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# Resilience, resources and concrete

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# RESILIENCE, RESOURCES AND CONCRETE

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## ABSTRACT

There is much evidence to support the contention that the earth's climate is changing. In recent years sustainability – that is, efficient use of resources to ensure a positive legacy for future generations – has been a focus. However, resilience – the ability to withstand calamitous events and maintain utility – is emerging as a complimentary strategy.

Concrete, as the second most consumed material after water, is able to contribute to both the sustainability and resilience of the community. The concrete industry has responded to the mitigation requirements to ensure sustainability, while continuing to the durability and resilience of the built environment. Recent developments to reduce the embodied emissions of cement and other concrete binders are discussed. The cement and concrete industry, through the Cement Concretes and Aggregates Australia, is fully involved in communicating the life-cycle benefits of its products. It maintains and active research program (the CCAA Technology Plan) which evaluates improvements and updates metrics, as a means of demonstrating the environmental benefits of concrete.

Resilience has been elevated to a Commonwealth government priority. Through the review of building codes and Standards, the ability to provide sufficient resistance in structures by informed choice of building materials is examined. The whole supply chain is involved in this examination and recent developments in rating particular building materials and land use has served to underline the credentials of concrete as both a sustainable and resilient material.

## KEYWORDS

Concrete, cement, aggregates, sustainability, life cycle cost analysis, resilience, functional resilience.

## INTRODUCTION

Cement, Concrete and Aggregates Australia is the peak body representing the interests of Australia's $7 billion a year heavy construction industry covering the cement, premixed concrete and extractive industries. The organisation's members operate rock quarries, sand and gravel extraction sites, cement production and distribution facilities and concrete batching plants throughout Australia (Cement Concrete and Aggregates Australia, 2014). Among its principal functions is to be the leading information provider on its members products through the technical library, a modest research program (Technology Plan) and liaison with other organisations ensuring the benefits and properties of concrete are fully understood.

Clearly there has been community and policy pressure to lower embodied emissions in construction. While recent changes in the government response to climate change have seen some movement in this area, there remains an underlying requirement to develop a strategy, or a number of strategies, to continue the trends already established. These strategies require a collaborative approach to reductions from manufacturers, specifiers and designers, in fact, all nodes in the concrete supply chain can contribute. The role of academia and research is to identify opportunities and evaluate options for reductions and provide support for their introduction. Many companies do not maintain an in-house research capability, and there is an opportunity to partner with individual enterprises, or industries, and commercialise research.

Concrete is considered a sustainable building material. There are many ways in which it can be considered within the framework of the “triple bottom line” approach to sustainability. These are shown in Figure 1:

**SOCIAL**

Essential part of construction industry (10% of GDP)

Provides livelihood for employees

Create structures providing safe shelter

Contributes to aesthetic of built environment

Flood and fire protection

**ENVIRONMENTAL**

Key enabler of renewable energy technologies

Superior performance
- Thermal mass
- Durability
- Sound Insulation

Readaptation and reuse of structures

Recycling of materials at end of life

**ECONOMIC**

Relatively low economic cost vs performance

Lowest whole-of-life cost (NPV) in infrastructure

Good geographic availability (lower transport costs)

Durability lowers maintenance costs

Figure 1. Concrete – sustainability in a triple bottom line context (South, 2012)

International pressure regarding sustainability has seen an industry based approach to both establishing agreed metrics and implementing action to improve those metrics. An example of this is the Cement Sustainability Initiative within the auspices of the World Business Council for Sustainable Development (World Business Council for Sustainable Development, 2014). This is a co-ordinated approach by 24 major world cement manufacturers, representing more than 30% of global cement production, to address the role of the cement industry in sustainable development. One of the main purposes is to identify actions and facilitate progress on those actions by the member companies. Through the Cement Industry Federation, the Australian cement industry has a role in this initiative.

The Australian cement and concrete industry continues to improve the sustainability of its products through a number of strategies. These strategies are aimed at:

- Reducing the embodied greenhouse gas content,
- Preservation of natural and virgin materials by developing and refining the use of alternate materials, and,
- Reducing the amount of waste through intelligent re-use and application of its products.

Concrete is essentially from a mixture of coarse and fine aggregate, with water and cement to bind these materials. Therefore it is prudent to also consider the strategies employed in the supply chain of aggregates to examine their contribution to the sustainability of concrete. It is possible to substitute natural coarse and fine aggregates with other materials, by-products from quarrying and other industries. The aggregate supply industry has developed and refined their materials streams to increase the amount of useable aggregate, and reduce the amount of waste materials. Indeed “manufactured sand” is a viable substitute for natural sand produced from material that would have previously been discarded.

Further, the addition of water is required for the hydration of components of the binder, and a contribution to the workability of the plastic concrete. Again, the substitution of potable (drinking) water with water gained from either on-site at the batching plant, or a recycled supply of suitable quality from other industries, is a viable strategy.

Both these actions, substituting whole or part portions of aggregate and water additions serve to contribute to the conservation of natural resources and minimisation of the volume of waste streams. This fact is recognised in the GreenStar MAT-4 Concrete Credit (Green Building Council of Australia, 2012), which encourages and rewards these sustainable strategies with points towards the overall ranking of the project.

## IMPROVING SUSTAINABLE CONCRETES

Building on the past strategies, the cement and concrete industry has sought to further reduce the embodied carbon content of Australian cements through an increase of the allowable mineral addition content in Type GP to 12%. This proposition, an increase from the present 7.5% (Standards Australia, 2010), would further reduce carbon emissions in the Australia by up to 270,000 tonnes per year, without compromising present concrete performance and durability.

An allowable mineral addition of 12% is somewhat lower than that permitted in other comparable jurisdictions. In Europe for example, up to 20% is in regular structural applications (European Committee for Standardisation, 2011), with specialty cement allowed a substitution of up to 35%. This has been the case in some European countries since the 1970s. In Canada (Canadian Standards Association, 2008), and later the US (American Society of Testing and Materials, 2012), cements with up to 15% mineral addition are in regular application since 2009. New Zealand allows up to 15% mineral addition(Standards New Zealand, 2009).

The industry undertook an extensive, and expensive, test program over the past 3 years. This involved performance evaluation in commercial concretes, with structural and durability properties resolved. The outcome, in line with an extensive reference list, shows that an increase to 12% would not result in any major performance detriment, with some properties showing a positive change.

This work programme will be used to support a proposed amendment to the Australian Standard 3972 -2010 – a process well underway.

## A LIFE-CYCLE APPROACH

To this point, we have considered just the environmental impacts of concrete and the gains made in lowering the embodied emissions contained in the material. A consideration of the commentary made in Figure 1, shows there are many areas which must be examined in determining the overall environmental impact of a construction project. There are many references which show that more than 80% of the energy impact of structures is though the operation and occupation of that structure (Ochsendorf, 2011), rather than the energy embodied in the framework of that structure. As strategies are developed to achieve sustainability goals, methodologies need to be developed that use a “whole-of-life, whole-of-building” approach to evaluate the overall environmental impacts, and apply this knowledge to develop future responses.

When comparing construction alternatives, a life cycle assessment (LCA) provides a level playing field. An LCA is based on a consistent methodology applied across all products and at all stages of their production, transport, energy use, maintenance, and disposal or recycling at end of life. Often the sustainability credentials of one building product over another are based on a few selected impact categories instead of a full life cycle assessment. For instance, there are LCA studies use only the measures of embodied energy or embodied $CO_2$ emissions. These comparisons are flawed because they only consider limited number of metrics and do not include all impact categories that should be in a full assessment. A full LCA (International Standards Organisation, 2006) should include the impacts of energy use and associated emissions over the life of the product or structure, such as climate change, acidification, materials acquisition, and human health effects.

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| **ROADING** | **Materials**<br>Extraction<br>Production<br>Transportation | **Construction**<br>Equipment<br>Traffic Delay<br>Transportation | **Use**<br>Rolling resistance<br>Carbonation<br>Albedo<br>Lighting<br>Leachate | **Maintenance**<br>Materials Phase<br>Construction Phase | **Construction**<br>Equipment<br>Landfilling<br>Recycling/Reuse<br>Transportation |
| **BUILDING** | **Materials**<br>Extraction<br>Production<br>Transportation | **Construction**<br>Equipment<br>Temporary<br>Structures<br>Transportation | **Use**<br>Plug loads<br>Lighting<br>HVAC systems<br>Thermal Mass<br>Routing maintenance | **End of Life**<br>Demolition<br>Landfilling<br>Recycling/Reuse<br>Transportation | |

Figure 2. Typical phases and components of the road and building life cycles (Special Research Brief - Concrete Sustainability Hub @ MIT, 2011)

Figure 2 shows in general detail the elements of a typical road and building life-cycle analysis. All phases of the life cycle are mapped, with the system boundaries described to how each phase may impact the environment. For a road project, this may include traffic delays during construction, the increased fuel requirements associated with surface roughness, ambient lighting requirements for safety, and safe disposal of materials at the end of the project's life. Likewise, a life cycle analysis for a building would include energy for heating, cooling and lighting, access requirements during construction, maintenance of interior and exterior surfaces and adaption/renovation requirements. It should be noted that it is often not possible to quantify these elements, but it is necessary to describe them, enabling discrimination of performance in determining the design and specification of the building.

A life cycle analysis may be further improved by extending the impacts to include economic factors – a life-cycle cost analysis (LCCA) (Special Research Brief - Concrete Sustainability Hub @ MIT, 2011). This should not be restricted to just the cost of construction materials, but include future maintenance and operation cost information. Therefore, initial decisions as to construction design can be made on the basis of overall environment and economic impacts over the entire life of the project.

## FUNCTIONAL RESILIENCE

The application of sustainability and life cycle approaches to evaluating construction projects evokes an obvious conclusion – the longer the life of the project, the better is the use of resources (provided maintenance requirements are minimal) and the better value delivered overall. This aspect permeates all aspects of design, construction and maintenance of the structure. Therefore, the life of the building is a fundamental design consideration.

The concept of "functional resilience" is defined as the structure's capacity to provide viable operations throughout an extended service life, adaptive re-use and the challenges of natural and man-made disasters (National Ready Mixed Concrete Association, 2009). Functional resilience is integral in the design and construction of many public structures, but has not necessarily been a prime design consideration for private construction.  However, there is a growing movement to provide resilient structures as a key component to economic, societal and environmental viability. Functional resilience is an outcome of a durable structure – the structure remains serviceable even though subjected to environmental distress.

## AUSTRALIAN CONTEXT

With a history of floods, droughts and fire, the Australian community has perhaps a greater appreciation of the impact of natural disaster on communities than many other societies. Our summers are characterised by loss of property through bushfire in many States, the north of the country lies vulnerable to cyclones, and the cycles of El Nino can be characterised by drought and flood in different parts of the nation, often at the same time.

These facts have been recognised by government policy, with the Council of Australian Governments endorsing the National Strategy for Disaster Resilience in 2011 (Council of Australian Governments, 2011). This strategy outlines seven strategic priorities for action and identifies priority outcomes ranging from emergency management to disaster preparedness. Specific areas of interest to the construction industry involve settlements and infrastructure, with the recommendation that codes and standards are monitored to ensure they are sufficient to meet the changing climate related hazard environment. It specifically addresses reconstruction:

> “Following a disaster, recovery efforts may require significant infrastructure reconstruction. Building public and private infrastructure to a more resilient standard, if appropriate, taking into account cost-benefit and other considerations, will reduce the need for significant expenditure on recovery in the future”(Council of Australian Governments, 2011)

Clearly, life cycle cost analysis is a means of enabling resilient reconstruction and evaluating options. As discussed previously, concrete provides appropriate, durable and cost-effective solutions to enable a community to endure and recover from natural disaster, and would be suitable construction material for many structures.

In 2014, the Australian Building Codes Board (ABCB) released the discussion paper “Resilience of Buildings to Extreme Weather Events” (Australian Building Codes Board, 2014). This arises from the fact that ABCB retains oversight of the National Construction Code (NCC) and must ensure that the NCC contains sufficient for building and plumbing systems to be resilient in the face of natural hazards. A 2009 review for the Commonwealth government by Allen Consulting Group (Allen Consulting Group, 2009) found that “standards for building design and construction do not currently reflect the potential impact of climate change”. It suggested the National Construction Code be open to change to reflect “climate change adaptation risks”. The discussion paper is an outcome of this and firmly places resilience as a strategy embedded in review of national construction and plumbing systems.

The cost impact of more frequent natural disasters is borne by both public and private insurers. In 2011 the Australian insurance industry paid more than $5 billion in building damage costs following declared catastrophes, in addition to the normal $115 million paid by the industry every day for other claims, including those for property damage following localised extreme weather (Australian Resilience Taskforce, 2012). Hence, the industry has a large interest improving the resilience of the built environment. One of the responses is the formation of the Australian Resilience Taskforce. This organisation is to align with the recommendation and frameworks concerning resilience, in particular the National Disaster Resilience Framework (NDRF) and the National Strategy for Disaster Resilience (NSDR).

The Insurance Council of Australia (ICA) is funding the development of a Building Resilience Rating Tool (BRRT) (Australian Resilience Taskforce, 2013b) that aims “to stimulate best-practice resilience in residential buildings” across Australia. The BRRT draws on the information contained in the Building Resilience Knowledge Database (BRKD) (Australian Resilience Taskforce, 2013a), a compilation of information on the resilience of building products and materials to extreme weather events. The Building Resilience Rating Tool (BRRT) takes into account all the factors that are specific to a property, including the location and the materials used in its construction and gives a single resilience rating. It also provides an opportunity to see which hazards a property is most susceptible to and which elements a structure are negatively affecting the rating. The current version of the BRRT (in beta version 2.0) is focussed on the performance of stand-alone residential property. Future developments will see the incorporation strata and commercial construction types.

## IS THERE A CONCRETE SOLUTION?

Structures that are built to minimum life safety provisions of building codes and standards should not be considered "green", sustainable or high performance regardless of their energy and water conservation or efficient use of natural resources, and indoor environment quality. Structures gaining the epithets of green or sustainable must also be long-lasting, durable and resistance to natural hazards. Sustainability must consider the whole life span of the structure – the potential for future re-adaptation and re-use, minimal maintenance costs, are all significant factors in delivering "functional resistance". Further, the ability to minimise replacement and reconstruction as a result of natural disasters contribute to a higher performance and greater value delivered by the building. This outcome, and its component parts, is illustrated in Figure 3.

Concrete building systems are especially suited to providing resistance to a wide variety of natural hazards. Concrete has the necessary toughness and mass to provide resistance to high wind loads and the flying debris during cyclones. Also, the high mass and structural integrity, enables a concrete structure to withstand the forces of water and debris during inundation, from flood or storm tides. Concrete has a high fire resistance and is non-flammable, which means it can contain fires in buildings and not contribute the spread of fire to other structures. Conversely, it can repel the onslaught of fire from outside a structure, as seen in bushfires. Finally, reinforced concrete systems can be designed and constructed to provide resistance to ground movement and earthquake without collapse.

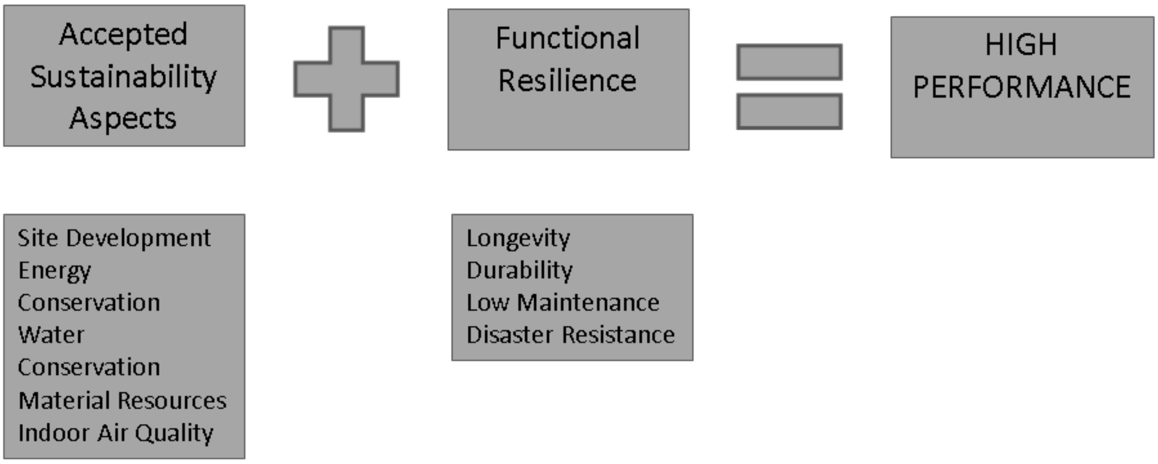

Figure 3. Aspects of sustainability and Functional Resilience contributing to a high performance structure (Lemay, 2012).

In all cases, the utility and function of a structure can be returned with minimal rectification.

## THE ROLE OF RESEARCH

In this paper, the progression and extension of the sustainability considerations to a life cycle approach, and then to a resilient outcome is demonstrated.

The Australian cement and concrete industry has sought to continually improve manufacturing efficiencies to reduce the environmental burden of its products. Lower emissions through substitution of cement clinker, while maintaining concrete and durability performance, is a positive approach to more sustainable built environment. Preservation of natural resources through substituting aggregates and water with re-used and recycled components minimises the draw on existing reserves of these materials, as well as lowers volumes in waste streams for certain industries.

The ability to withstand natural hazards during the life of a structure, is known as resilience. This property is of increasing concern to many sectors, not just designers and specifiers. Federal government and the insurance industry are anxious to ensure that public and private infrastructure provide maximum resistance to inundation, storm, cyclone, bushfire, and earthquake.

The road map for all these strategies is contained in the CCAA Technology Plan. In this plan a number of individual projects are identified, described and prioritised allowing for the planning of resources over a 3 year timespan. The Plan outlines the aspects of concrete and concrete technology which industry sees as important and worthwhile for the application of its products. There is a small budget allocation to complete these projects, which should be used to seed other sources of funding to complete.

The role of researchers will be crucial in realising the Plan. A collaborative approach, with real market and industry issues being examined, will ensure that concrete remains a relevant and widely used building material as the sustainability and resilience of structures become premium design parameters. This detailed evaluation can only be undertaken with the resources in laboratories, personnel and academic competence of tertiary institutions combined with the practical knowledge and expertise of industry.

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