UNDERSTANDING THE REGIONAL CONTEXT OF SUSTAINABLE CONCRETE IN ASIA: CASE STUDIES IN MONGOLIA AND SINGAPORE

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ABSTRACT

In order to improve the sustainability of the Asian concrete industry, it is important to understand the effect of regional context considering the widely varying socio-economic conditions present in Asia. This research in Mongolia and Singapore was conducted as a continuation of previous studies in Japan, Thailand and South Korea in order to further contribute to understanding regional context, particularly geographic, climate, and economic factors. Geography and climate were found to strongly affect the means by which durability should be assured in each country, as Singapore has a tropical climate whereas Mongolia experiences a large temperature variation with extremely cold winters. The ability to access construction materials and resources was also related to geography, as Singapore, while resource poor, is an international shipping center, whereas Mongolia has abundant resources but few access routes for imports. Quality control issues in Mongolia could be understood in the context of the lower level of economic development, whereas in Singapore the high level of development has lead to an emphasis on green construction, with the government taking the lead in implementing new systems and technologies.

Keywords: Sustainable development, concrete, construction, Mongolia, Singapore

1. INTRODUCTION

1.1. Sustainability and concrete

Concrete is the most widely used construction material on the planet and serves as the primary material in constructing the infrastructure necessary to provide society with basic safety and living requirements. The usage of concrete has been increasing as developing countries have begun investing in infrastructure systems such as highways, bridges, tunnels, and so on, with the result that concrete has become the second most-used resource in the world after water (Sakai, 2009). As human populations continue to grow and urbanize, so too will the demand for infrastructure increase, resulting in increased utilization of concrete to meet that demand. Growth and urbanization has, however, also been a primary driver of environmental deterioration, from destruction of ecosystems to increased emissions of greenhouse gases and other air-born pollutants. Observed changes in the global climate have increased awareness of the impacts of human activities on environmental systems and led to the formation of international committees on how to reduce environmental deterioration and mitigate future climate changes (IPCC, 2007).

Increased awareness of the environment has also led the concrete industry to consider its environmental impact and explore strategies for mitigation actions targeted at construction activities (Horvath and Matthews, 2004). Concrete's negative impacts come in several forms, from large-scale emissions of greenhouse gases and particulate matter to massive consumption of natural resources such as water, sand and aggregates. The production of cement – the main binder in concrete – alone is estimated to be responsible for up to 10% of global CO_2 emissions (Malhotra, 1999; Sakai, 2009), with over 50% of world cement production emissions coming from Asia alone (Humphreys and Mahasenan, 2002). Cement production also consumes large quantities of natural resources such as clay and limestone, and concrete production was estimated to consume more than 11 billion tons of sand, gravel and crushed rock per year in addition to over one trillion liters of water (Mehta, 2001). By some estimates, the cement and concrete industries are the largest consumers of these resources in the world, and while construction investment may be stabilizing or even shrinking in some developed countries, demand for and production of concrete-making materials is projected to continue to grow in many developing countries – particularly China and India (Sakai and Noguchi, 2013).

Proposed strategies for improving the sustainability of concrete include reducing resource consumption by utilizing waste and recycled materials; reducing CO_2 emissions by consuming less concrete in new structures, less cement in concrete mixtures, and less clinker when making cement; enhancing the durability of new construction; extending service life through maintenance management; selecting low-impact construction methods; and taking a holistic approach in concrete technology and education (Malhotra, 1999; Mehta, 1999; Mehta, 2001; Sakai, 2009; Mehta, 2009). These strategies, however, only suggest generalized guidelines and concepts. In order to practically implement sustainability in the concrete industry, there have been a variety of actions taken at the national or multi-national levels. One prominent example is the Concrete Joint Sustainability Initiative (JSI) in North America, an industry-wide Memorandum of Understanding which provides a framework and principles for supporting and coordinating the actions of industry stakeholders towards improving sustainability in the concrete industry (ACI, 2010). Other examples include the Concrete Industry Sustainable Construction Strategy in the United Kingdom or the Nordic Network "Concrete for the Environment." In the case of the Nordic Network, Glavind et al. (2006) noted that Nordic countries had chosen to face environmental challenges in different ways: Denmark established a center for green concrete whereas Norway developed an online, comprehensive database of important documents. The Asian Concrete Federation (ACF) has also established a sustainability forum with representatives from a wide variety of countries, including Japan, S. Korea, Thailand, Taiwan, Vietnam, Indonesia, India, and Mongolia, to tackle sustainability-related issues in Asia and to pursue the goals laid out in the 2010 ACF Taipei Declaration on Sustainability. This declaration includes six items: recognizing the importance of the Asian concrete society's role in achieving sustainable development; realizing the need for sustainable development by reducing resource consumption and carbon footprint; encouraging the concrete industry to provide safe, serviceable, and environmentally-friendly structures for the good of society; promoting the use of the best technologies and technological innovations for sustainability; informing the concrete industry and the public of the role concrete plays in sustainable development; and collaborating with other international associations towards the goal of sustainable development (ACF, 2013).

1.2. Considering the regional context

The differing approaches to concrete sustainability may arise from a more fundamental aspect of sustainability itself – that it is a human vision with human values, and thus the perception of or values applied to sustainability may vary, particularly by region or by culture (Bell and Morse, 2008). By extension, as sustainability has been famously described as being built upon the "interdependent and mutually reinforcing" social, economic and environmental pillars (United Nations, 2005), then strategies or activities which may be sustainable in one region of the world under a given set of social, economic, and environmental conditions may not be sustainable in a different region of the world under different conditions.

Concrete construction and materials are also often region-specific, as the activities and challenges faced by concrete industries depend on a variety of factors such as climate, geography, availability of resources, level of development and technology, transportation and shipping systems, construction culture and stakeholders, governing systems such as codes, guidelines, and specifications, and so forth. The implementation of sustainability in the concrete industry must therefore also take into account the actual regional and socio-economic conditions in which concrete construction will occur. Some research has applied life cycle assessment (LCA) to examine the effect of different regions and climates in the United States on energy savings of concrete buildings (Ochsendorf, 2010; NRMCA 2011). However, these studies were limited to a single developed country and focused primarily on the environmental benefits of concrete usage. In order to further understand region-specific issues and their relationship with concrete sustainability across a broader selection of countries and conditions, investigations were conducted in Japan, Thailand and (South) Korea through interviews with a wide variety of concrete industry stakeholders (Henry and Kato, 2012a; Henry and Kato, 2012b).

In Japan, the importance of durability for sustainable concrete was repeatedly emphasized in the investigation, which can be understood in the context of a decreasing and aging workforce with decreasing natural and economic resources. In addition, as the efficiency level of the Japanese cement industry is already high, enhancing durability is one strategy to reduce transportation- and construction-related CO_2 emissions. The importance of recycling in Japan could also be understood not as a means to further reduce waste generation, as Japan already enjoys a 96% recycling rate for concrete, but rather as a means for reducing the consumption of natural resources by utilizing recycled concrete as raw material in new construction instead of down-cycling it as backfill. Barriers to the implementation of sustainable concrete practice and materials may be the most specific to Japan's conditions. As noted by Chong et al. (2009), this may be due to that fact that sustainability in Japan is more driven by government forces whereas in the USA the private sector is expected to take the lead.

Thailand represents a unique case for sustainable concrete due to widespread adoption of fly ash concrete, which contributes to reducing the environmental impact of concrete materials. Investigation results found that, due to the low cost of labor, price serves as the most important criteria for concrete, which makes it difficult to test or adopt new technologies due to high cost competition. Most technology is diffused through the cement companies, which have the highest investment in R&D, although foreign consultants also provide such support. Finally, the lack of sustainability education makes it difficult to convince customers of additional value such as environmental impact reduction – thus education should form the base of promoting sustainable practice. Since environmental technologies cannot compete on cost, criteria for additional value are also necessary to concretely evaluate these characteristics.

In Korea, the government and major contractors are the major stakeholders, and sustainable materials and practices may be driven primarily at the construction level. The importance of utilizing contractors' construction knowledge towards reducing environmental impact was also identified in a previous study by Son et al. (2009). The Korean industry has to contend with domestic issues such as a shrinking domestic market, which may drive domestic contractors overseas where they can obtain greater experience with sustainable construction, and reduction in natural resources, which can be seen driving changes in the country's mindset regarding waste management and recycling. Usage of recycled aggregates in concrete structures will, however, need to overcome barriers such as negative public perception. While the government has taken measures towards CO_2 reduction, and there is action within the concrete industry towards a labeling system for ready-mix concrete and cement, increased cooperation among stakeholders will be necessary to move sustainable technologies from the laboratory to practice.

1.3. Research objectives

These previous investigations highlighted some general key issues related to the regional context of sustainable concrete such as the role of major stakeholders in developing and implementing new technologies as well as the creation and enforcement of standards and regulations, the importance of recycling considering resource depletion, the effect of negative social perception on the usage of recycled materials, the importance of durability considering changes in society, and the need for sustainability education and consideration of additional value criteria. However, the effect of climate-, geographic-, and economic-related factors was not clearly observed, particularly as they relate to durability performance – an integral part of improving concrete sustainability. In order to build a more diverse knowledge base for developing a roadmap to concrete sustainability in Asia, it is necessary to understand the relationship between these factors and sustainable concrete as well as further explore other perspectives related to those factors already uncovered in the previous investigations. Therefore, as a continuation of the studies in Japan, Thailand, and Korea, two additional investigations on the regional context of sustainable concrete were conducted in Mongolia and Singapore with the objective of understanding the regional differences in industry conditions and general sustainability issues, concept of sustainable concrete practice and materials, and barriers to implementing those practices and materials.

2. COUNTRY OVERVIEWS

Mongolia and Singapore were selected based on several factors. First, the authors have good professional and social connections in these countries, thus simplifying the process of finding key persons for carrying out the investigation. Second, these two countries have strongly contrasting conditions – particularly climate, geographic, and economic – which may help to reveal different aspects of the regional context of sustainable concrete than have been found in the previous studies. Some select characteristics of Mongolia and Singapore are summarized in Table 1.

Mongolia is a land-locked country located in northern Asia between Russia (to the north) and China (to the west, south, and east). Its landscape is characterized mainly by steppes and plains, with mountains and desert regions in the west and south, and although summers are generally hot, winter temperatures may reach as low as -40°C. Although it is the 19th largest country in the world by area, Mongolia is very sparsely populated, with a total population of only 3.13 million, of which roughly 1 million people reside in the capital city of Ulaanbaatar. Economically, Mongolia has both a low gross domestic product (GDP) and GDP per capita, but its level of development is expected to rise dramatically in the future, primarily due to investment in the mining of untapped natural resources.

In contrast, Singapore is an island city-state located in southeast Asia between Malaysia and Indonesia. It is the 192nd largest country in the world by area and 114th by population. However, Singapore's gross domestic product (GDP) is 40th and GDP per capita is 5th in the world. Its developed free-market economy depends heavily on exported products, and Singapore also serves as a major shipping and financial center. The climate is tropical and humid year-round, and temperatures range between 23°C and 32°C.

3. RESEARCH METHODOLOGY

Conditions in the Mongolian and Singaporean concrete industries were qualitatively investigated using in-depth, semi-structured interviews with various stakeholders in each country's concrete industry. These semi-structured interviews followed a general outline but allowed for areas of interest to be explored in further detail (Punch, 2005). The interview contents were broken into three sections, as summarized in Table 2, and followed the investigation objectives in order to clarify current industry conditions, sustainable concrete practice and materials, and barriers to implementing those practices and materials.

Thirteen interviews were conducted in total. In Mongolia, six interviews were carried out, with two interviewees representing the academic field, one from a ready-mixed concrete plant, one from a pre-cast concrete factory, one from a government agency related to construction, and one serving as a project manager of a large construction project. In Singapore seven people were interviewed, with two coming from a government oversight agency, one from the ready-mix concrete association, one from a cementitious materials supplier, two from a general contractor, and one from the academic field. While the number of interviewees was limited, they were selected with a focus on experts involved in the development, usage, and management of concrete so that general issues and their regional context could be identified.

4. INTERVIEW RESULTS: MONGOLIA

4.1. Concrete industry conditions

Concrete does not have a long history in Mongolia. Until the late 1940s, lime was the primary binder utilized for masonry and plaster mortars. However, from the late 1940s, Portland cement began to be imported from the Soviet Union. Industrialization of Mongolia occurred between 1965 and 1970, during which the first Portland cement factory was constructed in 1967 with the support of Czechoslovakia. This was followed by the construction of two more cement plants in 1984 and 1999 using Russian technology.

From 1990, Mongolia shifted to a market economy, leading to the privatization of many state factories and companies. During the decade following the shift to the market economy and into the 2000s, there was a sharp downfall in the construction sector, but the industry began to grow strongly again from 2005.

The concrete industry in Mongolia is composed of materials manufacturers, general contractors, private developers, and the government. As of 2010 there were 8 cement factories, 46 sand and aggregate producers, 69 ready-mix batch plants, and 96 factories manufacturing precast reinforced concrete products, and the majority of these are domestically owned and operated. There are also many general contractors operating in Mongolia. The larger contractors have some vertical integration, including basic research, and are also involved in materials manufacturing, such as the production of precast concrete elements. While most of the contracting companies are domestic, there is growing participation from overseas companies, particularly from China and South Korea. In addition to the large materials and construction companies, the Mongolian government also serves as one of the major stakeholders, generally in an advisory and supervisory role, such as when to halt construction during the cold winter season.

The cement used in Mongolia is either produced domestically or imported from China by train. It comes in a variety of quality levels, indicated by the cement "mark," and higher quality concretes generally require the usage of higher quality cements. River sand is the typical fine aggregate, and crushed granite is used for coarse aggregate. In the past, mountain stones were used for coarse aggregate, but this limited the concrete strength due to the smooth aggregate surface. Once the usage of angular, crushed aggregate became more common, however, this allowed for higher strength concretes to be achieved (in conjunction with higher quality cements), and the current maximum strength is around 45 MPa. Chemical admixtures are imported from China.

Most concrete is used for architectural structures such as buildings. There are not many applications of concrete for civil construction, as there is less demand for civil infrastructure relative to the demand for buildings. Architectural structures are generally concrete frames with masonry walls, and precast elements are often used to speed up the construction process or to continue construction into the colder winter months.

Concrete materials are primarily specified and evaluated by their compressive strength. Fresh properties such as slump and air content are also specified and evaluated but, although they are assured at the ready-mix concrete plant, they may not necessarily be measured upon delivery at the construction site. One unique aspect of concrete materials in Mongolia is the widespread usage of anti-freezing admixtures. As the outdoor temperature is below 0°C for several months of the year – usually beginning around late autumn – anti-freezing admixtures are essential for continuing construction operations into the winter months. Management of concrete curing is thus an important issue for concrete construction in Mongolia due to the large temperature differences which occur between the concrete inner core (70°C) and the outside air (-15°C to -25°C). During the coldest months, this difference may reach 100°C and result in severe cracking of the new concrete unless proper measures are taken. This usually entails covering the fresh concrete with plastic and felt and curing it with heaters inside a tent in order to reduce the temperature differential. When concrete is cast and cured in cold weather, accompanying test specimens are generally cured under the same conditions in order to ensure the development of the required performance.

4.2. Sustainable concrete practice & materials

Although awareness of sustainability in the Mongolian concrete industry is currently low, there are many possibilities for moving towards more sustainable materials, construction, and structures. Perhaps one of the most promising indicators is that the pace of change is very high, in part due to the mining boom, which is helping to raise interest in the construction field and promote the development of new and better construction technologies and practices. This trend is helped by Mongolian engineers who have studied or worked outside Mongolia and are now trying to help improve the domestic industry based upon their experiences in other countries.

Mongolia is fortunate in that it has an abundant supply of natural resources for making concrete (excluding water), and – although demand is high – there is little concern that these resources will be exhausted in the foreseeable future. However, due to the stoppage of concrete construction work during the winter, the summer months are characterized by a construction frenzy. As a result, there ends up being a shortage of many concrete-making materials, particularly cement. This highlights Mongolia's vulnerability to its limited number of supply routes and the difficulties of supply logistics. As there are no seaports, imports such as cement must be shipped via train from China, creating a bottleneck in the concrete construction supply chain during the high-activity summer months. While this places strain on domestic resources, it may also provide an opportunity for the utilization of waste or recycled materials to supplement raw materials.

Mongolia relies heavily on coal-fired power plants for electricity generation. These plants generate large amounts of fly ash by-product which could potentially be utilized as a supplementary cementitious material in concrete. However, the quality of fly ash produced from these power plants is poor and the fly ash is ultimately dumped. In addition, while other countries (most notably Thailand) are experienced with the use of fly ash in concrete, the Mongolian industry is unfamiliar with it and stakeholders are not aware of the benefits of fly ash concrete or how to design for it or build with it. Therefore, although there is a steady supply of fly ash available, it will require significant research investment and effort in order to produce a usable material and to educate the industry.

There are other recycled materials, such as recycled glass, which could also contribute to reducing resource consumption in Mongolia. As the labor cost in Mongolia is low, glass can be produced cheaply;

however, it may still have a higher cost relative to raw materials, and thus may require some incentive from the government in order to promote its usage.

One difficulty facing the development of the Mongolian concrete industry is the variation in quality of concrete materials and structures. Quality control is generally not specified in design and construction documents, which instead focus mostly on strength, and thus the batching, mixing control, casting, curing, and so forth rely on the competence of the ready-mix concrete supplier or the contractor, which results in inconsistent quality across the industry. Quality is also affected by the summer-time supply issues, as ready-mix concrete suppliers, in the case of a shortage, may mix-and-match whatever materials they have on hand, rather than strictly follow the design documents. On the project site, the know-how of contractors is important for assuring the structural quality, as they have to verify that the actual site conditions are following the design documents or contracts. Even on very large projects, however, quality control can be loose and low-quality surface conditions observed, which then require extensive patching operations. There are some efforts underway to ensure the quality of concrete materials and structures. However, quality control comes second to cost, and the implementation of conformation codes or other regulatory oversight by the government or public agencies may be necessary to encourage the industry to implement quality control practices.

Due to Mongolia's location and history, a wide variety of codes and specifications are in use, such as modified Russian codes or Chinese codes. The industry is currently, however, migrating to European design codes, and there are calls to implement ISO standards or a Mongolian National Standard for conformation codes to ensure material and structural quality. None of these codes, specifications, or standards addresses environmental impact.

Raising the level of technology in the Mongolian concrete industry could help move towards more sustainable materials and practices, but it will require more research, testing, and coordination of industry efforts. Furthermore, advanced technologies currently in use are usually imported, either from China or South Korea, and there is a lack of skilled workers who can maintain those advanced technologies. However, as the economy develops, the local research base and know-how will also grow and contribute to better implementation of new technologies.

One large environmental issue, especially in Ulaanbaatar, is air quality. A large population of Mongolians live in yurts and rely upon the burning of coal to generate heat, which creates low-hanging smog during the winter months. The government is thus working to construct buildings for these people to live in and reduce the amount of coal burning. In addition to yurts, there are also a large number of factories and manufacturers located within Ulaanbaatar who are also contributing to the air and noise pollution. Relocation of these facilities to outside the city would help improve the air quality and reduce dust and noise.

Another means for making concrete construction more sustainable in Mongolia would be to increase the strength of the reinforcing steel. Currently, the highest grade available is G390, but if higher grade steel was utilized it would allow for a reduction of the overall amount of reinforcing steel, which would also reduce the associated labor costs.

Finally, on-site generation of construction waste such as waste timber is another sustainability issue. Timber framework is widely used for concrete construction, particularly by Chinese contractors, but after the project completion this material is usually disposed of. The usage of steel framework, such as that used by South Korean contractors, reduces the amount of waste generation and can be reused, but also costs more than timber framework and would be more difficult for local companies to purchase.

4.3. Barriers to sustainable concrete

The barriers to sustainable concrete practice and materials are given in Table 3. Institutional-related barriers focus primarily on the need for codes and regulations, which are related to Mongolia's past reliance on imported codes and the lack of regulation on environmental and quality control issues. The economic barrier is related to the low cost of raw materials, which makes it difficult to use new material technologies with higher costs. On the technological side, the general low level of technology in the industry is a major factor, but future growth and development should help overcome this barrier. Another technological barrier is the variation in material and structural quality due to varying materials, techniques, skill levels, and so forth, and is related to the need for institutional oversight of quality control. Finally, knowledge barriers include the need to improve general technical know-how for better utilizing and maintaining advanced technologies as well as the general lack of awareness of sustainability and environmental issues in the Mongolian industry. This last knowledge barrier may be related to the general low level of importance given to sustainability and environmental issues in Mongolia, although some issues such as air quality are growing in importance.

5. INTERVIEW RESULTS: SINGAPORE

5.1. Concrete industry conditions

The government – especially agencies related to construction such as the Building and Construction Authority (BCA), Land and Transport Authority (LTA), and Housing Development Board (HDB) – is the lead stakeholder in the Singapore concrete industry. Concrete construction in Singapore is driven primarily by building construction led by both public and private developers, with the former consisting mainly of post-1965 highrise developments, whereas the latter consists largely of pre-1940 low-rise development. Due to the rising economic value of land space, however, buildings are often demolished even though they may only be a few decades old, which thus contributes to the high pace of building construction and concrete usage. Roughly 80% of residential buildings were built by the government (although they may be privately owned). In addition, as a policy-driven country, the Singapore government generally takes the lead and industries are expected to follow. BCA (and other agencies) implement government policies through regulation of the concrete industry by prescribing minimum standards which building professionals must adhere to. BCA also works to connect different stakeholders such as developers, contractors, or ready-mix concrete suppliers (RMC) with researchers at universities or institutes for solving industry issues or developing new technologies.

At the project construction level, contractors directly engage RMC to produce and supply concrete that meets a project's specifications. Due to this direct relationship, RMC can supply concrete very quickly if necessary. The majority of RMC are owned by domestic cement companies, although there are independent RMC as well, some of which are owned by overseas companies. Cement is sold directly to RMC, but independent suppliers must rely on cement from other sources. Aggregate is generally provided by international suppliers.

Investment in research and development is higher among government agencies, the larger concrete suppliers, and at academic and research institutions than among other stakeholders. The government also promotes initiatives or technologies for increasing construction productivity through public funding for approved projects. For private RMC and materials suppliers, new technologies are generally introduced by overseas companies which have sufficient cash flow to invest in research and development; most domestic companies in these areas have neither the time nor the resources to invest in R&D, as they are focused primarily on cost competition. When developing new concrete-related technology, stakeholders must consider both commercial viability and whether it will be accepted by BCA. However, the easiest or most cost-effective means of investing in new technology in Singapore may not be to directly develop it, but rather to purchase and then modify it based on the local needs or conditions.

Concrete specification in Singapore follows the British Standard BS-EN206 (SSEN 206). This specification is performance based, with third-party verification of production and quality control systems. The main conformity criteria for concrete are either compressive (for buildings) or flexural (for pavements) strength, and slump, which are checked on-site. For special applications, other criteria may be used such as heat of hydration or consistence; these must be checked by certification bodies.

Roughly twenty years ago, durability became a political issue due to poor construction practices at public housing projects. Around this time, the government implemented a construction quality excellence program, which led the industry by incentive and promotion, and encouraged innovation by demonstrating possible methods of improving construction quality. Durability remains an important issue due to Singapore's tropical climate.

Singapore almost wholly depends on the import of construction materials, but relies on the free market mechanism to balance out import costs. Hyper cost competitiveness is, however, a result of this openness, and the concrete industry is very price sensitive. Almost all cement is imported as a finished product and its price is low. This, combined with the industry's cost competitiveness, makes it difficult to promote the use of fly ash, ground granulated blast furnace slag (GGBS), silica fume, or other supplementary cementitious materials (SCM). Furthermore, although the benefits of using SCM in concrete are known and there is some push to use low-alkali cement or blended cements to enhance chloride ion penetration resistance, the usage of ordinary portland cement (OPC) is still widespread additionally due to contractors' and precasters' preference for faster-setting OPC, as they can thus remove and reuse formwork faster. In the case of fly ash, Singapore is surrounded by countries with a steady supply, but import is restricted because fly ash is a classified waste. Blended cements could be imported but have not yet been developed. For GGBS, marketing has to be done directly to contractors to get them to specify GGBS to RMC, but GGBS has to compete based on price, which is complicated by the handling and shipping costs from overseas.

Environmental issues facing the concrete industry in Singapore revolve around the limited availability of land. Disposal of waste is difficult, and the property market compounds this problem, as older structures are often torn down and rebuilt for better economic value, thus constantly generating demolition waste. Of this crushed concrete waste, large quantities are sent for disposal, although some is diverted for usage as backfill or temporary roadbed material. In addition, although CO_2 emissions due to concrete construction activity may be high, reduction of or restrictions on CO_2 are not yet a high priority as they may have an adverse effect on foreign investment.

Some measures towards reducing environmental impact and improving sustainability in construction have already begun. In 2005, BCA established the Green Mark scheme to promote environmentally friendly construction and operation of buildings. The scheme has advanced in small steps, rewarding desired practices by allocating points until such practices become standard and widespread, at which time the focus moves to the next desired practice. Through this process, Green Mark has evolved greatly since its inception and now includes categories for residential and non-residential buildings, existing buildings, office interiors, landed housing projects, new and existing parks, infrastructure, districts, and restaurants, and from 2008 BCA made green building qualification mandatory for new sites greater than 2000 square meters in size, regardless of category.

“Green” concrete was not originally included in the Green Mark scheme, but recent versions have moved to include concrete-specific items. Examples include general usage of washed copper slag, a by-product from grit-blasting for washing ships, and recycled concrete aggregates (RCA) in non-structural elements and the replacement of up to 10% of sand by mass with washed copper slag and up to 20% of natural aggregate with RCA in structural elements. Future updates to Green Mark will also begin to consider cement and related materials, such as blended cements, GGBS, fly ash, and so forth. As mentioned earlier, usage of these materials still faces many challenges, but it is hoped that including SCMs in the Green Mark scheme will help encourage their use in the future.

5.2. Sustainable concrete practice & materials

Several different areas for moving towards more sustainable concrete practice and materials in Singapore were identified. From the perspective of concrete engineering, the only evaluation criterion that was identified was life cycle cost (LCC). Currently, the industry is strongly focused on initial cost, but looking at the actual cost performance over the entire life cycle will contribute to the selection of more sustainable concrete structures and encourage practices which reduce long-term as well as short-term costs.

A wider variety of evaluation criteria were identified from the sustainability side. The evaluation of CO_2 and other greenhouse gas emissions is an important means for establishing current levels in the industry and providing a baseline. Management of the carbon footprint will also help contribute to the development of energy management plans to obtain greater energy efficiency, as Singapore relies on imported energy sources. Increased resource efficiency is important due to the reliance on imported aggregates and other materials; this is closely tied to the importance of improving the rate of recycling, as the usage of recycled materials can not only reduce the need for imported materials but also reduce domestic generation of waste, which can thus reduce strain on the limited disposal facilities. Finally, life cycle assessment (LCA) can combine the contributions of these criteria together to give a comprehensive picture of a given project over its entire life cycle, rather than focusing only on the initial costs and impacts.

The government has been active in providing incentives to developers to utilize sustainable and environmentally friendly materials and practices in forms such as the Green Mark scheme. These incentives have trickled down, as developers then give incentives to contractors, who give incentives to RMC, and so forth. However, a move towards regulation, rather than incentive, is necessary, such as specifying a minimum (rather than a maximum) amount of recycled materials in concrete. Such regulation needs to be carried out in a holistic, balanced manner. This means that feedback from the industry and stakeholders should also be considered, such as how they feel about sustainability, what is the financial effect, and how regulation-related issues affect actual construction on-site. The Singapore concrete industry is cost-cautious and sustainability is a secondary consideration; to overcome this, education for changing the perception of sustainability is necessary.

Singapore has many factors working in its favor to improve sustainability in the concrete industry. The government's push is already strong, with a strong supportive policy framework, and will get stronger if international agreements on environmental issues such as greenhouse gas emissions can be reached. Furthermore, the government is looking at the bigger picture – not just concrete – and is focused on results on a larger scale. One example is the Green Mark scheme; the government aims to have 80% of buildings certified under the scheme by 2030.

The government also has a close working relationship with other industry stakeholders. The industry has matured in terms of technical know-how and technology, and there are both skilled industry professionals and experienced academic researchers. These factors are important for reducing reliance on imported natural materials and strengthening the supply resilience of construction materials through the improvement of recycling technologies. Compared to other building materials, the recycling of concrete is relatively easy, as decent-quality RCA can be produced simply through mechanical means, but large-scale usage of RCA will require input and cooperation from all stakeholders.

5.3. Barriers to sustainable concrete

Thirteen barriers to sustainable concrete practice and materials are given in Table 4 by five categories. Institutional barriers include the focus on initial cost and fast construction schedule, as well as the lack of regulation on the recycling of materials. The first two barriers are related to the cost-competitiveness of the concrete industry, as cost is still one of the main issues related to sustainable concrete. Also, although Singapore is generally strict on materials regulations, there is a lack of regulation on the production of RCA; that is, anyone can crush and produce RCA. Economic barriers were also focused on cost-related issues, such as the increased cost of sustainable construction and the lack of tangible benefits for building "green." In addition, the inconsistent supply of recycled or sustainable materials was also identified as a barrier.

Socio-political barriers include the lack of motivation to use sustainable technologies and the negative perception of concrete and structures built from recycled materials. On the technological side, the need for more research on sustainable materials – in order to build familiarity with new technologies and to establish a longer performance record – was also identified as a barrier. Finally, knowledge-related barriers focused on the need for more education to develop knowledge about sustainability, which could be helped by more high-profile projects.

6. DISCUSSION ON REGIONAL CONTEXT

Geography and climate have a clear effect on the approaches and barriers to sustainable concrete. Singapore is surrounded by the ocean and has to deal with warm tropical temperatures and high humidity, whereas Mongolia has no coastline at all and a wide annual temperature range. Durability – widely acknowledged as an integral part of sustainability in the concrete industry – therefore has to be assured considering these varying conditions, such as exposure to a humid chloride environment in Singapore as opposed to the freeze-thaw and temperature-variation related deterioration in Mongolia.

The cases of Singapore and Mongolia also provide two contrasting examples of how geography affects the supply of resources. Singapore, while small and almost entirely reliant on imported materials, is a major shipping center with extensive port facilities, making it easy to manage the import of concrete- and construction-related materials. Mongolia, on the other had, has an ample supply of natural resources but is somewhat reliant upon imports during the peak summer months, and the limited number of routes for importing materials – primarily from China – often results in a bottleneck in the supply chain during the construction peak. Long-term sustainability of concrete in these countries is thus dependent on geographic features and location which enable the steady supply of resources.

Economic factors could also be seen to affect sustainable concrete in these two countries, both directly through the economic situation and indirectly through the relationship between level of development and technology-related issues. In Singapore, the focus on initial cost in bidding systems, the increased cost of sustainable construction, and the effect of sustainable practice on profits were identified as barriers to more sustainable concrete materials and practice. While Mongolia also has similar issues, the context in Singapore is much different, as it has a high cost-competitive and free market, which makes the industry very price sensitive, whereas Mongolia's market is much more limited due to the small number of import routes.

Technology-related issues appeared to be more critical in Mongolia, which has a lower level of economic development compared to Singapore. The low level of technology will require more research, testing, and coordination of industry efforts, in addition to the training of skilled workers to maintain the more advanced technologies imported from other countries. However, the level of investment and motivation to develop sustainable technologies appears to be very low in conjunction with the low awareness of sustainability. Technology development in Singapore, on the other hand, with its higher level of economic development, has greater investment in sustainability-related research, and new technologies are often introduced through the government's promotion of initiatives and public funding. However, in following with Singapore's cost-competitive environment, the easiest or most cost-effective means of technology development may be to simply purchase and modify it as necessary. As Singapore also has a matured industry with skilled workers, such acquired technologies can thus be utilized by the domestic industry.

Stakeholders' roles also play an important role in the approaches to sustainable concrete. In Singapore, the government is actively involved in policy-making towards changing the practices in the construction industry, and represents one of the stronger examples of a major stakeholder taking the lead in moving towards greater sustainability. Conversely, no single stakeholder was found to be the "major" or "lead" stakeholder in the Mongolian concrete industry, although some of the larger general contractors exhibit some characteristic traits such as vertical integration and investment in research and development. The Mongolian government has also shown some initiative towards reducing the problem of air pollution through residential construction to provide homes for people living in yurts, which would help reduce the smog produced by coal burning. At this point in time, however, few stakeholders are actively pursuing sustainability goals in the Mongolian industry, and thus it is unclear which stakeholders will take the lead in future development.

7. CONCLUSION

This paper summarized two case studies in Mongolia and Singapore which investigated general concrete industry conditions, issues related to sustainable concrete materials and construction, and barriers to implementing sustainability, and then analyzed these results to identify region-specific issues and clarify the relationship between regional context and sustainable concrete.

The Mongolian concrete industry is characterized by strong demand for concrete, particularly for architectural applications, which peaks during the summer months and tapers off during the winter. During the summer peak, demand is so high that the industry experiences shortages, a problem which is compounded by the limited number of supply routes for importing cement. Natural resources for producing concrete are widely available domestically, except for anti-freezing admixtures. Management of curing during the colder winter months is critical to prevent concrete cracking. Important issues for sustainability include the conservation of natural resources, management of supply logistics due to the high demand for materials during the summer months, and the implementation of quality control for materials and structures.

As an island city-state with little natural resources, Singapore is heavily reliant on the import of materials such as cement, blast furnace slag, aggregates, and so forth. The industry is therefore very price-sensitive, and cost competition is very strong. The government is, however, working to promote green construction through programs such as the Green Mark system. Resource and energy conservation are important for moving towards greater sustainability, and concrete recycling is one opportunity which Singapore can take to promote sustainability in the concrete industry. However, it will be necessary for the concrete industry to build experience with sustainable and recycled materials and to overcome the increased cost for green construction.

The results of these investigations not only highlighted specific aspects of regional context which were not emphasized in earlier investigations – particularly the geographic and climate aspects – but also reinforced and expanded other findings on aspects such as resource availability, economic situation, technology level, and the role of stakeholders. While the results from Mongolia and Singapore, combined with those from Japan, Thailand, and Korea, encompass a wide variety of conditions, continued research in other Asian countries – especially China and India, the two major developing countries in Asia – will be necessary to build a deeper, more comprehensive understanding of the regional context. Ultimately, a stronger, more diverse knowledge base on regional context could be used for building a roadmap towards concrete sustainability in Asia which considers the unique characteristics and needs of each country while identifying shared issues which countries could cooperatively improve together.

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Table 1: Characteristics of Mongolia and Singapore (adapted from CIA 2012)

Note: numbers given in parentheses are world rankings

Characteristic	Mongolia	Singapore
GEOGRAPHIC		
Area (km^2)	1,564,116 (19)	697 (192)
Coastline (km)	0	193
Climate	Desert; continental (large daily and seasonal temperature ranges)	Tropical; hot, humid, rainy; two distinct monsoon seasons; inter-monsoon – frequent afternoon and early evening thunderstorms
Terrain	Vast semidesert and desert plains, grassy steppe, mountains in west and southwest; Gobi Desert in south-central	Lowland; gently undulating central plateau contains water catchment area and nature preserve
PEOPLE		
Population (July 2012 est.)	3,179,997 (135)	5,353,494 (114)
Urbanization	62%	100%
ECONOMY		
GDP (2011 est.)	US$ 13.43 billion (142)	US$ 318.9 billion (40)
GDP per capita (2011 est.)	US$ 4,800 (155)	US$ 60,500 (5)
TRANSPORTATION		
Railways (km)	1,908 (73)	-
Roadways (km)	49,249 (81)	3,356 (163)

Table 2: Outline of interview contents

Theme	Description
Concrete industry conditions	Identify stakeholders, relationships, technology level, research investment, institutional characteristics, materials and resources, general environmental and sustainability issues
Sustainable concrete practice and materials	Identify changes needed to achieve sustainability, evaluation criteria, and opportunities for each country to improve concrete sustainability
Barriers to sustainable concrete	Clarify barriers to sustainable concrete practice and materials

Table 3: Barriers to sustainable concrete practice and materials in Mongolia

Category	Barriers
Institutional	▪ Lack of updated codes for Mongolian conditions ▪ Lack of codes or regulations for environmental impact ▪ Lack of regulatory oversight for quality control
Economic	▪ Low cost of raw materials
Technological	▪ Low level of technology ▪ Variation in quality of concrete materials and structures
Knowledge	▪ Lack of knowledge for maintaining advanced technologies ▪ Lack of awareness of sustainability

Table 4: Barriers to sustainable concrete practice and materials in Singapore

Category	Barriers
Institutional	▪ Focus on initial cost ▪ Fast construction schedule ▪ Lack of regulation on recycling of materials
Economic	▪ Increased cost of sustainable construction ▪ Lack of tangible benefits from sustainability ▪ Inconsistent supply of sustainable materials
Social	▪ No motivation to use sustainable technologies ▪ Negative perception of recycled materials
Technological	▪ Unfamiliarity with sustainable technologies ▪ Lack of track record for sustainable materials ▪ Lack of research on sustainable materials
Knowledge	▪ Lack of high-profile projects ▪ Lack of knowledge on sustainability