# Singapore's new National Library

Russell Cole Andre Lovatt Mani Manivannan
Alan Newbold Jim Read

**Singapore's National Library embraces innovations in information and communications technology, building physics, fire, and façade engineering to create a knowledge hub for the 21st century.**

1. The new National Library building in Singapore.

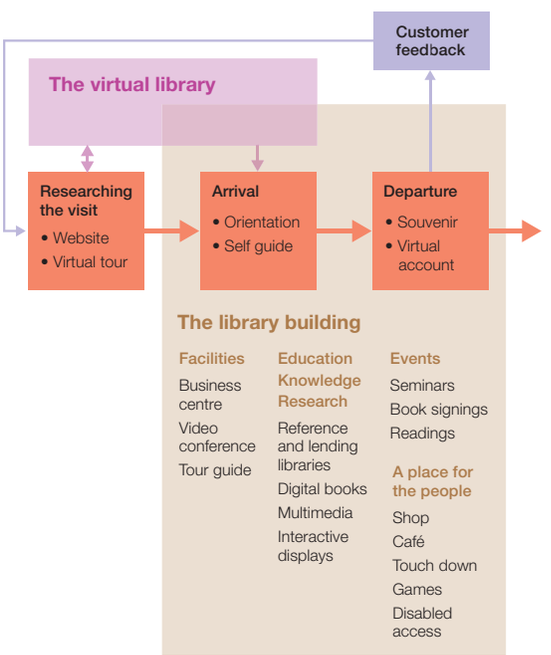
## Introduction

Singapore's National Library Board (NLB) is a statutory government organization globally respected for achievements in modernizing its public libraries. It operates 24 libraries across the island including the National Library, formerly housed in a much-loved but small brick building close to Fort Canning. In the late 1990s the NLB determined on building a new National Library to meet Singapore's aspiration as a centre for knowledge, learning, and technology - a state-of-the-art facility that combined a building for the tropics with the latest information technology.

The Singapore government, keen to lay the foundations for a 21st century knowledge-based economy, initiated the "*Library 2000* vision" in the mid-1990s, as a part of structural changes that would safeguard the future competitiveness of Singapore's economy. During the project's concept stage the then NLB Chief Executive, Dr Christopher Chia (holding a PhD in information technology), was tasked with achieving the vision and objectives set out in the *Library 2000* document. He promoted a new landmark National Library building as the key facility for realising those objectives.

Whilst an architectural statement was needed to connect with the citizens of Singapore, the contribution of technology to the success of the transformation project was given very high prominence. This focused on improving services to all types of library users – young and old, students and professionals - by giving access to patrons through both virtual and physical media, and at the same time reducing operational costs (Fig 2).

2. The visitor journey.



Traditionally, libraries are thought of as learned, academic, and rather stuffy environments. The vision here was to redefine the services offered and change the way they are delivered, and the NLB believed the solution lay in adopting innovative technology to bring a new learning experience to Singapore's citizens.

Named after Dr Lee Kong Chian, in honour of the Lee Foundation's S$60M donation, the reference library aims to be the premier research and academic resource on Singapore and the region, occupying Levels 7-13 at the NLB building, with a floor area of 14 265m$^2$. By July 2005, when the new building opened, the collection exceeded 530 000 print and non-print materials. The library's full range of services includes reading/meeting rooms, wireless access to the internet, access to electronic databases, document delivery, microfilm, reprography, and audiovisual resources.

The new facility is not only an impressive reference (and lending) library but also seeks to be a focus for national events and social activities, with a 615-seat concert-grade auditorium, 14 sky gardens, and a roof-top observation pod (Fig 3).

## Arup involvement

A consultant consortium led by the Malaysian-based architectural practice TR Hamzah & Yeang (now Llewelyn Davies Yeang) won the design commission early in 1999, and Arup's involvement dates from the same year. In December the communications group, based in London, was appointed by the NLB of Singapore as information and communications technology (ICT) consultant. The façade design involvement that stemmed from the consortium's competition win became, in 2001, a direct commission for Arup's façade engineering team in Singapore itself.

For the communications group this was a milestone win - the first assignment where it could offer a fixed-price tender for a long-term project without its staff being locally resident. Planning the bid response, collating relevant content and working up a financial model that factored effort, risk, and expenses over a period of four years (in the end six years) was a challenging task. After award of contract, the client praised the quality of the bid response, the range of skills and experience, the reference projects, and the understanding of the NLB's functional requirements in the context of a large construction project. Though Arup did not bid the lowest price, the team was determined to add significant value in the NLB's quest to lead in technology-based service delivery at the new library, interpreting the client's vision with creative yet practical ideas. Of particular value was Arup's international experience in procuring and deploying business-centric ICT solutions.

As for the façade design commission, during the development stage Arup worked closely with TR Hamzah & Yeang to develop the design and find solutions that maintained the design intent, achieved the technical performance requirements, and were practical. This last aspect was a particular challenge because of the envisaged ambitious form of the building. Arup was responsible for preparing outline designs and specifications for the tender package for the develop and construct main contract, and was a major participant in the client's tender review panel that eventually selected the main contractor Nishimatsu Lum Chang Joint Venture (NLCJV).

## The ICT design

An early challenge facing the communications team as it joined the project at scheme stage was to add innovation and value to the design proposals for technology systems. The team was asked to create and test concepts for several systems integration and intelligent building opportunities that would improve staff and visitor experiences.

In meeting this challenge, the Arup team was able to draw on extensive experience of both architectural and construction-facing aspects of ICT design, procurement, and delivery in offering its advice.

### *RFID and interface between CCTV and IP network*

One of the first major ICT projects that the NLB implemented, and in which it currently leads the way globally, was RFID (radio frequency identification) tagging. All NLB books in Singapore have a discrete passive RFID device to enhance four key library processes. This:

- eliminates the need for staff to be present for a patron to borrow or return a book (Fig 4)
- minimizes the time between a book's return and it being back on the shelf for others to borrow
- eliminates the need for a patron to return a book to the same library it was borrowed from
- improves security of the books - the NLB's most valuable asset.

A big problem with Singaporean libraries is their very popularity. To enable patrons to see the build-up of queues and the number of people in the library from its website, and without installing additional cameras, 32 analogue security cameras feeds that would not impact the integrity of the security system were selected and fed into multiple axis digitizers and then output through the IP network to the web portal.

3. The roof top observation pod.

4. The new automated borrowing stations.

5. The nGuide PDA in use.

*Customer experience enhancers*

Another challenge tackled by Arup was the NLB's requirement for its patrons' library experience to be enhanced. Arup's research & development group was commissioned to come up with some innovative ideas. These included concepts for capturing and visualizing, through devices like infrared motion sensors and computerized virtual networks, the movement of people and the patterns of their usage of the library's various services, and for personalized interfaces for users with the library. From these concepts came four major work streams aimed at providing IT solutions to meet the following NLB requirements:

*nGuide:* To enable NLB staff to give organized Library tours to visitors and VIPs, an "eControl" application was developed for remotely controlling all plasma displays individually via personal digital assistants (PDAs) connected to the WLAN (Fig 5). This enables tour guides to toggle content between dynamic signage, corporate presentation, video, and digital audio to match their verbal commentary as they follow the tour route. It can also identify immediately when additional stops are available on the tour whilst giving the latest commentary to the guides to update them on changes as they occur in real time.

*Virtual tour:* One of the hardest challenges was to make as much content as possible available via the internet, giving as many users as possible access to the Library's unique collections. Unfortunately copyright legislation has meant that this project is still ongoing. However, to give internet users some experience of the Library, a virtual tour at http://virtualtour.nlb.gov.sg/ provides a snapshot of the building's unique architecture and describes some of its facilities (Fig 6).

*Researcher portal:* One principal focus of the Library is the 500-1000 world researchers that come to the Library every year as part of an international research project. To facilitate access to the information they need, NLB required some specific portlets to be created. These give researchers a toolbox of resources, including access to premium databases and knowledge repositories as well as limited virtual storage for internet search results and other electronic data. In turn this led to redevelopment of the LKCRL and NLB websites at http://www.nlb.gov.sg (Fig 7).

*iSouvenir:* This kiosk (Fig 8) was designed for patrons to take something away with them as a souvenir of their visit. This included being able to print off bookmarks and send e-postcards or photographs to their friends. On opening day this proved to be one of the most successful additions to the library - the printer ran out of paper within an hour!


6. The virtual tour.


7. Researcher portal.


8. The iSouvenir kiosk.

9. The main server room.

10. In the large triple-height spaces of the library, the mobility afforded by wireless devices is important.

*Next generation infrastructure*

*MPLS LAN:* To support these applications, plus the other essential databases and NLB enterprise applications, all information is routed across a single NLB-owned IP infrastructure. Before the library opened, all the NLB central servers and core equipment was at the Network Operations Centre (NOC) in east Singapore, but having considered the implications for disaster recovery, security and risk of this set-up, Arup proposed to use the new Library's main server room (MSR) as a resilient hub for the NLB central servers and core equipment (Fig 9). Today, all the other 22 libraries are connected into the MSR and NOC through a diverse MPLS IP carrier grade network. Each server is also set up for full resilience should either the NOC or MSR fail. During commissioning of the IT infrastructure, a full power shut-down of the building was performed to make sure that the failover to the NOC would work under real fault conditions.

In addition to the MPLS core, the NLB had an extensive Cisco gigabit Ethernet network installed, able to provide fixed connections to the users at up to 1Gb/sec. This IP network has resilient connections to Singapore ISPs from opposite sides of the building.

*Wireless LAN:* One of the newest infrastructure elements to be installed is the extensive NLB-owned wireless LAN. This provides connections at up to 54MB/sec for NLB staff to their corporate services from anywhere in the library, and free internet access for users from any public area. About 100 hidden dual-standard access points in the ceiling connect into two resilient connected wireless LAN controllers supplied by Aruba Networks. This infrastructure is also used for additional services to NLB staff and the public, eg the nGuide application described earlier.

*Cabling infrastructure*

Due to the unique requirements to serve not only the NLB but the Drama Centre and other tenants' different ICT services, and the important regulatory restrictions in place for a Singapore government statutory body, three different cabling infrastructures were required. To provide connectivity to the various end devices about 6500 Category 6 ICT outlets were installed in various locations:

- in ceilings, for initial and future wireless LAN connectivity
- a "grid and grommet" solution on all library floors to give flexibility to change the floor layout, redo the ICT cabling, and eliminate intrusive and easily damaged floorboxes
- on all public-facing desks to enable patrons to access the free intranet services and the internet
- additional ICT outlets and wireless connectivity in all conference facilities and meeting rooms
- specific outlets to service the PA and RFID systems, and provide connectivity to the multimedia stations, kiosks, borrowing stations, and electronic catalogue search stations.

As well as the Category 6 cabling system, a supplementary Category 3 system was installed, terminating in different risers and a different central copper exchange for provision of a Centrex telephony service to NLB itself, and external connectivity from public telecommunications operators to other tenants of the building.

Finally, a coaxial-based distribution system was installed for the master antenna television system to distribute free to air and subscription television services to NLB and the tenants within the building from the television providers in Singapore.

11. Information counter: an essential and easily accessible resource for using the reference library.

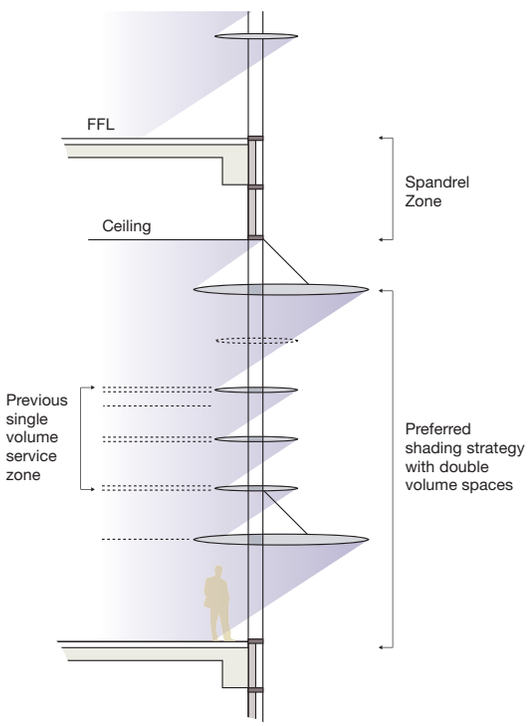
## The façades design

After award of the façades contract, Arup's role was to review the designs, fabrication, and installation. This involved working closely with the specialist sub-contractor on its designs, assisting with co-ordination issues, and working through the proposed details.

With the key need to support the architectural design intent, Arup reviewed the proposed materials and resolved the various interface and co-ordination issues with other elements and trades. For its part the contractor's team had to meet the demands of the performance specification. A large full-size mock-up of the façade was assembled to finalize the position of joints and selection of materials - the glass in particular.

### *Design for tropical conditions*

The library has a commanding presence in the Bugis–Bras Basah district of central Singapore, with its predominately white structure and surrounding shades. This is partly because the parameters set for the design team ultimately inspired and drove the architectural outcomes. The building had to be able to respond to the tropical climate. Solar heat, humidity, and light could potentially make it very uncomfortable for its occupants and threaten the important collection. The façade design was crucial in both respects.




12. Cross-section through sunshades.

13. Exterior sunshades in place.

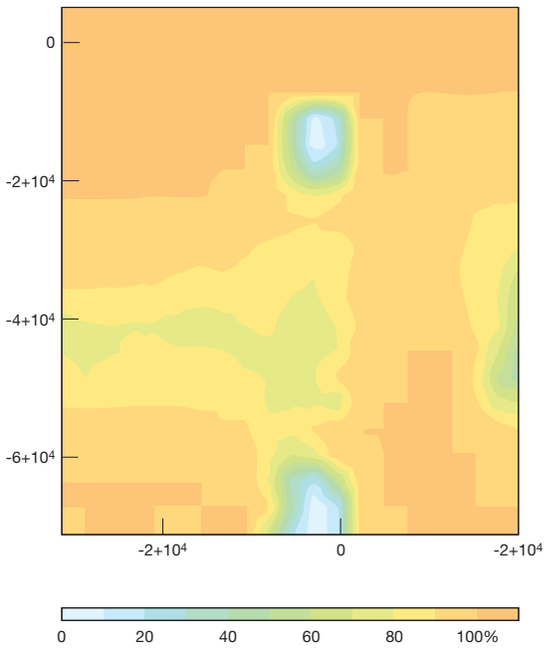
The building had to be heavily shaded to reduce solar heat gain through the façade, and so a 30° solar cut-off was adopted, ie there should be no direct sunlight visible in the building when the sun was 30° and more above the horizon. This gave the design team an unusual challenge: though almost no direct sunlight should enter the building between 10am and 4pm, as much useful daylight as possible still had to penetrate so as to allow artificial light to be reduced.

In response, the team designed what are probably some of the world's biggest sunshades on a curtain wall, projecting up to 1.8m from the face of the glass (Figs 12-14). These wrap around the building and control solar radiation and glare, yet maximize daylight. To speed installation and to avoid the difficulty of fixing in mid-air, they were attached to the curtain wall before erection. The need to support the sunshades and the 5.4m storey height led to the curtain wall mullion being 250mm deep - the maximum available for most aluminium extrusions.

It was accepted that part of the shades could be located inside the building as these would also cut the sunlight, but any energy in the radiation that had passed through the solar selective glazing would still enter the building. Several studies of window height and shade spacing were conducted to determine the best option. Eventually, a general vertical module of 1.1m was adopted with a 2.2m module closest to the floor. This generated shades up to 2.4m wide, with a 1.2m shade inside.

For the typical curtain wall panels, these shades were supported by deep steel plates projecting out of the aluminium mullions, in combination with tie rods. These were added at site, allowing the panels to be transported flat. Each shade had the same basic construction but the form was modified to create the intended sweeping lines. Clear double-glazing completes the façade, coated to cut down on energy transfer from solar radiation and ambient temperature. A visible light transmission that avoided glare problems was selected.

14. Interior sunshades in triple-height space.




15. Daylight autonomy map showing probability of daylight exceeding 250 lux.

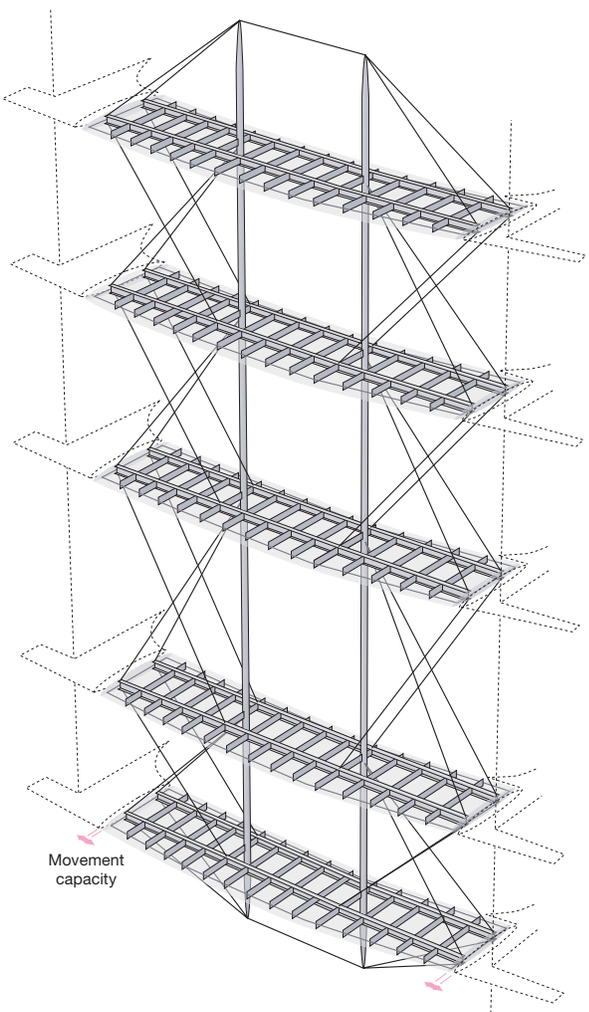
Some areas of the building have automated drop-down blinds that engage when the sun is too low for the sunshades to be effective; a daylight autonomy map (Fig 15) predicts that these will be needed for at least 2% of the year. (Daylight autonomy is the percentage of occupied times per year when the minimum illuminance level can be maintained by daylight alone.)

*Laneway sunshades*

The pattern of shades continues around the building. Between the two main blocks, they span up to 6m wide and 14m long, but only 400mm deep. Together with natural breezes, the shades here create a dramatic enclosed environment which, though in a humid tropical climate, remains comfortable.

From the start, the architect conceived these shades as being tied together by pairs of vertical tubes that do not reach the ground; and, as the shades are a continuation of the main shades for the curtain wall, they need to be as thin as possible. The structural concept developed into a floating framework of steel frames supported on bearings on the main blocks each side of the laneway. Diagonal ties were added, and the final arrangement is reminiscent of the wings on a World War One triplane (Figs 16, 17).

A complex arrangement of bearings restrains the suspended shades laterally and supports them vertically, but lets them articulate on plan and not tie the bundings together. To minimize the size of these articulated joint to account for building movement, one was to be put at each end of the sunshades, but during development of the final detail by the specialist subcontractor, the joint locations were studied further and it was decided to fix one end of the shade and let the other float. Nonetheless, the thin overall sections were maintained, resulting in a dramatic structure to enclose the laneway space.




16. The final design of the laneway sunshades recalls a World War One triplane.

*The beauty of glass versus the challenge of light*

The entire façade is glass. Considering the local environment, and the goals the design team was determined to meet, its selection and properties were critical to the building's success. The main contractor undertook a comprehensive study in which the visual light transmission of the glass in combination with the position of the shades was checked using a complete three-dimensional model of the building. Arup analyzed the process and its results in detail. The design intention was to use clear double-glazing, and the study verified that visible light transmission would be acceptable, but that some small adjustments to the shading arrangement, duly implemented, could produce even better results.

Thermal flows through the aluminium sections and the acoustic performance of the façade were also assessed in detail - leading to further refinements - but the biggest impact on the final shape of the extrusion came from incorporating conduit paths to the external lighting in the sunshades.

*Testing the design*

With the design finalized and custom aluminium extrusions in production, performance prototype testing on the curtain wall system ensued.

The test specimen was 10 full panels in two rows and a strip of half height panels. Assembling a full section of the curtain wall also allowed the architect to fine tune the design, and the contractor to trial production and installation methods. This demonstrated that the contractor's design met all the various strength, waterproofing, and air infiltration requirements. After the main test, panels were used to resolve a design issue as described below.

The library needs to be a quiet place, so the curtain wall was also subjected to acoustic testing, both for transmission of sound into the library spaces and to review the noise from rain falling on the aluminium sunshades.

17. Sunshades in position in the laneway.

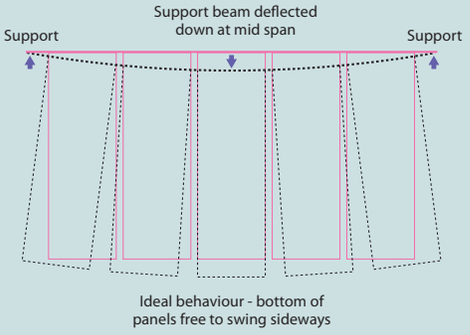
**The curtain wall - straight lines or stress-free deflections?**

During design development, the sub-contractor suggested a restraint to the bottom of the curtain wall panels, and so a clip was proposed in the cavity of the interlocking sill at the bottom of the prefabricated panels.

Although this would make aligning the panels easier, there was concern that it would prevent free movement and create stresses in them, leading to tears in the sealant or structural failures. Five panels from the prototype test were, therefore, suspended from a steel beam (representing the floor slab), and after a survey of their position and the joints, the beam was deflected and the panels' new position found.

They were expected to fan out, remaining square, with the slope of the top edge following the relative height of the brackets at each side (Fig 18). The restraint in the joint affected the panels, which now rotated, tipping the fixed bottom corner. The result was that the critical seal between panels was distorted increasing potential for leakage.

The joint was thus detailed to allow free movement and the panels' alignment achieved with care during erection.




18. Panel behaviour.

As production got under way, Arup team members visited the subcontractor's fabrication plant to review his progress and crosscheck his QA/QC procedures. Finally, the panel installation was inspected, including defect monitoring to ensure quality throughout the process.

*Maintaining an icon for the long term*

Given the building's unusual form, a full range of access equipment was needed. The main building maintenance unit is a gondola suspended from a monorail running around the underside of the roof level shading. To clean the glass between the shades, the gondola incorporates a pantograph system with counterbalances that positions the operators 500mm from the glass face. There is also capacity to carry the glass panels not accessible from the inside. Elsewhere on the building, access is provided to walkways with safety lines to allow cleaning and maintenance.

19. Opening celebrations, November 2005.

## Conclusion

The Singapore public's enthusiasm for the new library was demonstrated at the "Soft Launch" on 22 July 2005 when many people queued for hours before the 10am opening. On the first day there were 40 000 visitors, with 14 000 of them visiting the lending library and borrowing 12 000 books! Four months of consolidation followed, as staff, contractors, and consultants completed the final fit-out works ready for the official opening ceremony on 12 November in the presence of the President of Singapore (Fig 19).

In the same year The National Library won the platinum Green Mark Award, the Building Construction Authority of Singapore's highest honour for environmentally-friendly buildings. Buildings which have achieved the Green Mark Award are recognized for their sterling efforts and commitment towards environmental sustainability. In general, Green Mark buildings have adopted energy-efficient features and water conservation measures which set them apart from other buildings. They have also made substantial use of greenery in their projects and taken care in ensuring a good indoor environment quality for their users.

The National Library obtained the Green Mark Award for:

- initial design studies including computer stimulation and modelling to optimize the building orientation to protect from direct solar radiation and to maximize the use of daylighting and natural ventilation
- sunshading providing an additional shield against solar heat gain
- energy-efficient features including lighting, motion sensors, and equipment; daylight sensor used together with automatic blinds at the building façades
- extensive landscaping, sky terraces, and roof gardens to lower local ambient temperatures and the adoption of automatic irrigation system for rooftop gardens to conserve water
- automatic integrated daylighting zoning and control using daylight sensors.

### Fire engineering design

Arup's fire engineering group was engaged by NLCJV to assist with its bid for the main contract, and Arup's proposal to eliminate large proportions of the fire protection allowed NLCJV to submit the significantly lower price that helped it win the project. As a result, the National Library is one of the first buildings in Singapore to have performance-based design of its structural steel fire safety.

Traditionally, structural steel beams are coated with sprays, boards, or paints for fire protection. This can be expensive, and requires maintenance throughout the building's lifetime. Arup's design allowed for most of the steel floor beams to be either unprotected or to have reduced applied fire protection, while maintaining the building's structural stability in a fire. This enabled the bare steel structure to be expressed and enabled cost-effective construction of the building.

The performance-based solution also allowed the two blocks to face each other with no additional fixed fire protection systems. The authorities were initially concerned that a fire in one block could spread to the other, but Arup demonstrated this would not occur and eliminated the need to install additional fire protection measures.

**Russell Cole** is an Associate Director of Arup in the Singapore office.

**André Lovatt** is an Associate Director of Arup in the Singapore office.

**Mani Manivannan** is an Associate of Arup in the Communications London Group.

**Alan Newbold** is an Associate of Arup in the Communications London Group.

**Jim Read** is an Associate Director of Arup in the Communications London Group

**Credits**

**Client:** National Library Board of Singapore
**Architect of design:** TR Hamzah & Yeang Sdn Bhd
**Engineer of design:** Buro Happold Singapore Pte Ltd
**Communications and IT services, façade, and fire engineering designers:** Arup - David Barber, Michael Chin, Russell Cole, Ben Coulson, Daniel Davis, Ran Fan, Liew Kim Hoe, Rajan Janakiraman, Peter Johnson, Richard Johnson, Aditya Kapoor, Ken Kilfedder, Ada Law, André Lovatt, Chris Luebkeman, Mani Manivannan, Tom Mason, Robert Morgan, Graham Naylor-Smith, Alan Newbold, Pecksuan Ng, Jonathan Peats, Stephen Phillips, David Proe, Kash Qadeer, Mohan Raman, Jim Read, John Ryder, Sam Shemie, David Smith, Justin Trevan, Duncan Wilson, Ruth Wong, Joanne Woo **Project manager and quantity surveyor:** Rider Hunt Levett & Bailey **Design and build contractor:** Nishimatsu-Lum Chang JV **Project architect:** DP Architects Pte Ltd **Project civil/ structural engineer:** Maunsell Consultants (Singapore) Pte Ltd **Project M& E engineer:** Beca Carter Hollings & Ferner (SE Asia) Pte Ltd **Specialist façades subcontractor:** Permasteelisa Group
**Illustrations:** 1, 3, 20 Arup/KL Ng Photography; 2, 12, 15, 16, 18 Nigel Whale; 4, 9 Alan Newbold; 5 Teik Tian Seah; 6, 10 Jeffrey Ng; 7, 8 Singapore National Library; 11, 19 Jim Read; 13, 14, 17 Russell Cole.

20. The Singapore National Library at night.