



# Sustainable Construction

Materials for Buildings



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## FOREWORD

*Sustainable construction* refers to the adoption of building designs, construction methods and materials that are environmentally friendly. It also means using materials and resources that have sustainable supplies and are readily available from many sources. Through *Sustainable construction*, we will do our part to optimize the use of natural resources via recycling and reuse of materials. This will also reduce our dependence on raw building materials, given the current disruption in the supply of concreting sand and granite.

I urge all stakeholders in the industry, including developers, designers, builders and suppliers, to make a concerted effort to adopt *Sustainable construction* in their building projects.

This publication serves to provide an introduction to various *Sustainable construction* techniques and materials to industry stakeholders and consumers. Let us make *Sustainable construction* as a distinctive characteristic of our construction industry and of the built environment in Singapore.

Mah Bow Tan  
Minister for National Development



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# A New Opportunity

The building and construction industry plays a critical role in Singapore's economic and social development. By providing a first-rate built environment, it contributes to our continuing economic competitiveness and the quality of life of everyone who visits us or lives and works here. Going forward, the industry has to transform itself in order to deliver an excellent built environment for the future growth and development of Singapore as a global city of distinction. The Building and Construction Authority (BCA) has been working with the industry to promote the wider adoption of green building technology, energy efficient buildings, universal design and barrier-free access in our built environment. More, however, needs to be done.

Sustainable construction will enhance the resilience of our building and construction industry by using materials and resources that are available from many sources in the world. It also means adopting construction methods that are environmentally friendly, faster, quieter and less labour-intensive. It challenges our builders to use innovative materials and products that meet the ever rising quality expectations of their clients. And with sustainable construction, more materials that can be readily recycled and reused for the same or similar purpose will be used. This reduces waste and promotes environmental sustainability.

However, the drive towards more Sustainable Construction is achievable only when all the stakeholders in the industry, including developers, designers, builders and suppliers recognize and appreciate its importance. We need all parties to make a conscious decision to adopt the use of sustainable materials in their building projects. We also need to educate and raise awareness of consumers on Sustainable Construction since ultimately, it is consumers' demand that will motivate and even dictate the industry's trend.

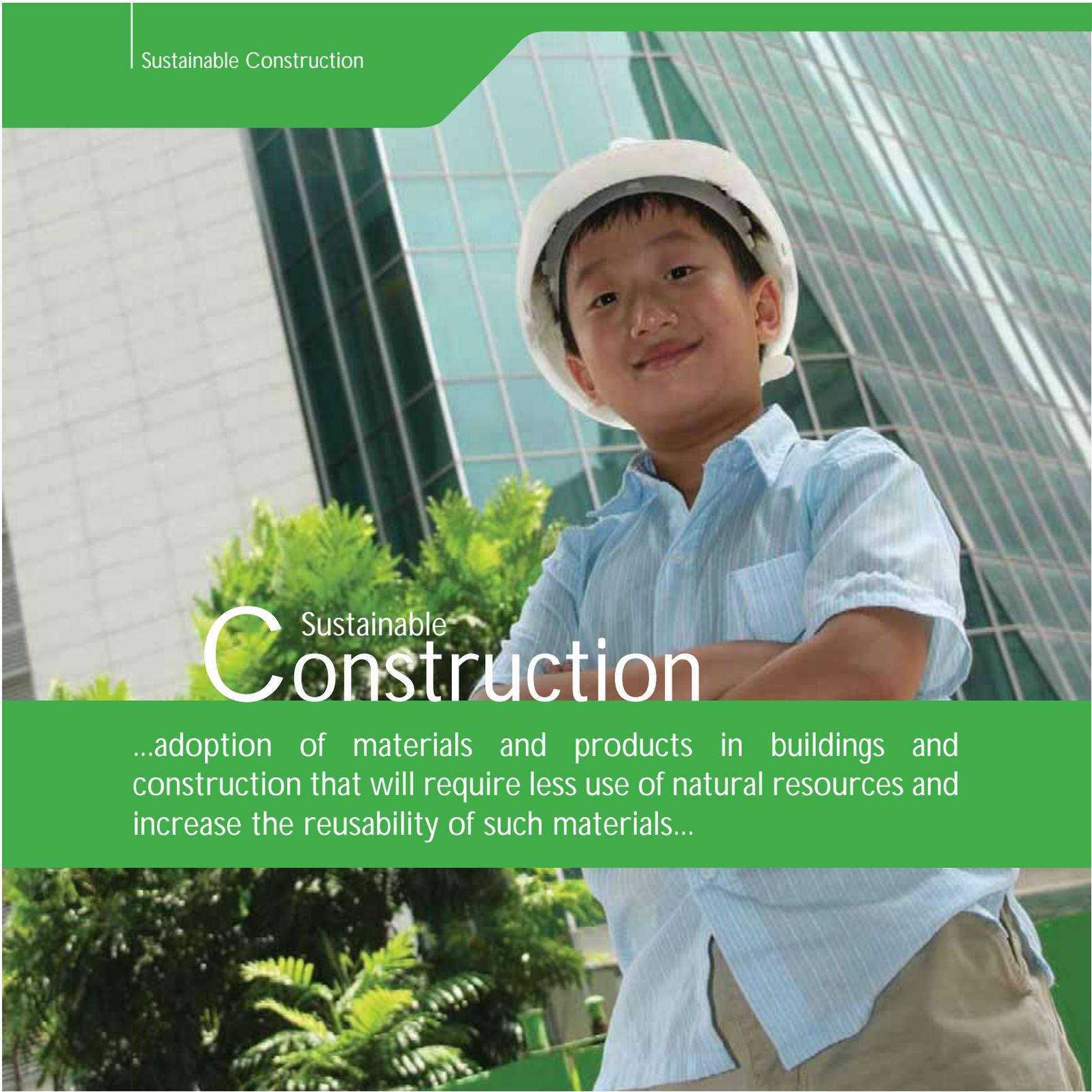
This publication focuses on the use of steel construction as well as other building components using sustainable materials. There are three parts to this publication. Part One introduces sustainable construction and the advantages of using steel. Part Two covers the various prefabricated building components such as drywalls, prefabricated bathroom units, claddings/facades as well as recycled substitutes and addresses performance issues such as fire resistance, vibration and acoustics. Part Three features overseas and local projects that have used sustainable materials in their construction.

This is a new opportunity for developers, designers and builders to bring the industry to another milestone in promoting the sustainability of our built environment.

Quek See Tiat  
Chairman  
Building And Construction Authority

Dr John Keung  
Chief Executive Officer  
Building And Construction Authority

Sustainable Construction



# Sustainable Construction

...adoption of materials and products in buildings and construction that will require less use of natural resources and increase the reusability of such materials...



*Steel and glass are examples of sustainable materials*

## **What is Sustainable Construction?**

Sustainable Construction is the adoption of materials and products in buildings and construction that will require less use of natural resources and increase the reusability of such materials and products for the same or similar purpose, thereby reducing waste as well. Sustainable construction also enhances the resilience of the industry as such materials are readily available in the world market. Steel, other metals, glass and prefabricated parts using combinations of these, as well as recyclable substitutes for concrete are examples of sustainable materials and products.



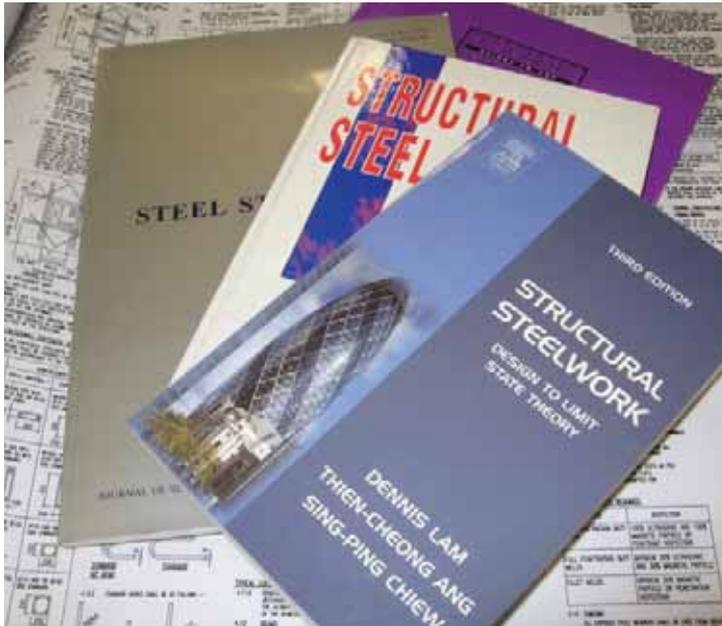
*The use of sustainable construction materials and products is part of the overall environmental sustainability effort*

## Sustainable Construction and Green Mark

In January 2005, BCA launched the Green Mark for Buildings Scheme to promote environmental sustainability in buildings. The Green Mark Scheme encourages the adoption of various green building features, technologies and innovations to achieve better performance in energy efficiency, water usage, use of recycled and reusable materials, indoor environmental quality and environmental management. Many new building projects are adopting the Green Mark.

The use of sustainable construction materials and products is part of the overall environmental sustainability effort. Sustainable construction will also be factored into the Green Mark for Buildings Scheme in the future.





*Bring in relevant suppliers and specialists early in the design stage*

## Achieving Sustainable Construction

Sustainable construction starts with planning and design. The developer's and designer's roles are therefore critical. However, as sustainable construction involves prefabricated products, it would be helpful to bring in relevant suppliers and specialists early in the design stage. Implementation down the entire construction value chain is also important. There is a need for sharing of knowledge and expertise in design and the use of such materials. Equally critical is the building of capabilities and skills in construction and installation. The performance of such buildings in safety and quality should remain



*The industry must build up its capabilities and skills in construction and installation*

high. As the use of steel in construction has been relatively low in the industry, the gearing up and development of such knowledge and capabilities will be given priority.

Design professionals (architects and engineers) can specify materials that reduce the use of natural resources such as sand and aggregates. In instances where non-structural concrete or aggregates need to be used, recyclable and reusable construction materials should be selected wherever possible. For instance, alternatives such as recycled crushed concrete can be used as hardcore in road or pavement instead of using new stones.

Other prefabricated non-concrete components such as glass facades, cladding, metal parapets, prefabricated bathroom units are good choices of sustainable products. Drywall partition system is also a good alternative as it consists of stud frames and plaster/cement boards and consume little sand.



*Prefabricated components like glass facades and metal parapets are good alternatives*



Steel is an excellent reusable material. Independent agencies (and some steel producers) around the world have performed life-cycle analyses on the environmental impacts of using steel. Based on the results, informed designers can confidently specify steel products in their various forms for projects of all sizes, from single storey, low rise to high rise buildings.



*Collection of scrap metal for recycling*



*Prefabricated steel sections do not generate any waste at the site*

Steel can be recycled repeatedly without any degradation in terms of properties or performance in quality.

Steel construction has excellent low waste credentials during all phases of the building life cycle. It generates very little waste, with the by-products of steel production widely reused by the construction industry. Any waste generated during manufacture is recycled. There is virtually no waste from steel products on the construction site.

Construction using sustainable materials offers many benefits throughout the various stages of a building's life cycle, as elaborated in the following pages.

## Benefits

### Strong and light

Steel has one of the highest strength to weight ratio of any construction material. Steel framing can weigh only one-third as much as traditional construction materials. When connected by fasteners, a steel frame is stronger than traditional systems. This provides savings in the foundation and to the amount of craneage needed on site.

Similarly drywalls are strong and yet lightweight. The drywalls are only 10-15% of the weight of masonry walls, but they can support plasma TVs and kitchen cabinets just as well as conventional masonry walls.

### Labour Saving

Lightweight steel framing systems are generally simpler to erect than conventional systems. Once the workers are experienced with steel, labour time and costs will be reduced considerably. In addition, framing members are manufactured

with pre-punched holes for running pipes and electrical wirings, minimizing preparation work for such trades.

### Design Flexibility

Because of its strength, steel can span greater distances offering larger open spaces and increased design flexibility without requiring intermediate columns or load bearing walls. For instance, an opening in a floor can be created by removing the desired number of steel beams with minimal hacking.

Such flexibility also extends to drywalls. Remodeling can be easily accomplished with non-load bearing drywalls. They can be readily relocated, removed or altered. Because studs are attached with screws, they can be moved easily to ensure accurate attachment of wall board and other components. This flexibility is very useful as home and office lay-outs need to be changed over the useful life of the building.



*Steel frames offer large open space*



*Drywalls are manufactured under stringent quality control*



*House using steel construction can save as much as 40% in construction period*

#### **Better Construction Quality**

Steel sections and joists are all manufactured according to international standards of strength and consistency under closely controlled factory conditions, resulting in uniform quality. No re-working is necessary at site.

Steel does not suffer from creep or shrinkage and when properly protected, does not rot or decay.

The other prefabricated components like drywalls are manufactured in factory under stringent quality control. The walls will always be straight and smooth without the need of plastering.

#### **Speed**

Steel buildings can be erected in much shorter time as compared to concrete buildings. Time saving in the construction period can be up to 40%.

#### **Minimal disruption**

Steel construction can dramatically reduce the impact of building activities on the surrounding area. This is particularly important in city locations or sites close to residential areas. Steel construction minimises noise and dust, shortens the construction period and reduces waste generation.

### **Buildability**

Much of the components for a steel framed building are pre-fabricated and pre-assembled in the factory. This reduces the amount of site work and increases the quality and precision of the site installation works.

### **Environmentally Friendly**

Steel offers a clean, efficient and rapid construction method, which reduces the impact of building activities on the environment.

All steel products are 100% recyclable. Today, around 40% of steel is produced from recycled materials.

The construction industry need to make a choice to ensure a better life for everyone now and for future generations, through the use of environmentally friendly materials that would reduce our dependence on non-renewable construction materials.



*Steel components can be installed precisely at site*



# Sustainable Materials

...the key challenge is to choose materials that can reduce burdens to the environment. The construction industry must recognise that developers, designers, builders and suppliers have a responsibility to develop systems, products and methods that are environmentally friendly.

In modern construction, the key challenge is to choose materials that can reduce burdens to the environment. The construction industry must recognise that developers, designers, builders and suppliers have a responsibility to develop systems, products and methods that are environmentally friendly.

## Recycling of Waste Materials

To enhance sustainability in the construction industry, wastes can be turned into resources to reduce disposal problems in Singapore.

A few types of waste are being studied, such as incinerator ashes from domestic refuse, spent copper slag fines which are residue from sand blasting and waste concrete from construction, renovation and demolition (CRD) of old buildings.

## Copper Slag

The application of copper slag in non-structural components like partition walls and road has proven its efficiency as a sand replacement. For structural usage, the use of copper slag as partial replacement of sand in concrete is allowed for up to 10% by mass. Tests have to be conducted to ensure that chloride and sulphate contents in the slag are within the allowable limits. Further research is necessary if the percentage replacement for sand is to be increased. The technology and process will involve the treatment and re-constitution of the spent copper slag to satisfy all the requirements for its use in making concrete.



*Processing of copper slag*



*Precast kerb using copper slag*



*Precast concrete internal partition wall using copper slag*

*Courtesy of A/Prof Wee Tiong Huan, NUS*

### CRD Waste

Concrete from construction, renovation and demolition (CRD) of old buildings can be recycled. However, there is difficulty in separating the stone, known as aggregate, from the cement for reuse in new structural concrete components. The cement-coated old concrete may weaken the new concrete if it is not treated properly. There are new technologies around the world

to separate the old cement from the waste concrete. The local researchers are currently conducting studies for local usage. Nevertheless, the use of waste concrete for non-structural concrete components such as partition walls, road kerbs, paving blocks are possible. Such application has been proven to be efficient and economical.



Courtesy of SamGreen Pte Ltd, a member of Samwoh Group of Companies

The projects below are some of projects using CRD Waste for non-structural concrete components which won the Green Mark Awards



*The Tresor*



*The Sail @ Marina Bay*



*Clydes Residence*



*Republic Polytechnic*

## Incinerator Ash

Singapore faces an unique challenge due to our limited land area and high rate of waste generation. Municipal Solid Waste (MSW) is generated everyday and the waste is disposed of by incineration. Incinerator ash or the MSW ash is the residual from the combustion of domestic waste. It is expected to have a variety of chemical species, some of which may pose environmental problems if it is not disposed off properly.

A project is being carried out to recycle the ash into an aggregate product using a patented

technology which has been used in various countries including the United States, Taiwan and Bermuda. The technology for processing the ash involved proprietary systems to remove ferrous and non-ferrous metals, screening, removing unburned materials, and treatment to mobilise certain heavy metals. The aggregate product has been tested to be non-hazardous and is safe for use. It has been used in diverse applications such as trench and backfill, shore protection, land reclamation, concrete block, base and sub-base for road construction.



Courtesy of Strategic Success Pte Ltd, a member of Samwoh Group of Companies



*Steel structural framing - steel column, steel beam, metal decking and bracing*

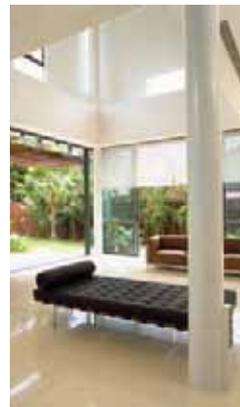
## Structural Framing

Besides the use of recycled materials, steel construction and dry construction methods also have a great deal to offer in sustainable construction. The use of steel framed construction in housing and commercial projects is beginning to gain market acceptance in many countries in Europe and the United States.

Steel construction is efficient, competitive and makes a significant contribution to the national economy. It enables the implementation of environmental management systems, off-site manufacture, noise reduction, waste minimisation strategies and recovery and reuse initiatives.

Structural frames for multi-storey buildings consist of an appropriate arrangement of slabs, beams, columns, foundations and bracings to resist the combined effects of vertical and horizontal loads (In Singapore's case, this is mainly wind load).

Various types of sections such as I-section, H-section and hollow sections can be used as columns. One advantage of using hollow sections filled with concrete is that their fire resistance can be improved.



*Circular hollow section infilled with concrete provides the required fire resistance - Courtesy of LOOK Architects*



*Openings in the beams ease the installation of services*

Beams are commonly made of I and H profiles. Sometimes openings are made in the webs of beams to ease the installation of horizontal services such as pipes, cables and ducts. The openings may be circular or square with suitable stiffeners in the web. Alternatively castellated beams can be used to achieve this.

Floors are required to resist vertical loads directly acting on them. They usually consist of slabs which are supported by steel beams. The most common type of floor slab used in conjunction with steel beams and columns is composite slab using steel decking. The advantage of using steel decking is that less concrete is required as it is used mainly as topping up of slab.

The dynamic action of wind becomes a more critical design consideration as the building height increases. Instead of reinforced concrete shear walls or cores, engineers should consider steel bracing as alternatives. These bracings may be of



*Steel decking only requires minimum concrete topping*



*Bracing provides structural stability to the building*

different forms such as cross-braced X shaped; V or inverted V shaped and symmetrical or asymmetrical portal.

## Fire Resistance

Steel is a durable non-combustible material with many excellent structural properties, but the mechanical properties of steel can deteriorate under elevated temperature. In Japan, there has been a strong effort to introduce a Fire Resistant Steel grade which has improved strength retention ratios at elevated temperature, but it has not been widely used in other parts of the world.

Today, most building codes contain prescriptive criteria that determine the requirements for the various types of construction heights, areas and occupancies.

Steel members can be insulated from fire effects through various means.

The most common method of fire protection is concrete encasement. While this is a simple method to adopt, it always results in bulky structural members, which defeats the purpose of having slender steel sections in the first place.

Besides the traditional concrete encasement, there are other alternative fire protection methods which designers can consider.



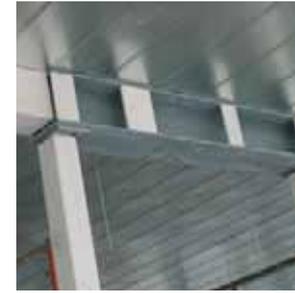
*Steel column is encased with concrete. Column at far left with steel reinforcement prior to encasement*



*Steel beams sprayed with Vermiculite*



*Intumescent paint on steel beams*



*Fire protection board*

- **Spray-applied Fire Resistive Material**

Vermiculite can be sprayed directly onto the steel beams and columns. However, as the resulting surface will not be smooth, this method is usually used where the steel members can be covered by a false ceiling or where the aesthetics do not bother the owners.

- **Intumescent Coatings**

For a better finished surface, intumescent paint would be a good choice. An intumescent coating has a pre-fire appearance of a thick film of paint. When exposed to fire, it chars, foams and expands significantly in thickness and delays temperature rise in the steel. Though it may be a more costly choice relative to other available fire protection, its light weight per surface area protected, durability, aesthetic acceptance for exposed steel, and good adhesion are some of the many benefits it brings. This allows designers to expose the beauty of the slender steel sections.

- **Fireproof Boards**

Another method to provide fire resistance is the use of fireproof boards. These calcium silicate boards or cement boards are cladded to the steel elements, giving excellent thermal insulation at high temperatures. They can even provide up to 4 hours of fire protection.

The suitability of a fire protection product for any specific application depends on several factors, including the required fire resistance rating, expected service conditions (exposure to weathering effects, vibration, accidental impact, etc), compatibility with corrosion protection requirement, aesthetics and economic considerations.

For the use of any fire protection to steel buildings, designers are advised to consult the Fire Safety and Shelter Department (FSSD) of the Singapore Civil Defence Force on the approved products and any restrictions on the various fire protection methods.



## Performance-based Fire Engineering

Prescriptive code criteria have been in place for decades to provide for fire resistance in buildings and other fire protection measures. While the traditional method of providing fire resistance through concrete encasement is an easy solution for most projects, its cost can be prohibitive for big projects.

Clients can now engage Fire Safety Engineers (FSE) registered with FSSD to carry out performance-based fire engineering to reduce the cost of fire protection without compromising safety standards.



*Carrying out performance-base fire engineering can reduce the cost of fire protection without compromising safety standards*

## What is performance-based fire engineering?

The use of science, engineering and analysis to provide fire safety precautions tailored to each building, based on a fundamental understanding of the behaviour of fire.

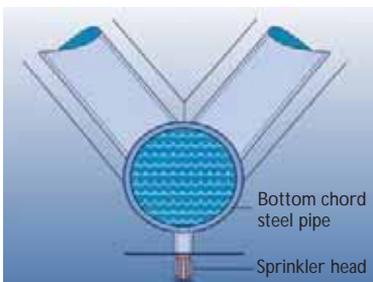
Performance-based fire engineering is chosen for various reasons. The buildings may be too complex to have relevant regulations. The conventional guidance can restrict design flexibility, especially if new materials are used. Performance-based fire engineering addresses issues beyond life safety and provides more cost-effective solutions.



*The National Library of Singapore was designed using performance-based fire engineering*

A few new local projects, like the National Library and AMK Hub, have been designed with performance-based fire engineering. The National Library is one of the first structures in Singapore to have its composite steel structure designed using performance-based fire engineering. Its design does not rely on a strict adherence to prescriptive building codes. The use of performance-based fire engineering enabled expression of the elegant bare steel structure and allowed for cost-effective construction of the building. The majority of the steel floor beams have reduced levels of applied fire protection. These design features have been expressed whilst still ensuring structural stability in the event of a fire.

Performance-based fire engineering can also result in innovative methods of providing fire protection.



*The Hong Kong Air Cargo Terminal Building*

The Hong Kong Air Cargo Terminal Building is one good example. As a result of a performance-based fire engineering approach, a water-cooled roof was adopted for the Terminal Building to eliminate the requirement for passive fire protection. The idea was to fill up the hollow steel section of the roof with water, and eliminate the need for the sprinkler pipework by fitting the sprinklers directly into the hollow roof sections.



*More attention has to be paid during the design process to prevent or reduce floor vibrations*

## Floor Vibrations

Floor vibration is not a new phenomenon. The increasing trend of building lighter and longer spans has caused greater awareness on the dynamic response of floors. More attention has to be paid during the design process to prevent or reduce floor vibrations.

Floor vibrations may be caused by occupant activities such as dancing, jumping, aerobics and sporting events or the operation of mechanical equipment such as heating, ventilation and air-conditioning systems (HVAC).

Traditionally, engineers tend to design for a minimum frequency. However the frequency of a floor does not indicate the amplitude of the vibration. Frequency indicates only the rate at which the floor moves; whereas amplitude describes the amount of movement. Therefore designing for frequency only is inadequate.

Many modern standards stipulate that design engineers must check to ensure that the floor vibrations do not cause discomfort to the users and must meet the serviceability requirements of the intended usage. In Singapore where most of our designs are in accordance to British Standards, engineers may refer to BS 6472:1992 to assess the acceptability of structures to vibrations.

For floors with regular floor grids, design engineers may also refer to simple design guides such as those provided by the Steel Construction Institute, UK, to gauge an estimate of the floor response. However, numerical modeling should be used if an accurate determination of floor vibration is required, especially if the floor requires a different vibration environment (for instance operating theatre areas at hospitals), or if the floor has an unusual framing arrangement.

## Corrosion Protection

Barrier protection is perhaps the oldest and most widely used method of corrosion protection. Two important properties of barrier protection are adhesion to the base metal and abrasion resistance.

Paint is one example of a barrier protection system. Although relatively easy to apply, the use of paint system requires maintenance, partial repainting and full repainting several times over a building's lifetime.

Another method of preventing corrosion is hot-dip galvanizing. Almost any steel that will

be exposed to the elements in some fashion (directly or indirectly) is a prime candidate for hot-dip galvanizing. The galvanizing process involves lowering the cleansed steel into 450 °C of molten zinc where the steel and zinc metallurgically react to form three zinc-iron intermetallic layers and one pure zinc layer. The three intermetallic layers that form during the galvanizing process are all harder than the substrate steel and have excellent abrasion resistance. They do not allow moisture and corrosive chlorides and sulfides to attack the steel.



*steel sections before galvanizing*



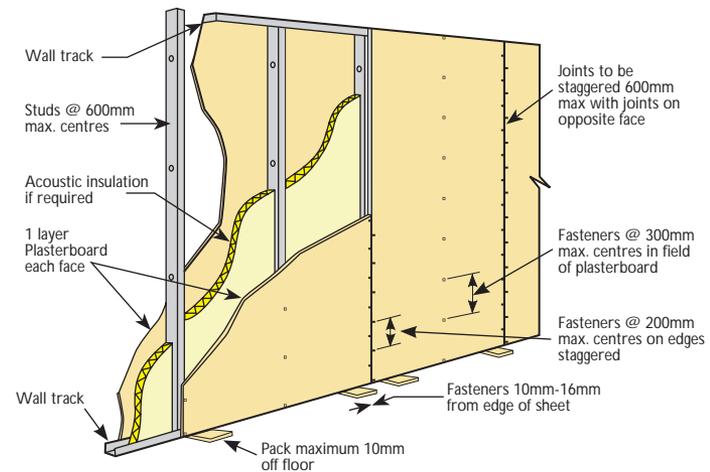
*steel sections after galvanizing*



## Dry Internal Partition Walls

Besides the main structural frame, the various components of a building can be constructed using the sustainable products and components. One very good example is the use of drywalls with plasterboards or fibre cement boards as internal walls, which is gaining popularity among the private residential projects.

The constant improvement in its performance means that it now meets high level specifications in the areas of acoustic insulation, thermal insulation and resistance to fire and damp conditions. Drywall is an ecological product, applied dry, generating no waste and pollution.





- **Heavy Duty**

Besides meeting statutory functional requirements such as fire ratings, the heavy duty drywalls are able to resist high impact and support loads such as cabinets.

Performance-wise, the system is suitable for severe duty usage, having passed the strength and robustness tests (e.g. Stiffness, Door Slam, Impact, Heavyweight Anchorages tests) in accordance to SS492:2001. The high impact resistance dry boards are tested to severe duty in strength and able to withhold minimum loading of 25 kg at each point. The fire rating for the board is about 60 minutes.

- **Lightweight and Slim**

Despite the “heavy duty” label, the drywalls are lightweight (about 10-15% of conventional brick walls); allowing designers to adopt lighter structures and foundations. The lightweight and slim drywall partition offers significant reduction in dead loads and is economical in terms of floor area savings.

- **Wide Range Available**

In addition, the different types of drywall systems available in the market also offer a wide range

of fire resistance and acoustic ratings to meet design requirements.

- **Ease of Installation**

The ease of installation of mechanical and electrical services within the boards has also reduced the noise pollution that may be created with the hacking of brick walls to embed the services.

- **Ease of Reconstruction**

The lightweight panels can be easily sawn on site and quickly replaced and relocated according to one’s needs without messy hacking of walls and creating debris to the environment. The use of this system also facilitates dry construction with no need for messy plastering as its smooth and even surfaces are ready to receive paint finishes directly.

Such advantages have led developers to use dry partitions for various projects, including good class residential apartments. City Developments Limited, Capitaland Residential Limited, Far East Organization and World Class Land have adopted high performance drywall system instead of conventional brick walls in their recent projects, due to its quality and sustainability.

## Acoustic Performance

The acoustic performance of the drywalls can be enhanced with the installation of rockwool between the boards.



*Sound transmission test on dry partition wall*

Sound Transmission Class (or STC) is used to rate interior partitions, ceiling/floors, doors, window and exterior wall configurations. STC is the decibel reduction in noise a partition can provide. The higher the STC value, the better is the acoustic performance.

Interior walls with bricks or concrete walls have STC of about 40, which is considered as "onset of privacy", suitable within the residential units. The lightweight and dry partition walls have an STC of about 33 without any insulation. Adding insulation like rockwool in the wall cavity would increase the STC to between 45 - 50. Hence, unlike brick or concrete walls where the STC is limited to the choice of material, the dry partition walls have the ability to improve on the sound transmission loss by increasing the cavity and insulation between the boards to yield an STC of as high as 63.

## Sound Transmission Class (STC)



- 25 Normal speech can be heard easily
- 30 Loud speech can be heard
- 35 Loud speech can be heard, but not understood
- 42 Loud speech can be heard only as a murmur
- 45 Must strain to hear loud speech
- 48 Only some loud speech can be heard
- 53 Loud speech cannot be heard

These residential projects shown below used drywalls as internal partition walls between rooms.



*The Pier@Robertson*



*Coastarina*



*Citylights*



*Savannah CondoPark*



*Central*



*Butterworth 33*



*St Regis Residences & Hotel*



*The Sail@Marina Bay*



*Residences@Evelyn*



*Parc Emily*



*City Square Residences*

## Glass and Cladding

Curtain walls, cladding and glass facades can be used to replace the traditional masonry and concrete walls. These facade systems offer new dimensions and excitement in architectural designs.

Curtain wall is a lightweight external wall system that is hung on the building structure. It is one of the favoured systems used in modern architecture and is characterized by grids of infilled material such as glass, metal, granite or a combination of these. Its flexibility allows architects to create striking designs for new buildings and refurbishment of old buildings. The reduction in weight leads to savings in structure and foundation.

Coatings on the glass panels can enhance the thermal insulation of curtain walls. The use of double glazing not only further enhances the thermal insulation of curtain walls, but also their acoustic performance.



*4-legged stainless steel spider within a tension truss point supported glass walls*

Glass curtain walls can be used with aluminium and granite panels with backpans and insulation in spandrel areas. Strategic use of insulation in solid and opaque areas of the elevations can allow these lightweight systems to achieve high thermal performance.

The panels can be pre-assembled under strict quality control and can incorporate architectural and solar control elements such as shading, lighting, light shelves and blinds. The use of modular and standardized panel sizes would speed fabrication and keep the cost down.

For areas of larger span, glass and aluminium can be used with steel sections, trusses and tension systems to provide light and highly transparent walls.



*Closed-up view of 4-legged stainless steel spider*



*Leonie Studio*

The use of glass/curtain walls provided unobstructed view and natural daylight for the users.



*Bishan Library – courtesy of LOOK Architects*



*National Library*



*Novena Square*

## Prefabricated Parapets

Parapets and railings can be designed to facilitate ease of construction and to achieve higher quality finished products. The use of metal railings or glass parapets can achieve practical and environmentally friendly design and enable effective design and construction work onsite. Some examples are illustrated here.



## Prefabricated Staircases

To many designers and builders, prefabrication of staircases is a preferred option as they are of better quality and easy to construct. The prefabricated staircases come in various sizes and steps, catering to different building heights.





*Use of shallow floor trap for pre-fabricated bathroom units*

## Prefabricated Bathroom Units

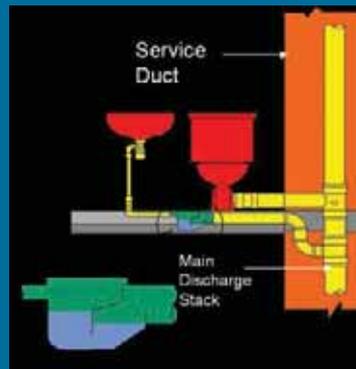
Another good way to reduce our reliance on concrete-based construction is to switch to prefabricated 3D components such as prefabricated bathrooms made of steel frame and boards.

The Housing and Development Board (HDB) has taken the lead in introducing the prefabricated bathroom units to projects at Hougang, Jurong, Toa Payoh, Queenstown, Sengkang and Punggol. A total of about 5,000 dwelling units had been installed with prefabricated bathroom units in the last 10 years.

The walls of the prefabricated bathrooms could be steel frame with calcium silicate wall or steel panel walls. The floor of these prefabricated bathroom units is concrete floor for better performance as a watertight system. The ease in maintenance has also allowed the homeowners to enjoy a better quality of life.



*Courtesy of HDB*



- Increase labour productivity
- Improve maintainability
- Improve product quality
- Improve customer satisfaction
- Reduce production wastage

## Steel Lift Shafts

The Lift Upgrading Programme (LUP) was introduced by the Housing and Development Board (HDB) in March 2001 with the aim of providing residents living in older HDB blocks with direct lift access on every floor and better lift services.

A conventional 12-Storey concrete lift shaft can use up to 90 cubic meters of concrete per lift shaft. Through the introduction of steel lift shafts in the LUP, the amount of concrete used is localized to only the lift pit. By switching to steel lift shafts, the amount of concrete used per shaft can be reduced by 90%.

The steel lift shafts are constructed using steel frame and metal claddings. At the lift lobby,

the current design uses concrete slabs. However, to further reduce the dependence on concrete, the HDB is looking into using alternative materials such as steel plates with cement screed finishing.

A total of about 15 new lift shafts have been installed in the LUP through pilot implementation in estates like Yishun, Marsiling and Jurong East.

The speed at which the steel lift shafts can be erected have greatly shortened the overall construction time of the LUP. From the good response of the pilot projects, steel lift shafts are being introduced to more precincts, thereby bringing forward barrier free access to the residents and improving their quality of life.



*Courtesy of HDB*

### Steel Lift Shafts

- Increase labour productivity
- Increase erection speed
- Reduction in material usage
- Reduction in foundation cost
- Reduction in crange cost



*Zhenghua Community Club - Courtesy of LCP Building Products Pte Ltd*



*Changi Airport Terminal 2*



*Sentosa Island Beach Station*



*Supreme Court of Singapore*



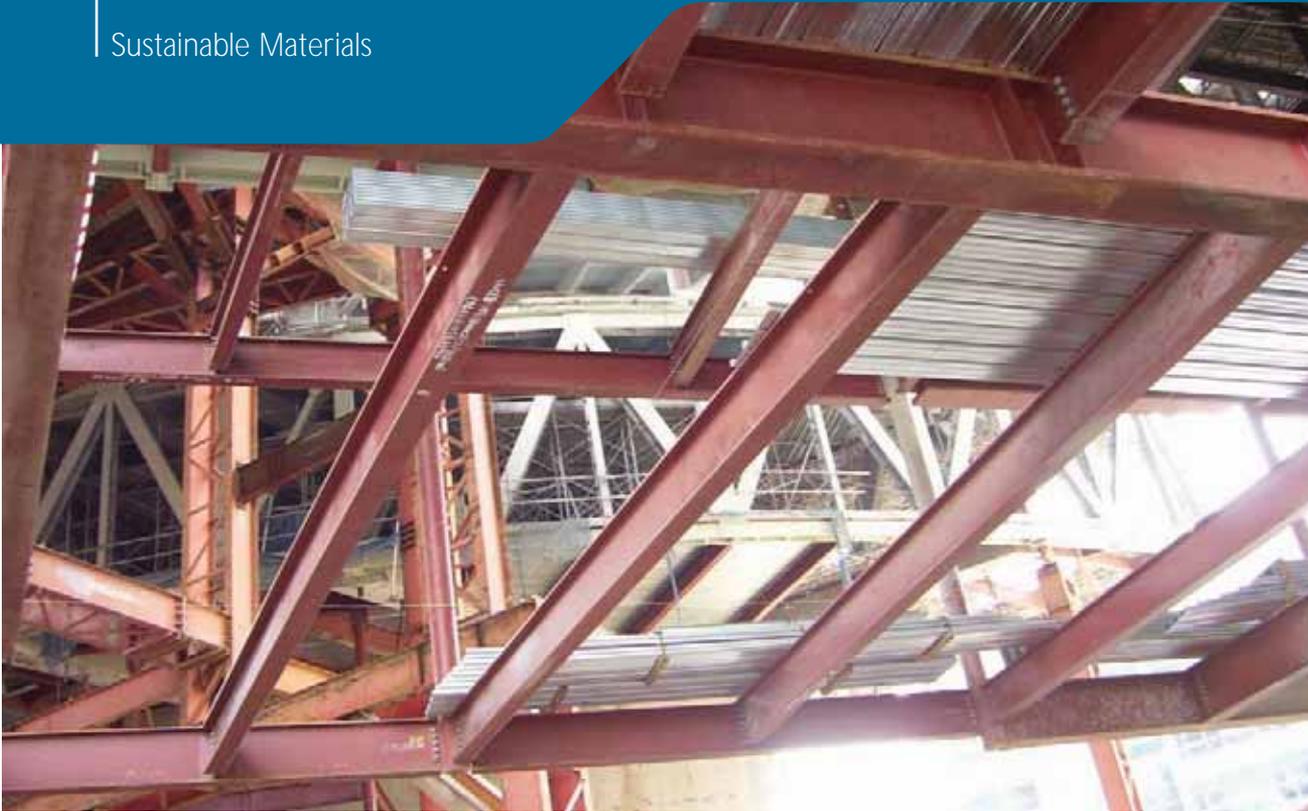
*Changi Airport Terminal 3*

## Prefabricated Steel Roof

Large column-free spaces are often more functional and aesthetically pleasing. To achieve such luxurious space below roof would often require the use of steel roof structures. Steel structures are flexible and are used to construct challenging structures such as the huge disc-like structure of the new Supreme Court Building.

Apart from their ability to enhance creativity, steel components are slimmer and can support

longer spans. A good example is the main roof to the new Singapore Changi Airport Terminal 3 building with a frontage of 300m in length and width of 215m. The longest free span is 60m supported by steel trusses. Significant savings in foundation is possible as steel has a higher strength-to-weight ratio as compared to concrete structures. Steel can span further than traditional concrete, with slimmer beams which make the overall structures more elegant.



*Steel systems can be erected in much shorter time*

## Evaluation of Steel Costs

One main reason for the relatively fewer steel buildings in Singapore is the higher cost of structural steel. Concrete has always been cheaper than steel, despite the fact that concrete prices have increased three-fold recently. However, it would be rather superficial if we just compare the material cost of concrete vis-à-vis with steel, without taking into consideration the benefits brought about by using steel.

Traditionally designers have considered only the initial cost of that part of the project for which they are responsible and have sought the most cost-effective solution for it. There is still relatively little regard given to total developmental costs. Evaluation of total developmental costs should be encouraged rather than focusing only on initial construction costs.

Total costs of a steel construction are affected by technical and environmental factors. Developers, designers and builders should take the following factors into consideration when computing the total cost of a steel building:

- **Speed of Construction**

The speed of construction of steel structures has been proven for many projects. The steel structural system can be erected in shorter time, as much as 40% faster than concrete construction for a medium rise building.

- **Financial Benefits**

Faster construction has additional benefits. It results in savings in the cost of site management and on-site activities. It reduces the cost of finance, since a shorter construction period



*Savings in foundation can be as much as 30% for steel building*

reduces the time during which interest has to be paid. Additionally, the rapid completion of a building also brings an earlier return on investment as the building can be occupied sooner, helping to offset the cost of borrowing or allowing finance for the next phase of a development.

- **Lightweight**

The lighter self-weight of steel means that for a similar sized building, the foundation can be reduced by as much as 30%, resulting in savings in the cost of the foundation.

- **Reduced Impact on Surrounding Area**

Steel construction can reduce the impact of building activities on the surrounding area. This is particularly important in city locations or sites close to residential areas. Steel construction minimises noise and dust, shortens the construction period and reduces the amount of waste generated. Delivery of materials can even be timed to suit traffic conditions and keep disruption in the area to a minimum.



*The steel sections from a demolished building can be sold as scrap metal and be recycled*

- **Environmentally Friendly**

Steel offers a clean, efficient and rapid construction method, which reduces the impact of building activities on the environment. The small amount of waste produced is generally recycled, and all steel is potentially reusable.

In addition, even the demolition of a steel building could bring about financial gain. The steel sections can be sold as scrap metal (which fetch a very good price nowadays) and be recycled.

The main advantages of a steel building are speed of execution, prefabrication and lightness. To realize such advantages, the design of the building must be taken as a whole; incorporating cladding, finishes and other building components. This approach also implies that the steelwork contractor should be involved at the earliest opportunity as part of the project team so that he can advise on a more efficient and cost effective steel solution. Project team members must have the discipline of producing the final design at an early stage and avoid late changes.

Projects Using Sustainable Materials



Projects Using  
**Sustainable Materials**

Residential • Commercial • Institutional



## Residential

- Erie On The Park, Chicago, USA
- 711 Upper Changi Road East, Singapore
- House at Lucky Gardens, Singapore

## Commercial

- ING House, Amsterdam, The Netherlands
- Hyatt Center, Chicago, USA
- AMK Hub, Singapore
- Fusionopolis, Singapore

## Institutional

- National Aquatics Centre, Beijing, China
- Supreme Court of Singapore



## Erie on the Park, Chicago, USA

Erie on the Park, a residential condominium building, is situated at Chicago's popular River North neighbourhood. The sleek 25-storey steel residential building showcases a building façade featuring exposed steel elements and curtain wall composed of steel, glass and mirror.

The typical floor plate of the building is in the shape of a parallelogram, and the typical floors of the building are framed in wide-flanged shapes with steel joist floors. The lateral system comprises three-storey high chevron mega-braced frames.

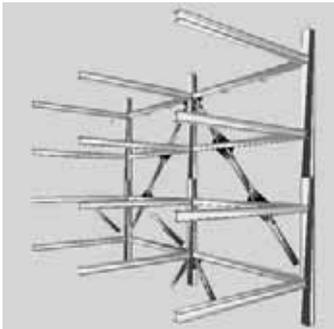
The architect moved two of the mega braces to the exterior of the building and eliminated the need for a concrete core. This gave the architect the flexibility in laying out the units, which was crucial as there were 23 different unit layouts for the condominium. The external structural steel bracing also allowed the architect to express it as part of the exterior cladding.

The use of steel both structurally and architecturally allowed the design team of Erie on the Park to create a distinctive building that stands out in the Chicago cityscape, where concrete is the typical choice for residential buildings.

*The completed Erie on the Park  
Photo by Hedrich Blessing*



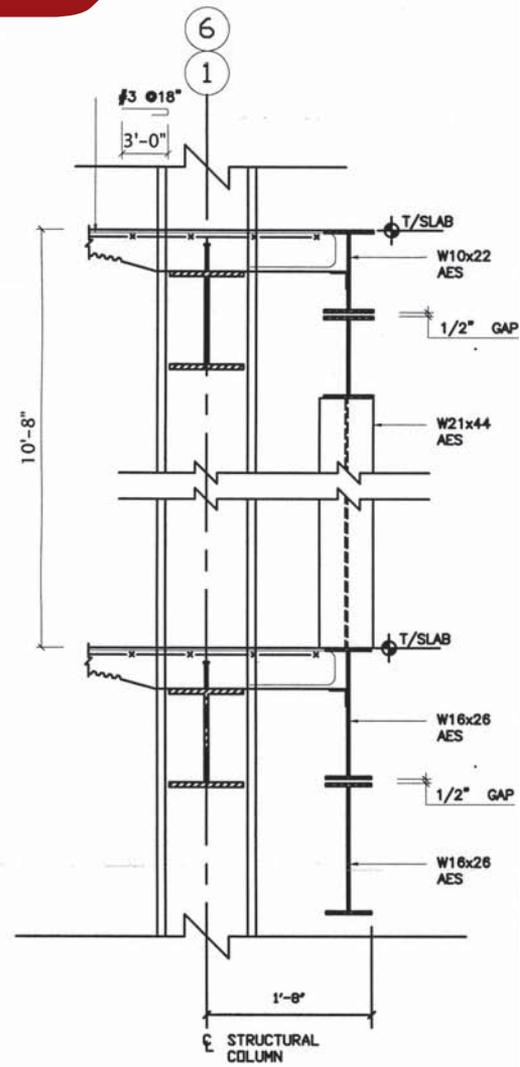
*Erie on the Park was constructed with structural steel framing and metal decking*



*Two of the braces were moved to the exterior of the building*

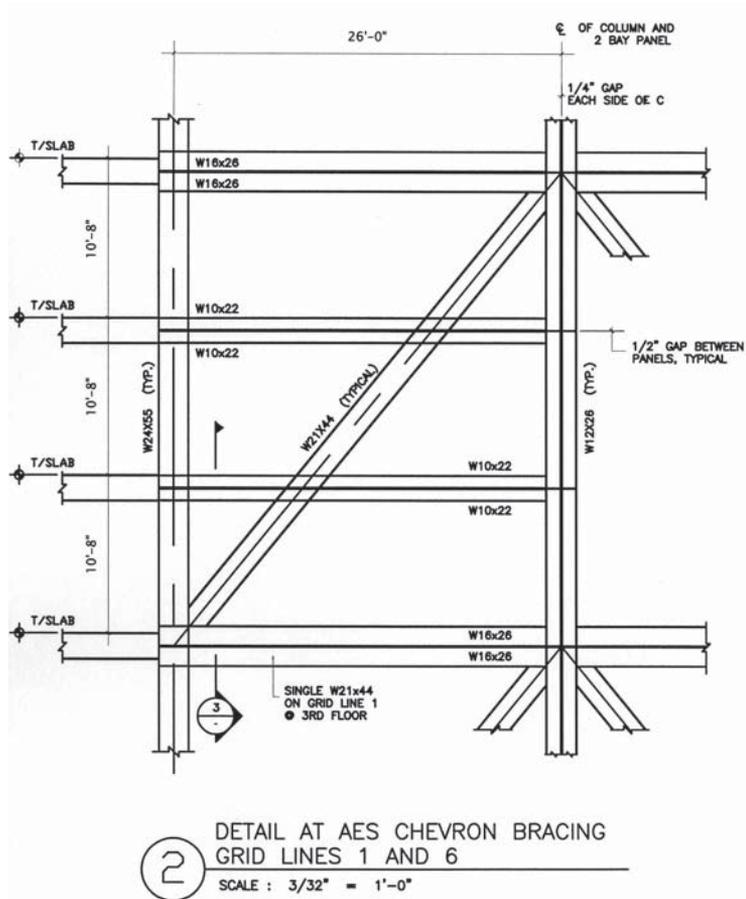


*The steel and glass curtain wall with the mega braces stands out against the surrounding masonry buildings  
Photo by Hedrich Blessing*



3 SECTION BETWEEN COLUMNS  
SCALE : 1/2" = 1'-0"

Section showing both structural and architecturally exposed steel. The 1'-8" (500mm) separation was held constant around the building's perimeter



*Details of architecturally exposed steel brace. The architectural steel brace mimics the structural brace behind it*

**Owner/developer**

Smithfield Properties, Chicago

**Architect**

Lucien Lagrange Architects, Chicago

**Structural Engineer**

Thornton-Tomasetti Engineers, Chicago

**General Contractor**

Wooten Construction Ltd, Chicago

Steel Fabricator: Zalk Josephs Fabricators, Stoughton

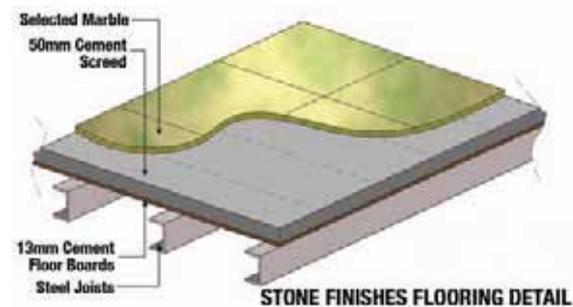
Joist Fabricator: Canam Steel Corporation, Washington

Steel Erector: Area Erectors, Rockford



### 711 Upper Changi Road East

This is a reconstruction project whereby the existing one-storey semi-detached dwelling house was reconstructed to a part two-storey, part three-storey semi-detached house. The project has adopted the concept called “System Efficient Building”, a simple and fast to construct method which makes future upgrading easy and flexible. The system used panels of galvanised steel, modular cement boards and steel roofing sheets riveted together to form a very strong yet light steel shell.

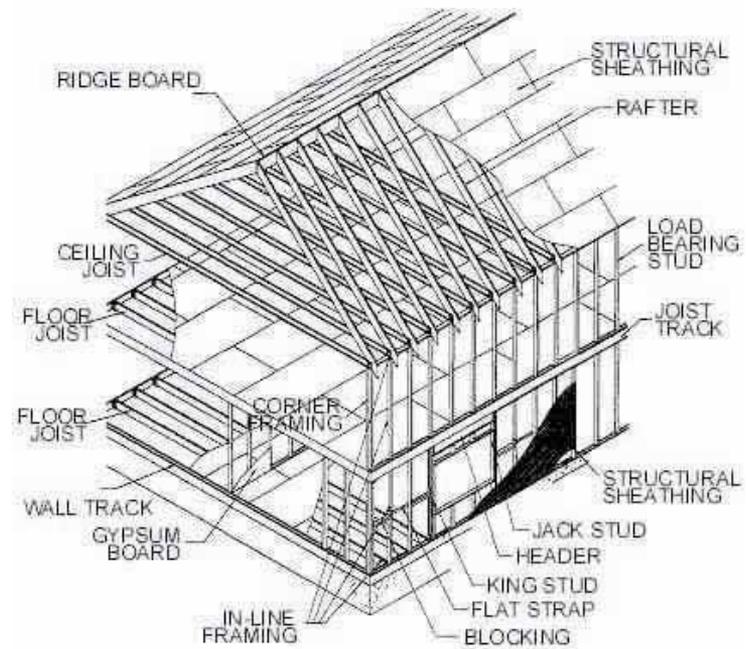


*Cement floor boards were used for the floor instead of conventional concrete flooring*



*Using light gauge steel to construct the house*

As this method of construction is light, there was no need for laborious and noisy piling works. This efficient system requires minimal site workers and eliminates the need for temporary material such as timber formwork.



**Owners**

Mr Ng Chan Sen & Mdm Jurena

**Architect**

A. Allliance Architects

**Structural Engineer**

SKC & Associates

**Builder**

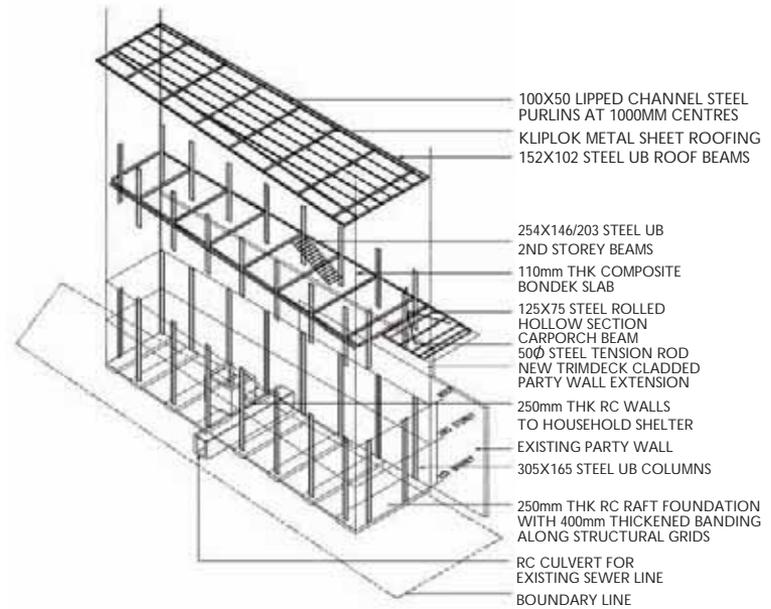
Pacific Prince International Pte Ltd

### House At Lucky Gardens

House at Lucky Gardens - a 2-storey corner terrace house located within a designated landed housing area off Upper East Coast Road. This project broke away from the conventional construction methodologies of a typical individual landed dwelling house.

It adopts lightweight construction for the superstructure from the outset and opted for steel columns and beams which, in addition to being light, could be prefabricated off site and installed quickly on site. The construction work generates less noise and dust, and is conducted over a much shorter duration of time.





**Owner**  
 Mdm Yam Lee Foon  
**Architect**  
 Tan + Tsakonas Architects  
**Structural Engineer**  
 Aston Consulting Engineers  
**Builder**  
 Caines Associates Pte Ltd

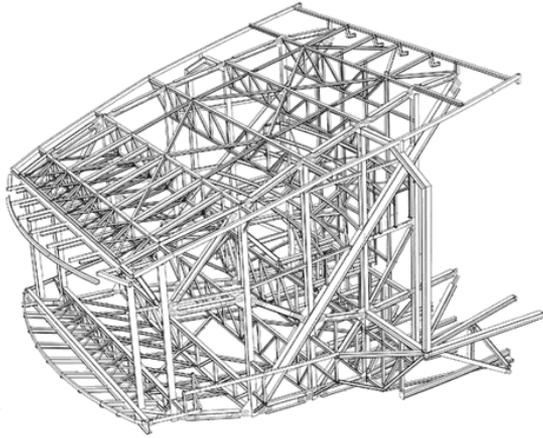


## ING House, Amsterdam, The Netherlands

ING House was commissioned by the ING Bank to serve as the Bank's Headquarters at Southern Amsterdam. The building, resembling a large beetle in shining glass and anodized aluminium, rests on ten-metre-high pillars. Steel and glass predominate the construction. Because of the ample use of glass, everyone working in the building has great views. ING

house has climate controlled outer walls. These ensure that outside noise is muffled and clean air comes in.

The project has been awarded numerous prizes, including the Aluminium Award, the National Steel Award Prize 2002, the "Glass" Award and the "LON" Award.



*Steel trusses were used to frame the ING House*



*Steel legs*



*Glass staircase*



*Rear view of ING House*



*Great views from the ING House*

**Owner**

ING Corporate Real Estate bv, Den Haag

**Architect**

Meyer en van Schooten Architecten BV, Amsterdam

**Structural Engineer**

Aronsohn Raadgevende Ingenieurs bv, Rotterdam

**Builder**

Bouwcombinatie SamenwerkING

**Steelwork Contractors**

Hollandia bv, Krimpen aan den IJssel – Heerema bv,

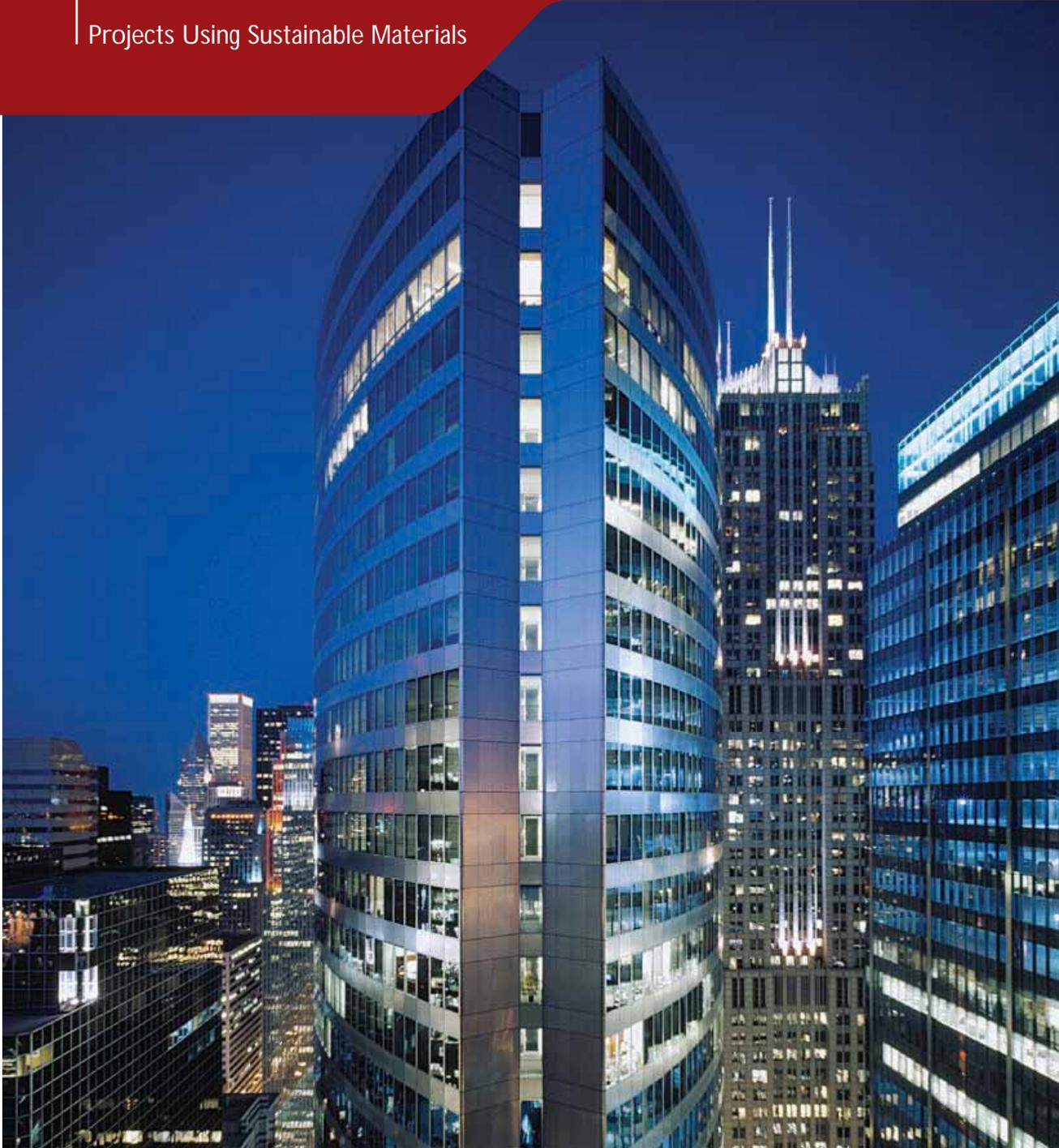
Zwijndrecht – Oostingh Staalbouw bv, Katwijk

**Architect Interior**

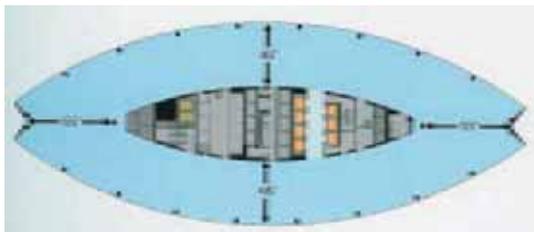
mw. Trude Hooykaas (OTH)

**Technical Advisor**

Van Heughten



*Photo by Steve Hall/Hedrich Blessing*



## Hyatt Center, Chicago, USA

Chicago's newest landmark is designed by the prestigious architectural firm Pei Cobb Freed & Partners.

The 49-storey tower resembles a football with sharply notched ends. Steel frames with metal decking were adopted for the construction of the building.

The long façade curves gracefully back to accommodate a public garden that complements the sleek expanse of glass and stainless steel spandrels, softening the hard lines and hard surfaces.

### **Owners**

Pritzker Realty Group & Higgins Development Partners

### **Architect**

Pei Cobb Freed & Partners

### **Structural Engineer**

Environment Systems Design

### **Builder**

Bovis Lend Lease

*All photos courtesy of the Hyatt Center*



## AMK Hub

AMK Hub is located on the site of the old Ang Mo Kio bus interchange at the town centre bounded by Ang Mo Kio Avenue 8, Ang Mo Kio Avenue 3 and existing HDB blocks. The existing Ang Mo Kio MRT station is located across Ang Mo Kio Avenue 8 at approximately 40m away from the development, and part of this mixed development is within the MRT protection zone. The development has a Gross Floor Area of approximately 48,250 square metres which consists of three basement levels and four levels of podium structures, and is integrated with an air-conditioned bus interchange.

The superstructure is formed of structural steelwork composite system, with composite steel decking, composite steel beams and composite

steel columns. The metal sheet decking serves as the bottom reinforcement of composite flooring system as well as permanent formwork to omit the temporary staging during construction. Additional steel reinforcements are provided to comply with the fire resistance requirement. The thickness of the composite slabs range between 135mm and 200mm, depending on the loading requirement. Being more efficient, the use of steel construction has enabled the project to be completed 2 to 3 months faster as compared to a conventional concrete-based construction.

The composite beams/truss system, as primary members acting together with the secondary composite beams, provided the most economical

solution to the project. Similarly, the composite design of concrete encased steel section and in-filled concrete circular steel tube provided the most practical and economical solution in the construction. Besides enhancing the load capacity, the composite columns also provided more flexible connection arrangement for steel beam fixing from all directions. The lateral stability of the building relied on reinforced concrete corewalls (lift shafts and staircases) which are rigidly braced and connected with the steel beams / columns through the rigid floor diaphragm.

Fire specialists were engaged to evaluate the fire safety in the project. The critical structural elements like steel main beams and exposed steel column surfaces are sprayed / covered with fire protection system.



**Owners**

SLF AMK Pte Ltd/NTUC Income Insurance Co-operative Limited/NTUC Fairprice Co-operative Limited

**Architect**

AT3 + ATA Architects

**Structural Engineer**

Beca Carter Hollings & Ferner (SE Asia) Pte Ltd

**Builder**

Lum Chang Building Contractors Pte Ltd

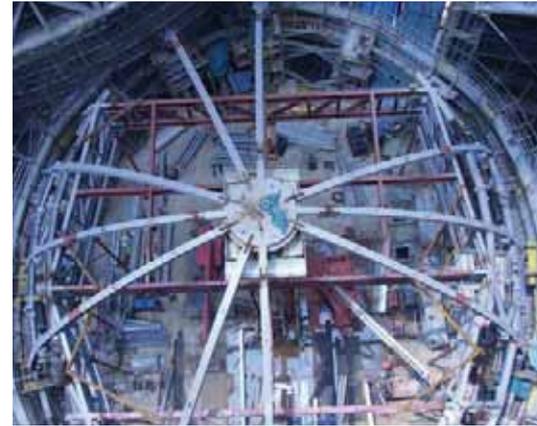




## Fusionopolis

Fusionopolis consists of 2 blocks of 22 & 24 storeys soaring to an overall height of approximately 135 metres, a retail podium, a theatre pod and 6 levels of basement.

The complex features a high density and integrated mixed use programme comprising Business Park R&D spaces, retail & food and beverage outlets,



*Construction of the theatre pod.*



*Mega truss.*

a health club with a roof top swimming pool, serviced apartments and a theatre.

Conceived as an iconic building for one-north, the building possesses a distinctly recognizable and memorable external form. Extensive use of structural steel in combination with reinforced concrete (r.c.) core walls were adopted for the



*Fusionopolis is currently under construction.*

structural system. Horizontal mega trusses or girders were then cantilevered from these core walls at intervals of approximately 30 metres.

Typical floor plates of steel columns and beams and composite slabs were placed between these mega trusses; providing column free interior spaces and the varied shapes for the floor plates without the need for transfer columns and beams.

The structural expression, combined with the dramatic curved sloping roofs, the sleek curtain wall façade and distinctively evocative theatre pod lends the building a sophisticated and modern image.

Fusionopolis, presently under construction, is envisaged to be a dynamic and vibrant environment

when completed and will provide impetus to the realizing of the one-north master plan vision of a place to Work, Live, Play and Learn.

**Client**

JTC Corporation

**Concept Architect**

Kisho Kurokawa

**Project Architect**

JURONG Consultants Pte Ltd

**C&S Engineer**

JURONG Consultants Pte Ltd

**M&E Engineer**

JURONG Consultants Pte Ltd

**Main Contractor**

Shimizu Corporation



©Martin Saunders + Arup

## National Aquatics Centre, Beijing, China

The National Aquatics Centre, also known as the Water Cube, is one of the infrastructures built for the 2008 Beijing Olympics.

The Water Cube may look like an array of soap bubbles, but its structure is highly repetitive and buildable. The Water Cube is essentially a structure made from an organic network of steel tubular members and clad with translucent ETFE (ethyl tetra fluoro ethylene) cushions. The Water Cube is comprised of a series of steel tubes welded to round steel nodes.

ETFE is a tough recyclable material with a durability of more than 20 years. It is strong, lets in light, has excellent insulation properties and yet is incredibly lightweight. By cladding the Water

Cube in high-tech ETFE cushions, 20 percent of the solar energy falling on the building is trapped within the building and is used to heat the pools and the interior area.

Arup's fire engineers used performance-based fire engineering to develop a set of provisions specifically tailored to the Water Cube. This is because the winning design did not fit into China's prescriptive building code. This approach allows greater flexibility, a more cost effective design and enables the individual needs of the client and project to be met. It also allowed the architect and Arup to create the architectural vision without being restricted by the limitations of a prescriptive code.

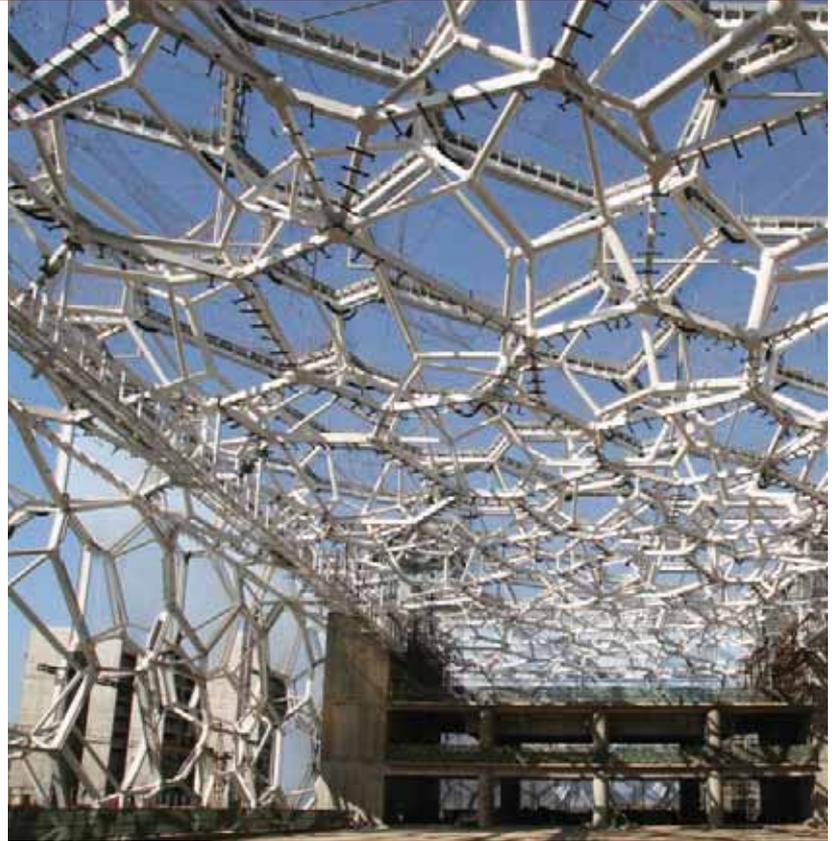
A complex combination of structural and fire engineering analysis demonstrated that for the potentially worst fire scenarios in the building, the structure would continue to carry the loads without failure, and therefore did not require fire protection to the steel.



©Arup + Ben McMillan



©Arup + Ben McMillan



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**Client**

Beijing State-Owned Assets Management Co

**Project Manager**

Three Gorges Corporation

**Consortium Leader**

China State Construction Engineering Corporation  
(CSCEC)

**Design Consortium**

Architect: PTW Architects & China  
Construction Design Institute (CCDI)

Engineer: Arup & China State Construction  
Engineering Corporation (CSCEC)



## Supreme Court of Singapore

The building mass of the new Supreme Court is segmented into distinct blocks which separately house the appellate courts, high courts, administration offices and a major tenant - The Singapore Academy of Law.

To give the court blocks the flexibility to expand and reconfigure the internal layouts, large structural spans were required, whilst high headroom was needed for better quality of space.

The challenge of slender column and beam sizes, with long structural spans (12m and 16m in the court blocks) and shallow structural space required that the building's weight be designed as light as possible. Steel construction with composite steel decks was the logical choice. To meet the aesthetic requirement of concrete frame with unblemished off-form surface finish, the steel beams and columns were integrated with precast concrete. The use of precast

concrete also served to provide fire protection to the steel members.

The disc shell roof was built entirely in steel, which helped to create the desired curved roof form, and was also economical to build. The disc is a two-storey high, 67-metre diameter circular structure. Circular tension ring members were incorporated at the base and at regular intervals along the span of the spine beams to ensure lateral stability of the roof structure.

Fire protection to resist structural collapse of the dome was achieved by two protective systems i.e. intumescent system for exposed steel structure and sprayed system for hidden structural elements.

A thin-film, intumescent paint fire rated coating was used for the exposed supporting columns. This allowed the designers to expose the structure

in its purity with the appearance of painted steel, yet provides fire-resistance ratings of up to 90 minutes. The remaining unexposed structural steel beams and columns were protected via vermiculite-based sprayed systems. Inspections of the quality of the coating and thickness checking

were done immediately after the spraying. These sprayed materials were chosen as they were quick to apply, inexpensive and could be adapted to cover complicated shapes including the voids between metal deck floors and steel beams.



*Prefabricated composite columns and beams*



*Disc's radial steel ring beams*



*Disc Leg*



*Composite floor construction using steel deck and minimal concrete topping*



*Aerial view of the shell roof*

**Owner**  
Supreme Court of Singapore  
**Architect**  
CPG Consultants Pte Ltd  
**Design Consultant**  
Foster and Partners  
**Structural Engineer**  
CPG Consultants Pte Ltd  
**M&E Engineer**  
CPG Consultants Pte Ltd  
**QS**  
CPG Consultants Pte Ltd  
**PM**  
PM Link  
**Builder**  
IRE-Sato Kogyo JV  
**Facade Consultant**  
Arup Facade Engineering



*Side Atria with glowing translucent stone-glass wall*

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- City Developments Limited
- Corus South East Asia Pte Ltd
- CPG Consultants Pte Ltd
- Far East Organization
- Housing and Development Board
- Interiors Supply Pte Ltd (USG Boards)
- IRE-Sato Kogyo JV
- JTC Corporation
- JURONG Consultants Pte Ltd
- LCP Building Products Pte Ltd
- LOOK Architects



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- National University of Singapore
- SamGreen Pte Ltd
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- UOL Group Limited
- World Class Land Pte Ltd
- Yongnam Holdings Limited

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