INTRODUCTION
The design and construction of sustainable buildings involve striking a sensible balance of social, environmental and economic considerations. Concrete, in its many forms, is a versatile building material that can provide many sustainable benefits by virtue of its economic, thermal mass, durability, fire resistance, acoustic performance, adaptability and recyclability. Choosing the appropriate method of concrete construction for the particular type of building will ensure these benefits are utilised to deliver the most sustainable outcome.

Social – Buildings must provide a safe, healthy and comfortable interior environment. Considerations include:
- Structural integrity
- Vibration
- Weather protection
- Fire resistance
- Acoustic performance.

Environment – Buildings must be constructed such that the whole-of-life energy use and associated greenhouse gas emissions have a low environmental impact. Considerations include:
- Life-cycle assessment
- Thermal mass
- Cooling of urban areas
- Recycling.

Economic – Buildings must be durable, low maintenance, reusable and energy efficient, during both the building construction and operation phases.
Considerations include:
- Construction costs
- Construction programmes
- Net lettable area
- Whole-of-life value
- Building reuse.

This Briefing provides designers, builders and owners with an understanding of the significance of concrete in producing sustainable buildings.

**Figure 1** The three considerations of sustainable development

**FORMS OF CONCRETE CONSTRUCTION**

**General**

Reinforced concrete, in its many forms, is a versatile building material that can provide many sustainable benefits by virtue of its economic construction, thermal mass, durability, fire resistance, acoustic performance, adaptability and recyclability. Choosing the appropriate method of concrete construction for the type of building will ensure these benefits are combined to deliver the most sustainable outcome. Some concrete systems are detailed below, highlighting how they might enable the designer and builder to better balance the economic, environmental and social impacts of a building.

**Cast-in-situ concrete**

Cast-in-situ reinforced concrete structures consist of horizontal elements (beams and floors) and vertical elements (columns and walls) connected by rigid joints. Reinforced concrete frames provide resistance to both gravity and lateral loads via the bending and shear resistance of the beam and columns. The ability to construct formwork on site, to any desired shape, and to place reinforcement at strategic locations, ensure great flexibility during the design and construction stages.

**Precast concrete**

Precast concrete elements, such as wall panels, beams and floors (purpose-made or standard sections), offer particular benefits:
- Waste within a controlled factory prefabrication environment is minimised.
- Tight factory quality control results in high quality finishes.
- Work on site and the manufacture of precast elements can proceed concurrently, resulting in a more efficient and faster construction programmes.
- Construction site labour is minimised, since site formwork and reinforcement fixing is reduced. Site waste and noise are also reduced.
- Precast lends itself to ‘design for disassembly’ and reuse of the elements.
- Sandwich panels consisting of two layers of concrete, separated by an internal layer of insulating material, commonly high density polystyrene provide elements with both high thermal mass and high thermal insulation. Superior energy efficiency can be achieved by utilising sandwich panels in the exterior walls of buildings.

Precast elements are increasingly being incorporated into medium-rise commercial and residential buildings. This is demonstrated by Bishops See South Tower, Perth, shown in Figures 2 and 3.

**Tilt-up construction**

Tilt-up construction differs from construction using factory-precast components in that the elements are cast on the job-site (on a ground floor slab or temporary casting surface) and tilted into position. The panels may be loadbearing or non-loadbearing and may feature a wide range of applied or formed finishes. As with the factory-precast approach, sandwich panels can be produced by the tilt-up method.

Tilt-up is well established in Australia, and is the preferred system for many types of low-rise buildings, including warehouses, industrial buildings, offices, schools, hospitals, service buildings and, increasingly, housing. Tilt-up provides a number of similar sustainability benefits as precast concrete construction, especially speed of construction, energy efficiency and longevity. The method is efficient, because the wall panels can be formed and cast while the rest of the building is being designed or built. This overlapping of disciplines makes for earlier project completion. Tilt-up construction has the added benefit of reduced transportation costs.
Post-tensioned concrete
Post-tensioned concrete consists of reinforced concrete floors, beams or walls, into which post-tensioning ducts are cast. High tensile steel strands or bar are passed through the ducts, tensioned and grouted. The resulting post-tensioned members deflect less than normal reinforced concrete; and are particularly suitable for long spans.

The advantages include:

- **Longer spans.** The ability of post-tensioned concrete floors to achieve longer spans can reduce the number of support columns and walls required, resulting in larger column-free spaces. In commercial buildings this is a particular advantage, permitting flexible office layouts; and typically achieving higher rental returns.

- **Reduced floor-to-floor height.** Post-tensioning typically achieves floors of less overall depth for a particular floor loading, thus reducing the floor-to-floor height. In multi-storey construction, the resulting reduction in the height of all vertical elements gives a significant cost saving.

- **Superior slab deflection control.** The level of post-tensioning applied to a slab can be adjusted to cater for the degree of deflection control required. This can neutralise service load deflections. There is no need for pre-cambered formwork, to cater for expected deflections; resulting in considerable cost saving.

- **Efficient use of formwork.** Large flat post-tensioned slabs are simple to form, due to the reduced need for step-downs in formwork at beams.

- **Shorter construction cycle.** Appropriately designed post-tensioned slabs, with high-early-strength concrete, permit early stripping of formwork. Faster floor construction leads to quicker re-use of formwork, and increased speed of overall building construction.

- **Reduced materials handling.** In comparison to reinforced concrete, post-tensioning typically permits thinner slabs, hence a reduction in concrete volume and the related materials handling, delivery trucks and pumping.

**SOCIAL CONSIDERATIONS**

**Structural integrity**

The structural design and construction of concrete elements in buildings (including cast-in-situ reinforced concrete, precast concrete, tilt-up and post-tensioned concrete elements) is well understood by architects, structural engineers, builders and project managers. The Building Code of Australia (BCA) and a suite of Australian Standards (focussed on AS 3600) regulate the structural requirements of concrete buildings. This leads to safe structures, able to withstand any of permanent, imposed, wind, earthquake and snow actions.

**Vibration**

For common spans, the relatively high mass of concrete floors leads to natural damping and low vibration. For more-stringent criteria, such as for laboratories or hospital operating theatres, the additional cost to meet vibration criteria is small compared to lightweight construction.

**Weather protection**

High quality concrete, properly compacted and cured, effectively detailed, and (in some cases) coated, can contribute to a durable weather-proof building envelope.

**Fire resistance**

Concrete does not burn and does not emit any toxic fumes when subjected to fire. It will not produce smoke or drip molten particles.

For these reasons, in the majority of applications, concrete can be described as ‘fireproof’. Concrete structures generally do not require fire protection if appropriately designed, because of their inherent fire resistance. This removes the time, cost, additional materials and labour required to provide separate fire protection measures.

The fire resistance requirements are specified in the BCA and the means of compliance for concrete are set out in AS 3600. Subject to appropriate support conditions, a 120-mm-thick concrete wall can provide two hours fire resistance. Thicker walls provide greater resistance. Similarly, concrete floors, beams and columns can also be designed to adequately comply with fire-resistance requirements specified in the BCA, without requiring specialised fire protective measures. This is a potent advantage of the use of concrete in buildings.

Concrete’s inbuilt fire resistance can restrict smoke from spreading, and will maintain the building’s strength during a fire. After a fire, the continuing structural integrity and reduction in smoke damage also reduces the magnitude of insurance claims. The structure can often be reused, rather than being consumed in the fire or requiring demolition to remove melted and buckled members.

Concrete structures both protect life and preserve property, thereby contributing to enhanced social and economic performance of the built environment.

**Acoustic performance**

Excessive noise has an adverse effect on personal health and wellbeing, ability to perform quiet tasks, and productivity in general. Hearing loss due to prolonged exposure to noise is well documented. The issue of sound insulation and acoustic performance of homes and offices has grown in importance, due in part to the growing demand from governments for increased density of urban development.

In general, increasing the mass of a wall or floor improves the sound insulation of a room; hence concrete offers a good barrier to airborne sound. Impact sound can be controlled with appropriate floor and ceiling finishes.

The inherent mass of concrete can minimise the need for additional finishes required to meet acoustic
requirements, with concrete walls providing an effective buffer between:
- outdoor noise and the indoor environment;
- road noise and residential areas, via a sound barrier;
- adjoining apartments or other spaces, via a separating wall.

ENVIRONMENTAL CONSIDERATIONS

Life-cycle assessment

The importance of assessing a building’s environmental performance based on life-cycle assessment cannot be over emphasised. The majority of energy use and greenhouse gas liberation occurs during the operational phase of buildings, and far exceeds the energy used and greenhouse gas liberation in the construction phase (embodied energy).

Guggemos & Horvath confirmed this in a recent USA study that compared the environmental impacts of constructing a steel-framed and a concrete-framed building. (They concluded that there was little difference in embodied energy between the two forms of construction).

A true indication of the sustainability of building materials and buildings can be achieved only by consideration of both the construction phase and the operational phase of the building, over its whole service life, ie a Life Cycle Assessment.

A Life Cycle Assessment (LCA) examines the environmental impact of a system throughout the whole of its life, ie from the time the resources are removed from the ground to the time when they are retrieved at the end of the system’s life, Figure 4. It must also include consideration of the effect that the particular building system has on the operational (heating and cooling) energy.

Cement Concrete & Aggregates Australia commissioned a series of case studies to be conducted by the then Department of Public Works and Services (DPWS) of NSW to demonstrate the use of LCA as a tool for assessing and comparing whole buildings over their entire life cycle. Details can be found on www.ccaa.com.au.8

CCAA LCA case studies indicate that the energy used to produce the construction materials (embodied energy) is generally less than 10% of the operational energy (including heating, cooling and lighting) used over a fifty-year life. It is the operational energy that contributes to the majority of the total energy consumption over the whole life cycle of the building.

The environmental impacts of the operational phases increase proportionally with the length of the life cycle of the building.

Commercial and industrial case studies highlight the fact that the majority of energy is used during the operational phase of the building. Figure 5 shows that less than 10% of the total life cycle energy is produced during the construction phase.

**Thermal mass**

Thermal mass (also called thermal capacitance or heat capacity) is the ability of a body to store heat. It is designated by \( c \) and typically measured in units of MJ/m³K or MJ/K or the equivalent MJ/m³°C or MJ/ºC. Together with effective ventilation, solar shading and building orientation, the use of thermal mass is a critical component of passive solar design of buildings. Buildings with a medium to high level of thermal mass are characterised by their inherent ability to store thermal energy, and then release it several hours later. Thermal mass can make a significant contribution in reducing energy consumption and green house gas emissions, while maintaining the occupancy comfort. More detailed discussion of thermal mass when used in passive solar design can be found in *Thermal Mass Benefits for Housing*10.

![Figure 4 Life cycle assessment process](image)

![Figure 5 Energy used on three CCAA warehouse life cycle examples studied](image)
Cooling of urban areas
In urbanised parts of the world, the towns and cities are generally hotter than the rural areas surrounding them. As these centres increase in size, ambient temperatures increase accordingly. On hot summer days, ambient conditions in urban areas can be 2 to 6°C hotter than in the adjacent countryside. This phenomenon is known as the 'urban heat island effect'; and is quite separate from global warming caused by greenhouse gas emissions. In addition to the discomfort so caused, and the additional demand for artificial cooling, urban heat islands can influence rainfall patterns, with increased rainfall downwind of cities compared to the upwind areas.

The common measure of the 'urban heat island effect' is Albedo. This is the ratio of reflected to incident electromagnetic radiation power, and is indicative of the reflectivity of a surface. Albedo depends on both the nature of the surface, the frequency of the incident radiation, the direction and directional distribution of the incident radiation.

Exposed building materials with high Albedo reflect more heat, and lead to cooler cities. The Albedo of normal portland cement concrete is approximately 0.35, with values as high as 0.7 to 0.8 for white portland cement concrete. In contrast, dark materials such as new asphalt can have an Albedo as low as 0.05.

The incorporation of high-Albedo concrete products in exposed surfaces such as pavements can significantly reduce the heat island effect and lead to cooler urban areas.

Recycling of materials
While the sustainability of buildings can be significantly increased by extending their useable life, there comes a time when they must be demolished and replaced.

The demolition of cast-in-situ, precast and tilt-up reinforced concrete can be achieved relatively easily by modern cutting, breaking and lifting equipment.

The demolition of post-tensioned concrete requires more careful consideration. Commercial buildings increasingly incorporate post-tensioned floors, which should be adequately supported and isolated during the process. Bonded tendons are mandatory in Australian post-tensioned concrete design. In this system the steel strand is bonded via the grout and duct to the concrete. Therefore, any cut through the tendon has a local effect only. At a bond length away from the cut, the tensile strength is relatively unaffected. Experience has shown there is no explosive release of energy when the concrete is broken out in small areas, because the strand is fully grouted and bonded.

Once demolition has been completed, the concrete and reinforcement can be separated for recycling as aggregate and steel respectively.

A demolished building provides a potentially rich source of recycled aggregate for a range of applications. Recycled aggregates can be used for building products, in road construction, or land reclamation, thereby reducing the amount of material sent to land fill and reducing the need for virgin materials in new construction. Currently the majority of recycled aggregates tend to end up as sub-base and fill, including use in road building and airfield pavements. Standards Australia Handbook HB 155 provides further information on the use of recycled concrete aggregates.

Reuse of concrete components
While the sustainability of buildings can be significantly increased by extending their useable life, there comes a time when they must be demolished and replaced.

If the original design accounts for the deconstruction process in an orderly way, much of the building material can be reused.

The following example of sensible reuse of concrete components is quoted in the Sustainable Concrete website, '…the Mehrow Residence, an area near Berlin. Here the German architect Hervé Biele from the Conclus architect practice, has designed new family housing that reused the complete walls, floor plates and ceilings from a demolished communist-era 11-storey tower block or ‘plattenbauen’. The only significant energy costs arose from the transportation of the five-tonne panels and the use of a portable crane to lift them into place on site. However, the usual fuel emissions associated with aggregate extraction, cement manufacture and mixing were eliminated, making the reuse of pre-fabricated panels a very sustainable option. For the Mehrow Residence, the demolition firm provided the panels free of charge, which saved them the disposal cost and the architects the material cost…’.

Other construction costs that should be considered when designing a building are:

- Footing. Footings typically represent 3% of a building’s cost. For the heaviest reinforced concrete solutions, the footings will be more expensive, but, in relative terms, this represents only a small cost. The use of post-tensioned slabs, which are typically 15% lighter than other forms of construction, can minimise this cost.

- Cladding and facade. Facades typically represent up to 25% of the building cost. Minimising the building’s overall height, by using post-tensioned slabs, will
significantly reduce the facade costs. The minimum floor-to-floor height of a commercial building is almost always achieved using post-tensioned concrete flat-slab floors.

- Partitions. Sealing and fire stopping at partition heads is simplest with the flat soffits associated with post-tensioned floors. Significant savings of up to 10% in the partitioning cost can be made, compared to the similar partitions abutting a profiled soffit with beams or drop-slabs. This can represent up to 4% of the frame cost.

- Air tightness. Concrete edge details are simpler to seal and have less risk of air leakage, thereby ensuring the efficient performance of heating and cooling systems.

- Floor system. The current trend in commercial buildings for open-plan floors and minimum columns makes long-span floors attractive. Post-tensioned band beams with one-way flat slabs provide the most economical long-span floor systems. More information on economical span ranges for different floor systems can be found in Guide to Long-span Concrete Floors\textsuperscript{15}.

- Services co-ordination/ installation/adaptability. The installation of services is simplest when they are below a flat soffit. This permits maximum off-site fabrication, higher quality of work and quicker installation, all potentially reducing costs. The soffit of a concrete flat slab provides a zone for the running of services free of any beams or other protrusions. This, in turn, reduces coordination requirements and reduces the risk of errors\textsuperscript{14}.

Construction programmes

Construction of concrete framed buildings requires only short lead-in times; with modern formwork systems, floor-to-floor construction periods can be reduced. Four-day floor cycles have been achieved on projects such as 333 Ann Street, Brisbane\textsuperscript{3} Figure 7. Concrete also provides a safe working platform and protected workspace, so that services installation and follow-on trades can commence early in the programme.

Net-lettable area

The number and size of columns has a major effect on the net-lettable area of a building. Reduction in column size can be achieved by the use of high-strength concrete. The selection of an efficient floor system can also have a significant effect on a commercial building’s net-lettable area. Post-tensioned floors, capable of long spans with only small deflections, minimise the number of columns needed. Concrete structures with reduced floor-to-floor heights potentially permit additional floors to be provided within the same overall building height.

Whole-of-life value

Concrete’s range of inherent benefits including thermal mass, fire resistance and durability means that concrete buildings tend to have lower operating costs and lower maintenance requirements. These sustainable attributes are discussed in more detail in the previous section Environmental Considerations, page 4.

Building reuse

In former industrial areas and inner city precincts, there are many old factories, old warehouses and the like that have been converted into very desirable dwellings. Concrete buildings can often be adapted fairly easily for new uses, eg:

- Unused office space in buildings with post-tensioned slabs can be used for residential accommodation, thus capitalising on the thin floor slab with flat soffits.
In some circumstances, post-tensioned concrete slabs can be penetrated to provide access for ducts and the like. They derive their tensile strength from high strength steel tendons, spaced at approximately 1-m centres. Depending on the specific application and provided sufficient concrete remains with sufficient compressive strength, the concrete may be penetrated between the tendons without the need for strengthening.

Central city tower blocks are now also being recycled, as highlighted in CCAA’s Concrete Concepts Case Study 14\(^{15}\) on Condor Tower in Perth where a 10-storey office building was converted to a 29-storey residential tower. Figures 8 and 9.

Effective building reuse usually requires the building structure to be left largely intact. Refurbishing:

- saves natural resources, including the raw materials, energy and water. Materials otherwise required for new structures;
- reduces the quantity of solid waste sent to landfill;
- prevents pollution that would result from the extraction, manufacturing and transportation of virgin materials.

The high durability of concrete buildings is a key factor in their suitability for reuse. In addition to its long service life, concrete offers a low-maintenance surface. Planned maintenance will assist in lengthening a building’s life and improve the chances of its reuse.

The Green Building Council, Australia’s\(^{17}\) Green Star assessment tool, recognises the importance of building reuse by awarding it additional credit points which assist in achieving a higher ‘green’ rating for the building.

Concrete – the responsible choice

From a social perspective, concrete buildings provide a safe, healthy and comfortable interior environment. Well developed design principles complying with the relevant codes and standards provide structural integrity. Concrete floors exhibit low vibration, and concrete walls can be easily weather proofed. Excellent fire resistance and good acoustic performance enhance the quality of life in concrete buildings.

Concrete buildings have a low environmental impact, low whole-of-life energy use and associated greenhouse gas emissions. The high thermal mass of concrete leads to efficient passive thermal design. Its relatively light colour (high Albedo) can lead to a considerable reduction in the heat-island effect of cities and towns. Concrete materials are particularly suited to recycling. Economic considerations rate highly in the decision-making process for new construction. Sensible selection of various concrete elements, such as precast concrete, tilt-up and
post-tensioned concrete will result in decreased construction costs and shorter construction programmes. The use of high-strength concrete (to minimise column dimensions) and post-tensioned floors can increase the net lettable area. The resulting buildings have an enhanced whole-of-life value, which, with some foresight, can enjoy extended life through reuse rather than demolition.

There is increasing awareness of the need to provide sustainable buildings. Concrete is the responsible choice for sustainable development.

REFERENCES
1 Concrete Concepts Case Study 12, Bishops See South Tower Building, Perth, Cement Concrete & Aggregates Australia, March 2009.
6 AS 3600 Concrete Structures Standards Australia, 2009.
7 Data Sheet, Cement Concrete & Aggregates Australia, 2009 Sound Insulation Properties of Concrete Walls and Floors.
10 Thermal Mass Benefits for Housing, Cement Concrete & Aggregates Australia, Briefing 12, 2010.
12 VanGeem M Albedo of Concrete and Selected Other Materials Construction Technologies laboratories, Inc. 19/10/02, website: www.lehighcement.com/ Education/
13 Guide to the Use of Recycled Concrete and Masonry Materials (HB 155), Standards Australia, 2002.
16 Concrete Concepts Case Study 14, Condor Tower, Perth, Cement Concrete & Aggregates Australia, February 2010.

CCAA OFFICES
SYDNEY OFFICE: Level 6, 504 Pacific Highway St Leonards NSW Australia 2065 POSTAL ADDRESS: Locked Bag 2010 St Leonards NSW 1590 TELEPHONE: (61 2) 9437 9711 FACSIMILE: (61 2) 9437 9470
Brisbane OFFICE: Suite 2, Level 2, 485 Ipswich Road Annerley QLD 4103 TELEPHONE: (61 7) 3227 5200 FACSIMILE: (61 7) 3892 5655
MELBOURNE OFFICE: 2nd Floor, 1 Hobson Street South Yarra VIC 3141 TELEPHONE: (61 3) 9825 0200 FACSIMILE: (61 3) 9825 0222
PERTH OFFICE: 45 Ventnor Avenue West Perth WA 6005 TELEPHONE: (61 8) 9389 4452 FACSIMILE: (61 8) 9389 4451
ADELAIDE OFFICE: PO Box 229 Fullarton SA 5063 TELEPHONE: (61 8) 8274 3758 PREMIXED CONCRETE AND EXTRACTIVE INDUSTRIES OFFICE PO Box 243 Henley Beach SA 5022 TELEPHONE: (61 8) 8353 8151 FACSIMILE: (61 8) 8125 5822
TASMANIAN OFFICE: PO Box 246 Sheffield TAS 7306 TELEPHONE: (61 3) 6491 1509 FACSIMILE: (61 3) 6491 2529 WEBSITE: www.ccaa.com.au EMAIL: info@ccaa.com.au

Disclaimer: Cement Concrete & Aggregates Australia is a not for profit organisation sponsored by the cement, concrete and aggregate industries in Australia to provide information on the many uses of cement, concrete and aggregates. This publication is produced by CCAA for that purpose. Since the information provided is intended for general guidance only and in no way replaces the services of professional consultants on particular projects, no legal liability can be accepted by CCAA for its use.

CCAA respects your privacy. Your details have been collected to provide you with information on our activities, publications and services. From time to time your details may be made available to third party organisations who comply with the Privacy Act such as affiliated associations, sponsors of events and other reputable organisations whose services we think you may find of interest. If you do not wish to receive information from CCAA or wish to be taken off the database please write to the Privacy Officer, CCAA, Locked Bag 2010, St Leonards, NSW, 1590

ISSN 1447-199X