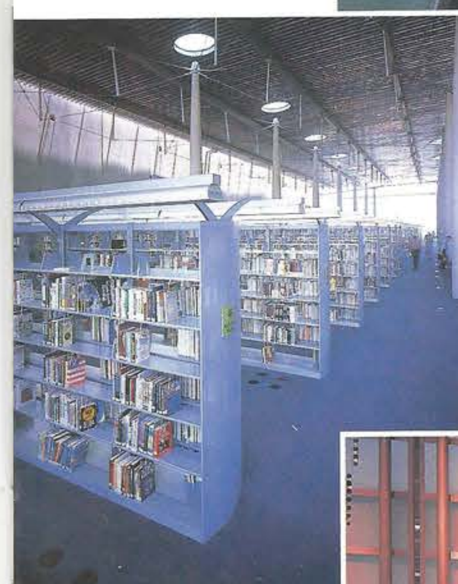
Working on such a tight budget, a rigorous services distribution logic was critical. The design team could not rely on the common solution of a dropped ceiling with services in a free-for-all below a structural zone. Budget and aesthetics dictated that the entire architecture, structure, and services be integrated.

The floor-to-floor heights needed to be minimised because of budgetary limitations and yet a sense of public graciousness was desired, which led to the use of structure as architectural finish. A very flexible, modular, precast concrete box was created and organised on a 32ft 8in (9.96m) square grid, a finely tuned dimension based on a library stack, with a specially-designed overhead light giving constant illumination down to the base of the shelf. The module was structurally efficient and repetitive, and by co-ordinating it with the stack layout, the design greatly increased stack capacity compared to a standard 30ft (9.14m) structural module. The precast floor framing is a double-T system over dropped girders. The ribs on the Ts are 30in (760mm) deep, which provides the necessary structural depth for heavy library loads as well as a service zone. The Ts span east-west on the grid lines across the building from saddlebag to saddlebag, whilst the girders similarly span north-south parallel to the saddlebags. Along the building's perimeter length, two precast concrete load-bearing walls separate the saddlebags from the main library space, doing triple duty by providing architectural finish, thermal mass, and lateral structural stability in the longitudinal direction.

To allow for services distribution in the space between the Ts, the precast girders were lowered, with their tops at the bottom of the Ts. The services run between the T-spaces, organised into horizontal zones of HVAC, lights, sprinklers, power, and data (Fig 8). The main building services distribution from the saddlebag mechanical and electrical rooms run parallel to the saddlebags, just inside the perimeter, and are integrated in what are known as the 'power bellies', two of which occur on every floor, except level five. The main HVAC supply and return ducts are in these zones as well as the main electrical power, data, and telephone cabling, plus fire sprinkler trunklines.

In the reading room at the top of the building, a cable roof covers the double-height space. The design recognised that the need for air-conditioning here should not mask the aesthetic simplicity of the roof's structural design nor the concept of the tapered 'candlestick' columns. To avoid distributing ducts at high levels, an integrated raised floor system was provided to distribute conditioned air, communications, and electrical power.

6. Looking down the 'crystal canyon' central atrium.



7. Left: Book stacks and roof structure in fifth level reading room.

8. General view showing precast girders and services between double-T floor units.

Cable truss roof

The library's crowning glory is this fifth floor reading room with its 'tensegrity' cable roof and views to the Phoenix skyline.

A network of diagonal interlocking cable trusses is supported vertically on tapered precast concrete 'candlestick' columns on the building's primary grid, and anchored at two edges by the lateral steel trusses of the saddlebags. Above the cable trusses is a system of tubular steel purlins with 7.5in (190mm) deep metal deck, insulation, and ballast. The sides of the metal deck ribs are perforated for acoustic absorption (Fig 9).

The diagonal column-to-column cable trusses consist of an upper and lower 15/16in (23.8mm) diameter cable chord separated by two vertical 4in (100mm) diameter steel pipe struts. These are common to two intersecting trusses, and continue up above the top cable chord to support the tubular steel purlins and deck. The trusses resolve at their ends to a single node at mid-depth, the top of each 'candlestick' column, which stops short of the roof surface by 6ft (1.83m). The design of that node was of particular architectural attention; it is in the shape of an abstract 'candle flame'.

Centred directly over each column is a circular, glacial blue, translucent skylight lens with a very small clear glass hole positioned such that at the summer solstice, the sun at solar noon 'lights' the candle flames at the tops of all of the columns to celebrate the first moment of another desert summer (Fig 10). The cable truss network receives its prestress from each point where the net meets the saddlebags' lateral frames. The cable net forces are diagonal to the saddlebags, resolving the prestress and loading forces into components in the precast walls along the length of the building, and into the braced frames within the saddlebags.

Structural system

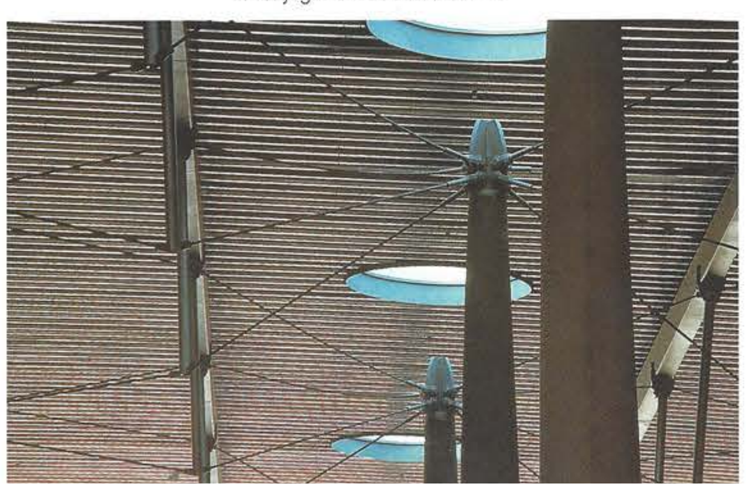
As already noted, the main structure is essentially a precast concrete box, formed of double-T ribs east/west and inverted precast girders north/south. The latter are supported by precast concrete columns with customised column capitals forming a structural corbel. The curving shape of the capital reflects the curvatures of the building's architectural language. Precast concrete bearing walls act as shear walls in the north-south direction. The saddlebags flanking the box have steel braced frames to provide lateral stability in the east-west direction by means of braced frames, as well as anchoring the cable roof.

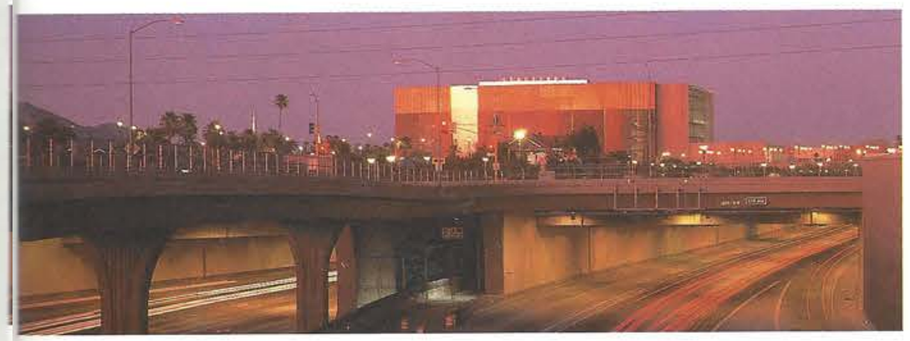
Most of the building's components were precast and prefabricated off-site and assembled on site, much like Lego. After the foundation concrete was poured, the structural steel saddlebags were erected, and then a crane used to erect the precast concrete walls and floor systems between the saddlebags. Precast concrete columns, Ts, and girders were placed, floor by floor. Topping slabs were poured in place on top of the Ts to provide a continuous diaphragm, and finally the cable truss roof was installed.

Some of the library is supported over the I-10 freeway (Fig 11). During the original construction of the deck park's tunnel structure, the area over which the library now sits was identified as supporting a future office building.

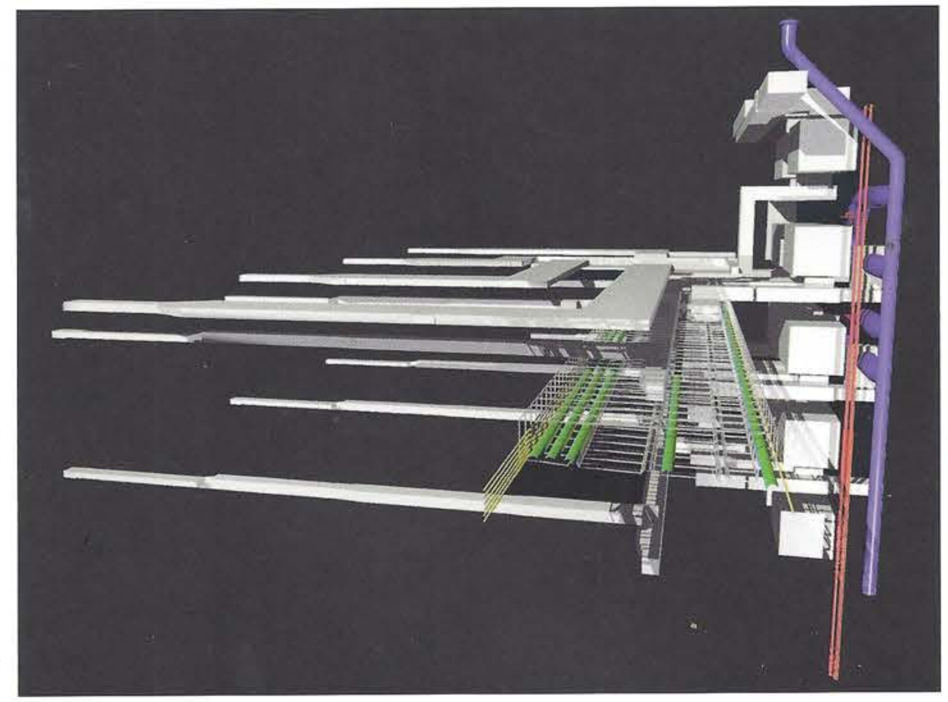
9. Below: Reading room.

10. Skylight lenses over columns.





11. Library as seen atop I-10 freeway overpass.



12. Air handling units and air and piping services distribution.

At that time, of course, future column grids and loading could not have been anticipated, and the deck park pedestals installed to receive future loads were not consistent with the 32ft 8in (9.96m) column grid, nor could they support five storeys of library. A series of in situ concrete grade beams were therefore used to transfer the column loads to the pedestals provided for anticipated columns. Because of the loading limitations of the tunnel structure above the freeway, the library's height over the tunnel is limited to two storeys and all elements made of lightweight concrete.

Mechanical systems

Gas absorption chillers and boilers in the ground floor mechanical room provide chilled water and low temperature hot water to the air-handling units in the saddlebag mechanical rooms, and to each variable air volume (VAV) unit reheat coil. The lower four floors have a VAV system, with ductwork and the VAV boxes located in the structural Ts served from the floor-by-floor main ducting running in the 'power bellies'. Air distribution into the spaces is provided through specially designed perforated ceiling panels, designed and tested at the maximum and minimum flow rates to ensure adequate air distribution through the range of flow rates. The top floor was provided with a raised floor air-conditioning system utilising smoke barriers to provide the plenums, ensuring adequate flow through the diffusers at the furthest point from the air-conditioning units (Fig 12).

It is worth noting that during design, the cooling and heating load calculations indicated that the building would use 10% less energy than dictated by the State authorities. A1996 study by students from Arizona State University indicated that the predictions were being exceeded by a further 15%.

Electrical systems

The building is serviced by two 3000A incoming supply lines from the Phoenix Power Company; the supply voltage is 480V/277V, three-phase, four wires. Power distribution is divided into east and west zones, each with two electrical risers located north and south as part of the saddlebags, which allows the cables for both feeders and branch circuit wirings to be most efficient.

Circuits serving light fixtures and receptacle outlets run inside the designated zone within the structure of the precast Ts at ceiling level as part of the overall service integration distribution.To bring power and communication wiring to each work desk, Arups developed with the architect a cable drop method, where flexible conduits snake around a tensioned aircraft cable fixed between ceiling and floor.

This provides both power and communication cables where the user wants them, as well as creating a playful sculptural gesture. On the fifth floor reading room, a raised floor accommodates the power and communication cables.

Software programmed to follow the sun's path oversees the movement of the horizontal solar louvres that reduce direct sun penetration into the building. The mirrors on the skylights above the 'crystal canyon' atrium lightwell rotate so that maximum sunlight can be directed into this space. A central computer room services both the library and the community's branch system. It also provides Internet access for local patrons.

Translucent glass divider walls between the library's public rest rooms use fibre optic cables, which appear to visitors as ever-changing colour stars.

Summary

From the initial phone call to regular visits after completion, to library patrons excited about their new building, to realising a construction cost of $100/ft^2: this project exemplifies the building engineering philosophy of Arups in California. On a recent tour with a client around the building, the success was summed up by his reaction: 'All this for $100/ft^2!' Will Bruder is among the few architects who believe not only in the master builder concept, but the master builder who listens to his clients and collaborators and moves forward with them.

Credits

Client:
City of Phoenix, Ralph Edwards, Library Director

Architect:
bruder DWL architects
(joint venture between William P Bruder, Architect Ltd and DWL Architects and Planners)

Structural, mechanical, electrical, public health, and acoustics engineers:
Ove Arup & Partners Rob Bolin, Peter Budd, Larry Chambers, Jacob Chan, Donna Clandening, Nancy Hamilton, Richard Hough, Scott Hudgins, Mike Ishler, Alan Locke, Dan Ursea, Atila Zekioglu

Consultants:
Professional Library Consultants and Mason Associates (library)
Lighting Dynamics (lighting)
Tait Solar Company (daylighting)
Construction Consultants Southwest (cost)
FTL/Happold (structural fabric)
Baltes/Valentino Associates (local MEP consultants)
Martino & Tatasciore (landscape architect)
Hook Engineering (civil engineering)
Dillion and Associates (code)
Fowley Associates (graphics)

General contractor:
Sundt Corp

Illustrations:
1, 2, 5-11, Bill Timmerman
3, 4, 12: Ove Arup & Partners