The IES Journal Part A: Civil & Structural Engineering

ISSN: 1937-3260 (Print) 1937-3279 (Online) Journal homepage: http://www.tandfonline.com/loi/tiea20

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The IES Journal Part A: Civil & Structural Engineering
Vol. 3, No. 3, August 2010, 196–202

Taylor & Francis
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(*Received 30 April 2010; final version received 6 May 2010*)

Sustainable construction is critical to Singapore's national development as Singapore has little natural resources. Nearly, all construction materials have to be imported and it is therefore vital to improve Singapore's efficiency on the use of natural resources. Since 2007, the Building and Construction Authority (BCA), together with Singapore's construction industry, strives to promote the adoption of sustainable construction materials and practices. Central to the drive of sustainable construction is the Sustainable Construction Masterplan, with five major strategic thrusts outlining strategies to achieve resource efficiency. The five strategic thrusts cover initiatives from government support, legislation to research and development support. This article also presents some recent initiatives of sustainable construction, such as the development of demolition protocol and sustainable construction capability development fund. The findings of a recently completed full-scale study on the use of recycled concrete aggregates in structural elements of a 3-storey office building are also presented.

Keywords: sustainable construction; government policies; building regulations; recycled concrete aggregates

1. Introduction

Sustainable development has always been a key policy in Singapore's national planning and development. For a small country like Singapore, sustainable development is not an option but a necessity. Being a city state boasting a 5 million population with a land area of about 700 square kilometres, the challenge lies in achieving the right balance between economic growth and environmental sustainability.

It is against this backdrop that the Sustainable Singapore Blueprint (Inter-Ministerial Committee on Sustainable Development 2009) was announced by the Singapore government in April last year. The Sustainable Singapore Blueprint is the culmination of work undertaken by the Inter-Ministerial Committee on Sustainable Development (IMCSD). One of the key thrust of the Blueprint is improving resource efficiency and achieving zero landfill. The building and construction sector, being one of the key drivers of Singapore's economy (19.8% growth in 2009) (Statistics Singapore 2010), will be at forefront of this national effort. It is with this in mind that the Building and Construction Authority (BCA), together with industry associations and major government agencies, formulated the Sustainable Construction Masterplan as part of the contribution to Singapore's sustainable development.

The BCA is an agency under Singapore's Ministry of National Development to champion the development of a safe, high quality, sustainable and friendly built environment.

2. Sustainable construction masterplan

In Singapore's context, Sustainable Construction focuses on the adoption of materials and products in buildings and construction that will consume less natural resources and increase the reusability of such materials and products for the same or similar purpose. Two key focus areas of sustainable construction in Singapore are (a) recycling and use of sustainable materials; (b) efficient design to optimise use of natural materials.

The masterplan is anchored by five strategic thrusts as shown in Table 1.

2.1. Strategic thrust 1: Government taking the lead in adopting sustainable construction

To show strong government support in driving sustainable construction, BCA, together with regulatory and government procurement agencies, as well as main industry associations, formed the Sustainable Construction Steering Group (SCSG). This high-level inter-agency committee oversees and strategises the implementation of Sustainable Construction

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ISSN 1937-3260 print/ISSN 1937-3279 online

DOI: 10.1080/19373260.2010.491641
http://www.informaworld.com

Table 1. Five strategic thrusts of sustainable construction masterplan.

	Efficient design to optimise use of natural materials	Recycling and use of sustainable materials
Strategic Thrust 1	Government taking the lead in adopting sustainable construction	
Strategic Thrust 2	Promoting sustainable construction in private sector	
Strategic Thrust 3	Building industry capabilities	
Strategic Thrust 4	Strategic profiling and raising awareness to generate sustained demand	
Strategic Thrust 5	Setting minimum standards through legislative requirements	

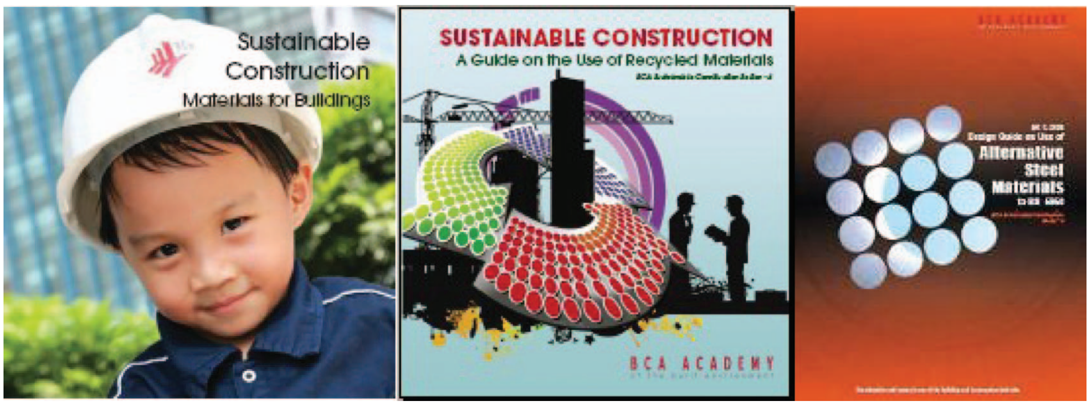

Figure 1. Some of BCA's publications on sustainable construction.

Masterplan and ensure collaboration across whole spectrum of the construction industry.

Government also takes the lead in adopting sustainable construction in public sector projects. For example, the major public housing developer, the Housing & Development Board (HDB), uses structural steel extensively in its lift upgrading projects (Housing & Development Board 2010) all over the island. HDB also specifies the use of recycled aggregates in non-structural elements in their projects and conducts sequential demolition for demolition of old housing blocks. The Land Transport Authority (LTA) has also piloted a trial test on the use of Incineration Bottom Ash (IBA) as alternative materials in road construction.

Green procurement practices will also be adopted for public sector developments, with new government buildings designed to achieve the highest tiers of green building rating (Green Mark Platinum and Green Mark Gold Plus) and adopt sustainable construction practices such as the use of recycled materials in construction.

2.2. *Strategic thrust 2: Promoting sustainable construction in the private sector*

Driving sustainable construction in the private sector requires more effort and persuasion to developers, engineers and contractors. Nevertheless, there are promising signs that the private sector starts to embrace sustainable construction as part of their corporate social commitment to the environment. Projects such as the Goodwood Residence and the Tampines Concourse are examples of private sector initiatives to use sustainable materials in construction.

For the Goodwood Residence, the developer embarked on a 'Zero Waste' Concept to achieve 100% waste recycling. Demolition of the existing buildings was done systematically so that recycled aggregates from the demolition waste could be reclaimed for the manufacture of precast internal partition walls.

Another commercial building, Tampines Concourse, held the distinction as being the first carbon-neutral building in Asia-Pacific. Recycled materials such as copper slag, ground granulated blast furnace slag (GGBS) and recycled concrete aggregates (RCA) were extensively used in both its structural and non-structural components. As a result, more than 1000 tonnes of natural sand and granite have been saved and 6750 tonnes of carbon dioxide have been offset during the construction.

2.3. *Strategic thrust 3: Building industry capabilities*

The Masterplan recognises the need to build up industry competencies and capabilities in sustainable construction so that the industry can integrate sustainable construction into their design and construction processes. In 2007, a S$50 million 'Research Fund for the Built Environment' (BCA 2010) was

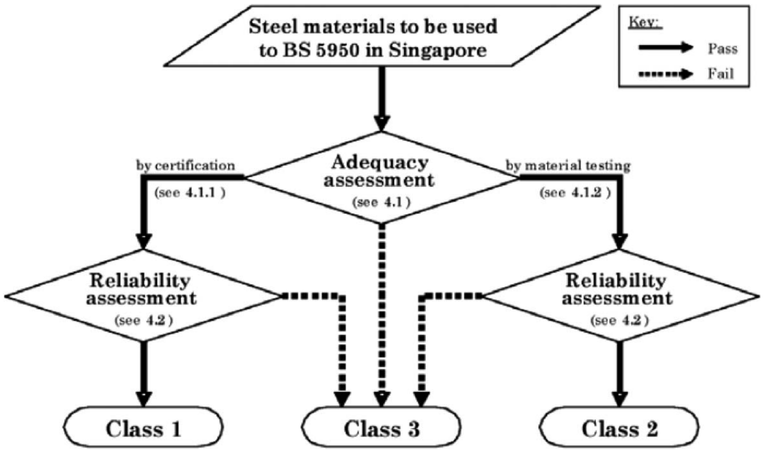

Figure 2. Overall framework for classification of alternative steel materials in BC1:2008.

launched to kick-start R&D efforts in green buildings development and sustainable construction. Relevant areas of research include the use of RCA in structural concrete and the conversion of dredged materials and selected industrial waste into manufactured aggregates.

In addition, to show government support in promoting sustainable construction, a S$15 million Sustainable Construction Capability Development Fund (BCA 2010) was recently announced to further build up the capabilities of the industry in adopting sustainable construction practices and technologies. The funding scheme would be described in greater details in section 3.5.

For industry professionals, BCA has organised a series of seminars, publications (BCA's publications on sustainable construction (Figure 1)) and training courses to share the vision of sustainable construction. In order to keep abreast of the latest developments in sustainable construction, BCA also led industry delegations to countries such as Japan, the Netherlands and UK.

It is also important to establish benchmarks to measure the extent to which sustainable construction is being adopted on a project basis and for the industry as a whole. On a project basis, concrete usage index (CUI, Table 2), calculated based on the ratio between volume of concrete used against the total floor areas of the building, is used to assess the concrete usage efficiency for different projects. For the industry as a whole, essential data such as quantity of construction waste generated annually and consumption of recycled materials are crucial to the strategic planning of sustainable construction in Singapore. The cost-benefit analysis of waste recovery and sequential demolition also need to be studied. In general, various concepts in sustainable construction, such as carbon footprint, would be researched further to determine its relevance in local context.

Figure 3. Samwoh green building.

Table 2. Concrete usage index (CUI) limit for residential buildings.

Category	CUI limit
Residential building (up to 15 storey)	0.55
Residential building ($>$ 15 storey)	0.60

CUI = (concrete volume in m^3)/(constructed floor area in m^2).

2.4. *Strategic thrust 4: Strategic profiling and raising awareness to generate sustained demand*

As part of BCA's efforts to engage the industry continually on the benefits of sustainable construction, conferences and exhibitions have been organised to provide a platform for knowledge sharing. The inaugural Conference on *Recycling for Sustainable Construction* was held in November 2007. BCA also recognises the importance of end-user education in driving the demand for a built environment achieved through sustainable construction. The BCA Gallery, launched in April 2008, serves as BCA's platform for public outreach, especially to the younger generations.

Leveraging on the publicity of high-profile events in Singapore such as the ISWA/WMARS World Congress jointly organised by the International Solid Waste Association and Waste Management & Recycling Association of Singapore in November 2008 and the inaugural International Green Building Conference in October 2009, BCA has been actively involved in these events to raise the profile of sustainable construction movement in Singapore. BCA also hosted an International Panel of Experts (IPE) on Sustainable Construction in April 2009 to review and enhance Sustainable Construction promotional efforts. The IPE comprised of four renowned experts from UK, USA and Austria, with the participation of two local experts from the academia. In addition, the 3-day IPE sessions were open to about 200 participants from the industry, academia and public sector agencies to engage the IPE in rigorous discussions on advancing sustainable construction in Singapore.

2.5. *Strategic thrust 5: Setting minimum standards through legislative requirements*

Legislative requirement remains one of the most effective ways to drive sustainable construction. However, a phased approach is needed to ensure that the industry is ready before imposition of any legislative requirement. To enable the use of manufactured and RCA in local construction work, the existing Singapore Standard on aggregates would be replaced by a new standard, the SS EN 12620 (2008). In addition, BCA has required all demolition contractors to declare the quantity of demolition waste that would be generated, as part of the conditions of the permit to commence demolition work. This is to facilitate the strategic planning based on the supply and demand of recycled aggregates.

Moving forward, BCA aims to introduce procedures such as the demolition protocol through CP11 (Code of Practice for Demolition) to pave the way for mandatory recycling of demolition waste, should there be a need. BCA may also explore the merits of mandating developers to recycle part of the demolition wastes generated and use them in construction of new buildings on the same site.

On steering the industry towards embracing more eco-friendly materials, BCA has amended the Approved Document in the building regulations to incorporate the latest revisions to cement, aggregate and concrete production codes to allow the use of low-carbon cement and RCA. BCA will continue to promote the use of low-carbon cement and RCA before deciding to make it mandatory when the industry is ready.

Another legislation lever available would be through amending the assessment criteria of Code for Environmental Sustainability (BCA 2008) (Table 3). The Code has been successfully implemented for green building design, and it contains elective items on sustainable construction practices such as the use of recycled materials and limits on CUI. BCA will also consider requiring all new buildings to meet a minimum requirement on sustainable construction practices under the Code if there is a need to speed up the adoption.

3. Latest initiatives of sustainable construction in Singapore

The following sections will highlight some of the recent initiatives that would take sustainable construction in Singapore to a greater height.

3.1. *Demolition protocol*

Demolition protocol is a set of procedures on how demolition wastes should be managed to maximise resource recovery of demolition materials for beneficial

Table 3. Elective criteria on sustainable construction under the code for environmental sustainability.

Items	Scoring criterion	Points
(a) More efficient concrete usage for building components.	0.1 point for every percentage reduction in the prescribed concrete usage index (CUI) limit for residential buildings	Up to 4 points
(b) Conservation of existing building structure.	Extent of coverage : conserve at least 50% of the existing structural elements or building envelope (by area)	2 points
(c) Use of sustainable materials and products in building construction such as:		
(i) Environmental friendly products that are certified under the Singapore Green Labelling Scheme (SGLS).	1 point for high-impact item 0.5 point for low-impact item	Up to 3 points
(ii) Products with at least 30% recycled content by weight or volume	1 point for high-impact item 0.5 point for low-impact item	Up to 3 points

reuse and recycling. It aims to produce cleaner demolition waste to a quality acceptable for waste recyclers to produce high-quality RCA. The protocol consists of the following:

3.1.1. Pre-demolition audit

Pre-demolition audit is important as it enables the quantity of recyclable materials such as concrete and bricks to be identified. The level of material segregation required is also determined through the audit to maximise the resource recovery.

By distinguishing parts of a building that are constructed entirely in concrete, cleaner demolition concrete waste can be easily segregated.

3.1.2. Sequential demolition

The demolition process is separated into phases in which individual materials are carefully dismantled one step at a time and salvaged for reuse and recycling. The wastes generated in each dismantling stage should be of similar type and nature such that contamination by non-recyclable items can be significantly reduced. The sequence of demolition is principally carried out in reverse order to the construction process.

3.1.3. On-site sorting

For demolition wastes to have meaningful applications, it is vital that the wastes are properly managed and stored separately on site to avoid cross-contamination of wastes. Once the demolition wastes have been properly separated, they can be channelled to appropriate recycling facilities for further processing into useable products.

3.2. Accreditation scheme for C&D waste recyclers

One of the impediments for the industry to adopt sustainable construction is the quality assurance of recycled materials, especially their use for structural applications. In order to address the concern on the quality and consistency of recycled materials, BCA and the Waste Management and Recycling Association of Singapore (WMRAS 2010) have launched an accreditation scheme for construction & demolition (C&D) waste recyclers. It aims to improve the quality consistency of RCA production. In time, quality consistency of other recycled materials will also be included in the accreditation scheme. Only recycling plants producing RCA complying with SS EN 12620 and BS 8500-2 will be certified to supply aggregates suitable for structural applications.

A more comprehensive classification system is currently being studied, where the usage may differ depending on the percentage mix of impurities of masonry content.

3.3. Design guide on use of alternative steel materials to BS5950 (BC1: 2008)

As part of the initiative to facilitate steel construction in Singapore, BCA launched the Design Guide on Use of Alternative Steel materials to BS5950 (also known as BC1:2008) (BCA 2008). The prevalent steel design and construction code of practice in Singapore is the British Standard BS 5950, and its application is strictly limited to structural sections manufactured to the relevant British standards, such as BS EN 10025. However, as demand for steel construction increases in Singapore, there is a need to widen the source of steel and consider using steel manufactured to standards from other countries, such as America, China, Japan or Australia. The BC1 design guide is a unique approach (Figure 2) to address this issue.

BC1 design guide serves as Singapore's national code of practice for the use of alternative steel materials in design to BS5950, including those manufactured to British Standards. It provides lists of certified steel materials according to five major steel manufacturing standards in the world: British/European, American, Chinese, Japanese and Australian/New Zealand. The certified list in the design guide gives engineers the assurance that these materials have passed a set of performance requirements, such as strength, ductility and impact toughness. The design guide also provides design recommendations to engineers on the design strength to be adopted when using alternative steel materials.

While the design guide widens the source of steel substantially, it also ensures that only adequate (in terms of material performance) and reliable (in terms of quality assurance) steel, regardless of the standards to which they are manufactured, is used in the design and construction of structural steelworks.

3.4. New regulatory framework for reusable structural steel

Steel strutting system is being used extensively in underground building work as part of the earth retaining structure. While steel sections are inherently reusable, the quality of reused steel sections remains a concern, especially when steel strutting forms a very critical part of earth retaining structures. BCA, together with the industry, recently established a quality assurance system based on the BC1 system described in the section above. The quality of reused struts will be assessed by third party independent audits conducted by Inspection Bodies and the assessment will cover two aspects: material traceability and material reusability.

In general, only steel materials found in the certified list in BC1 should be permitted for use and only one single steel grade should be used. Proper corrosion coating including proper blasting and priming should be applied to the steel sections. The reused sections should undergo mechanical test and chemical composition test for every 200 tonnes. All sections should also be given a unique identification number to ensure traceability. If the sections intended for reuse fail to meet the quality control requirements on thickness or other sectional dimensions, the design capacity should be downgraded to that of the next lighter section size.

3.5. *Sustainable construction capability development fund*

In March 2010, a new $15 million Sustainable Construction Capability Development Fund (SC Fund) was launched to build up the capabilities of industry players in adopting Sustainable Construction practices and technologies, and eventually steer the industry towards self sustenance in the demand and supply of sustainable materials in Singapore.

Designed to boost the construction industry's demand and supply for sustainable materials, the SC Fund is intended to build up capabilities of industry stakeholders such as demolition contractors, recyclers and ready mixed concrete suppliers. The incentive scheme operates on a co-funding basis, with up to 50% support for qualifying costs on a reimbursement basis.

The SC Fund can be used for enterprise-level projects and industry-level projects, where a group of unrelated companies can apply the fund to improve on their collective capabilities in sustainable construction. Some examples of areas supported by the SC Fund would include technology upgrading (e.g. through the purchase of equipment), process improvement resulting in accreditation or certification, as well as pilot projects on new methods or materials to build up the industry's knowledge and competency in sustainable construction. As the first dedicated Capability Development Fund for Sustainable Construction, it would be another major incentive for those in the industry who are committed to sustainable construction practices.

4. Case study – Samwoh eco-green building

To promote a wider use of RCA in structural elements, the industry needs to be convinced on the long-term performance of RCA concrete in structural elements. Currently, the use of RCA in concrete at low percentages (10–20%) is already allowed in Singapore. In order to explore the performance of concrete using a higher percentage of RCA, a full-scale study was conducted on Samwoh's Eco-Green Building (Figure 3), a new 3-storey office building by Samwoh Corporation, a leading concrete aggregate recycler in Singapore.

The Samwoh Eco-Green Building project is one of the sustainable construction-related projects funded by the MND Research Fund for the Built Environment. The objective of the project is to conduct a full-scale study to evaluate the use of different percentages of RCA in structural concrete for buildings. The study was carried out in two stages:

(a) Stage 1 – Laboratory evaluation of the performance of concrete using RCA; and
(b) Stage 2 – Structural health monitoring of a 3-storey building constructed using concrete with RCA.

The findings of the study were reported in the paper titled *Efficient utilisation of recycled concrete aggregate for structural concrete applications* by Ho *et al*. (2009) and are summarised below.

Previous studies on concrete with RCA replacement have reported that compressive strength, splitting tensile strength, flexural strength and modulus of elasticity decrease with increasing percentage of RCA replacement (Ho *et al*. 2009). In Stage 1 of the study, the optimal design of concrete mix with various percentages (from 0 to 100%) of RCA would be determined and used in the construction of the Eco-Green Building. Extensive instrumentation will also be installed in critical structure elements of the building to monitor the structural behaviour and performance of concrete. The data will be collected for structural analysis and validation of concrete performance.

On the basis of cube test results, five different design mixes (M1 to M5) with different RCA replacement levels were tested (Table 4). For low and medium strength concrete, the compressive strength was reported to remain consistent, even on a slightly increasing trend with increasing percentage of RCA

Table 4. Range of w/c ratio for M1 to M5.

Mix identification	M1	M2	M3	M4	M5
W/C ratio	0.67	0.53	0.45	0.40	0.35
Cement content (kg/m^3)	270	330	390	450	510
Water content (kg/m^3)	180	175	175	180	180

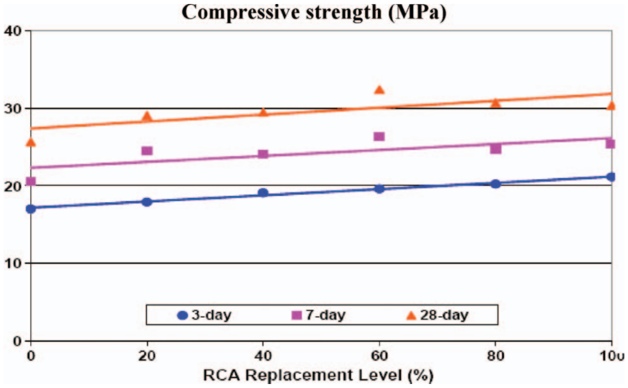

Figure 4. Compressive strength results for M1 (high w/c ratio).

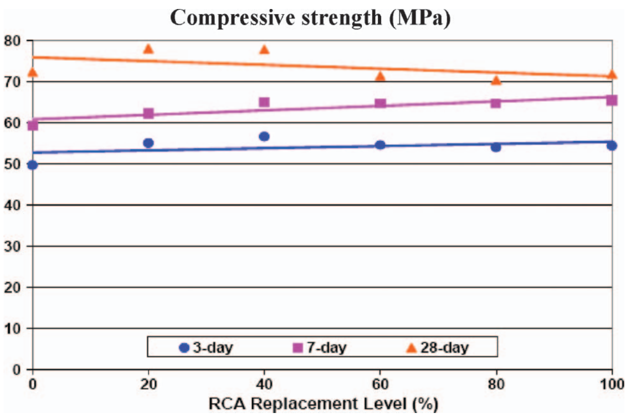

Figure 5. Compressive strength results for M5 (low w/c ratio).

replacement. The investigators suggested that the free water content added for the hydration of cement was absorbed by RCA, thus achieving a lower effective water/cement ratio. In such cases, higher dosage of admixture would need to be added to avoid loss of workability. For high-strength concrete (Figure 5), the compressive strength suffered a slight drop as RCA replacement ratio increased, but the drop was not significant according to the investigators. The investigators attributed this to the development of the interfacial zone (ITZ) between the mortar and coarse aggregate and the weaker bonding strength between the new cement paste and RCA (Ho *et al.* 2009).

The Samwoh Eco-Green Building remains the first in South East Asia to be constructed using concrete with RCA beyond code limits for structural concrete. The results from the project can be used to expand building codes to permit the use of RCA in structural building construction as well as to build confidence on the use of such material. The success of the Samwoh Eco-Green Building project is a testament to the critical role of research and development in advancing sustainable construction, and serves as an important showpiece of applied R&D in concrete technology.

5. Concluding remarks

Since the sustainable construction drive began in 2007, with the support and effort from the industry, public sector and research organisations, modest yet encouraging progress has been observed in terms of rising awareness and increasing use of recycled materials. More private and public sector projects are in the pipeline to adopt sustainable construction materials and practices. With well-defined strategies and strong support from the industry and the government, BCA is confident that the drive towards sustainable construction will gather pace in the years to come.

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