PRELIMINARY STUDY REPORT ON

High Volume Supplementary Cementing Material Smart Technology and Its Application in China

CHINA ACADEMY OF BUILDING RESEARCH

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Contents

1 Abstract

Supplementary Cementing Material (SCM) as the sixth component of concrete is applied more and more commonly and widely. The use of SCM not only saves concrete production cost, but also improves mixture properties and durability performance of concrete. More importantly, it is an effective way of recycling solid wastes. SCM has been used successfully in numerous construction projects in China. But use of SCM still faces a number of challenges, such as lack of information on the pros and cons of SCM and improper training.

Many fruitful researches on application of SCM were carried out in Canada. EcoSmart is the Canadian non-profit organization promoting the increased use of SCM in “Green Concrete”. It collaborated with 20 Canadian organizations including software development company, such as SIMCO, cement producers, contractors, architects, engineers, and other public organizations. A Supplementary Cementing Materials Optimization System Consortium was established by EcoSmart and its partners. Supplementary Cementing Materials Optimization System (SOS) has been developed successfully and widely applied in Canada. The economic benefit and environmental benefit were very significant. And it obtained accordant appreciation.

The central idea of this report is that based on the current situation of concrete industry in China, analyze the economic benefit and social benefit of SOS application in China, and then put forward the necessary adjustment and research for the SOS application in China, the key technologies that should be developed, the data that should be investigated, the research methods and execution plans that should be adopted, and the expected achievements and benefits. Beijing area is designated to be the first SOS research and application pilot to develop the SOS for North China. Subsequently, the systems for East China, South China and northeast area of China will be

developed. Finally, the smart systems of different areas will be optimized and integrated to be a complete SOS suitable for China. And that will be very helpful to promote the high volume SCM application technology all over China.

2 Background knowledge

2.1 Current Situation of Concrete Engineering Technology in China

2.1.1 Development of Concrete Construction in China

Concrete is one of the basic raw materials for economy development and social progress. It is the material of highest demand in China. Recently, the constructions of major concrete infrastructures including express highways, high-speed railways, hydro-power projects, south-to-north water diversion project and west-east natural gas transmission project were developed rapidly in China. The cement production and concrete consumption keep increasing fast. The national gross production of concrete was more than 2.7 billion m^3. (Based on internet data) Gross production of cement in China from 2001 to 2010 is shown in Figure 2.1-1, and the production development of ready-mixed concrete in China in Figure 2.1-2. At this moment, the concrete industry shows a constant and solid growth. The quantity of ready-mixed concrete manufactures in the east coast cities and some inland cities has nearly reached saturation point. However, the small and medium-sized cities in western and middle China have great potential for development.

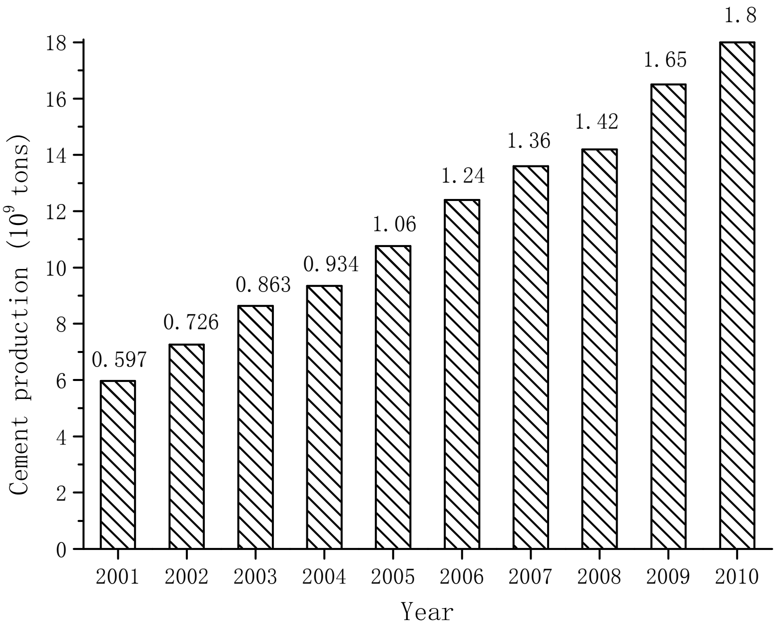

Figure 2.1-1 Gross production of cement in China from 2001 to 2010

In 2000, the concrete industry in China began to develop fast. The annual growth rates were mostly beyond 30%. But the regional developments were extremely uneven. According to investigations on recent national concrete productions, it is found that the 80% came from East China, North China and central south China, especially East China. Since 2006, the annual concrete production ranked first in China for four consecutive years, and was about 50% of the national gross production. In the view of development of concrete production in recent years, the growth rate of northwest and southwest areas were significantly higher than that of east area. Therefore, the central west area and small and medium-sized cities where the concrete constructions are relatively underdeveloped will be vigorously developed in the future.

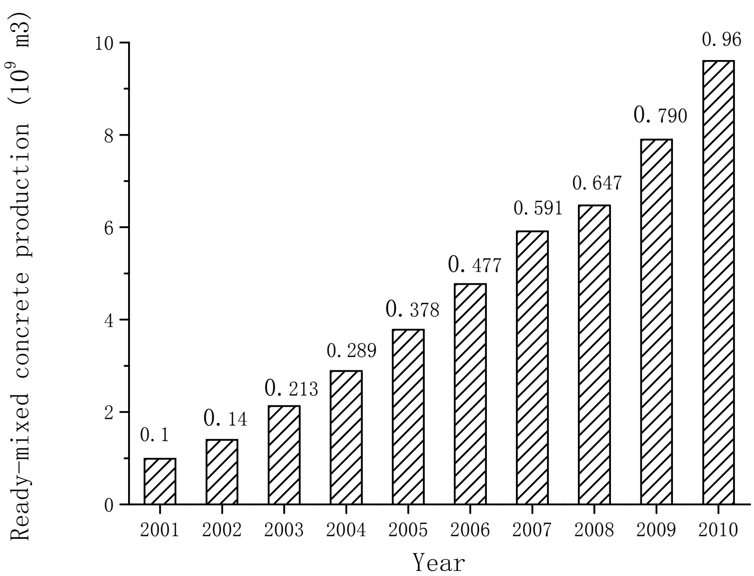

Figure 2.1-2 Gross production of ready-mixed concrete in China from 2001 to 2009

2.1.2 The Application of Supplementary Cementing Material (SCM)

The original components of concrete were only cement, aggregate and water (and air). With the development of concrete technology, some inorganic materials began to be used in concrete. The initial reason using inorganic materials was for the economic purpose. It was found in engineering application that using these inorganic materials would not only reduce the cost of concrete production, but also improve the workability of concrete mixture and durability of concrete. Through the researches, it was found that some of these inorganic materials have cementing property or potential cementing property, the first can improve the concrete performance simply by physical reaction, and the latter can improve it by both physical and chemical reactions. They are collectively called SCM. Table 2.1-1 shows the basic cementing characteristics of some major SCM. In recent years, people's increasing attention on living environment boosted the application of SCM. On one hand, the production of Portland cement is harmful to the environment, because it consumes a large quantity of mineral and clay resources, also releases large amount of GHG, CO_2 into the air. On the other hand, the discard of the huge amount of industrial solid wastes will cause the environment pollution, and should be treated urgently.

Table 2.1-1 Basic cementing characteristics of different SCM

Item	SCM	cementing characteristics
1	Ground granulated blast-furnace slag	Latent hydraulic activity, partial hydraulic activity
2	Pozzolanic (Type N)	Latent hydraulic activity after addition into Portland cement
3	Low-calcium fly ash (Type F)	Latent hydraulic activity after addition into Portland cement
4	High-calcium fly ash (Type C)	Latent hydraulic activity after addition into Portland cement, but small self-hydraulic activity
5	Silica fume	Latent hydraulic activity after addition into Portland cement, but significant physical reaction
6	Calcium filler	Physical reaction, but small latent hydraulic activity after addition into Portland cement
7	Other filler	Chemical inertness and physical reaction

Fly ash is the industrial waste from coal-fired power plants, and the most common SCM. In some developed areas, fly ash has become the indispensible component of ready-mixed concrete. Even demand exceeds supply. The applications of fly ash are quite different in different areas. In the developed east coast area, fly ash is used widely. Often Grade III fly ash is used as Grade II one in building construction. While in central west area, the technology of fly ash application is relatively underdeveloped. The huge amount of fly ash is piled up, and not utilized effectively. There are some problems about application of fly ash. For example, due to the reduction of concrete alkali content, the risk of reinforcement corrosion will increase, and the concrete curing should be more careful. For China, the two most urgent issues affecting fly ash application technology are the following: a. widely promoting the fly ash application in central west area; b. improving the application technology of low-quality fly ash.

Ground granulated blast-furnace slag (GGBS) is the by product of the steel industry, and one common SCM. It nearly becomes the indispensible component of high-strength concrete. GGBS has high latent hydraulic activity, especially in the alkali conditions of hardened cement paste. Without influence on mechanical properties of concrete, the addition of GGBS can greatly reduce the hydration heat, and improve the concrete durability, especially the corrosion resistance. Now, GGBS has been widely applied in various construction fields. The key point of further research is how to improve the utilization rate and utilization level.

Besides fly ash and GGBS, the other SCM such as silica fume, phosphorus slag powder, limestone powder and pozzolanic are also applied in concrete construction in China. Silica fume is a key component of high-strength concrete (strength class is not less than C60). Phosphorus slag powder and pozzolanic are local materials. They are usually applied in hydro-power projects, and not applied on a large scale across the country.

2.1.3 Government Directions for Low-carbon Economy

Energy saving and emission reduction, and solid wastes utilization are the recent important development strategies, which the central government made a series of policies to support, such as the China “twelfth-five years” plan.

The cement industry is a high energy consumption industry. During the production, not only a large amount of limestone and clay is consumed, but also numerous dusts and gases, such as GHG, CO_2 that has negative impact on the environment. To solve the problems, except improving the cement production technology, the most effective way is reduction of clinker instead of large addition of SCM. Using industrial wastes as SCM in concrete will not only reduce the cement content, but also recycle them. Some SCM can even improve the concrete properties. That totally complies with relevant national policies.

2.2 Why the SOS Program would Benefit the Concrete Construction Industry in China

2.2.1 Technical Requirements of Concrete Construction

After twenty years of development, great progress has been made on concrete technology in China. Big changes on concrete technology are taking place in China day by day, especially after the national large-scale construction. The technical requirement of concrete is not only on the mechanical properties but also on performance parameters such as hydration heat control for mass concrete, or concrete durability for key construction projects. The actual demands of various concrete projects cannot be met only by cement. Other raw materials and technical measures need to be applied, such as addition of special chemical admixtures, use of SCM, and application of fiber reinforcements. Among them, use of SCM is an important measure for improving concrete durability and mixture workability. But it requires a higher technical level of the users. The users should have the comprehensive understanding of SCM characteristics, and know the pros and cons of SCM to ensure the application of SCM without any problems. SCM can be widely used in numerous fields of engineering in China that will significantly boost development of low-carbon and green technologies of the concrete industry.

Now diversified categories of SCM are being used in concrete industry. Their hydraulic characteristics are varied. Without sufficient knowledge, the application of SCM in concrete construction is susceptible to have various problems. Meanwhile, if the technical staff is not been trained properly on the application of SCM, they cannot fully understand the properties of SCM. On the premise of no experience of construction application, they would not like to use SCM that limits the large-scale and fast promotion of new SCM. Therefore, a smart system must be established to share the existing SCM application technologies and experience all over the country, enlarge the range of SCM application, reduce the cement content of concrete, and boost the sound development of the concrete industry.

2.2.2 Impact on the Environment

Statistically, the annual amount of industrial wastes in China is more than 600 million tons. Only 40% is utilized, which is far beyond 70%~80% in developed countries. China is in the stage of rapid development of infrastructures constructions. The cement production in 2009 was 1.68 billion tons. The ready-mixed concrete production was 800 millions m^3, and the design production reached up 2 billion m^3. Cement and concrete industry is the most important approach to realize the harmless treatment, reutilization and reduction of solid wastes. Since 2006, the work on energy saving and emission reduction in cement and concrete industry was carried out effectively. The annual treated or reused amount of various industrial wastes exceeded 400 million tons. The methods for comprehensive utilization of various industrial wastes can be classified in three categories: a. using as raw material of cement production; b. using as blender of cement; c. producing SCM. Due to the high requirements of raw material and blended cement, and the complicated and diversified chemical composition of industrial wastes, producing SCM is the most effective way of reutilization.

It was reported that the total amount of carbon emission in China in 2009 was about 8 billion tons [1]. The cement production was 1.65 billion tons. Based on the experience that producing one ton of cement released one ton of CO_2, the CO_2 amount of cement industry in 2009 was about 1.65 billion tons that took up around 20% of the national carbon emission. The cement industry therefore was one of the major carbon-releasing industries. Promoting the application of SCM can reduce the usage of cement clinker. With the application of high volume SCM smart system which can conservatively reduce 5%~10% of cement usage, in China, annually more than 100 million tons of cement can be saved, and about 100 million tons of carbon emission can be reduced. That will remarkably reduce the total amount of carbon emission caused by cement industry with significant environmental benefit.

2.3 Advantages of China Academy of Building Research

As the largest comprehensive research and development institute in the building industry in China, China Academy of Building Research (CABR) carries out its mission in catering to the needs of building and construction industries nationwide, putting forward solutions for the key technical problems met in engineering based on applied research and development, providing technical development and consulting services, and undertaking building design and construction activities. CABR is responsible for the development and management of the major engineering construction and product standards of China.

CABR is responsible for a large number of research projects on concrete industry, including National Eleventh Five-year Project: The key technology and product development for sea sand application in building engineering, the public research project of the ministry of science and technology of the PRC Research on standard test and evaluation methods of concrete durability, the technical R&D project Research on key technology of green high performance concrete, etc. Meanwhile, in China, CABR also takes the responsibility of managing and developing the key standards and specifications in the field of concrete engineering,

a) *Specification for mix proportion design of ordinary concrete JGJ 55-2000*
b) *Standard for test method of performance on ordinary fresh concrete GB/T 50080-2002*
c) *Standard for test method of mechanical properties on ordinary concrete GB/T 50081-2002*
d) *Standard for test methods of long-term performance and durability of ordinary concrete GB/T 50082-2009*
e) *Ready-mixed concrete GB/T 14902*
f) *Standard for inspection and assessment of strength of concrete GB/T 50107-2010*
g) *Technical specification for application of mineral admixtures, etc.*

Numerous technologies referring to concrete industry are in the leading position in China, such as concrete standardization technology, high-strength and high performance concrete technology, SCM application technology, techniques of inspection and evaluation on concrete durability, etc.

CABR is the consultant of the ministry of housing and urban-rural development on high-strength and high performance concrete technology, carrying out series of fruitful researches in this field. Using SCM is one of the major measures for the production of green high performance concrete and improvement of concrete durability. CABR already possessed a large number of data and experience on the application of SCM to support the complete and applicable technical platform. CABR as the chief developer of the overwhelming majority of key standards on concrete industry can perfectly harmonize the promotion of SOS with current relevant standards.

2.4 History of Collaboration between China and Canada via SOS

Program

China and Canada are both members of Asia Pacific Partnership for Clean Energy and Climate (APP), and working for recycling economy and low-carbon economy. The high volume SCM smart technology following the trend of low-carbon economy has been sponsored by APP. In 2009, CABR started talking with EcoSmart. EcoSmart made a brief introduction about SOS to CABR, and then both parties discussed on the cooperation. During 20^{th} to 22^{nd} October 2010, Michel de Spot, the CEO of EcoSmart, attended the National Green Concrete Technology Seminar hosted by CABR and other relevant units in Chengdu, China, and made a presentation on topic of “Research and Application of SOS”, which is highly praised by the attendees.

After this seminar, the project team was organized by CABR to discuss the possibility and execution plan for promotion and application of SOS in China. On January 19^{th} 2011, Mr. Michel met and discussed with the Chinese project team in Beijing. Both parties put forward their opinions and execution plans respectively. Through the detailed discussion, finally the united working plan was formed. Two parties both acknowledged that SOS illustrates a good prospect of application in China. CABR will work for upgrading and promoting SOS in China. This study forms the first step, and also the foundation of two parties’ cooperation. In the next phase, the two parties will follow the detailed plan outlined at the end of this report with the goal to develop and improve the application technology of low-carbon concrete in China.

3 Objectives

SOS is an online smart system providing expert guidance of the addition of SCM. This system integrates the latest application technology of SCM with relevant intellectual properties and practical experience from partners. Conclusively, this expert system based on network was established. It is a user-friendly web-based software that will facilitate “green concrete” by sharing information on the successful use of SCM. Based on existing construction technologies and field experience, and supported by quantitative engineering data, the optimum SCM content for the concrete can be provided according to the actual service conditions, the conditions of SCM and other raw materials, and the technical requirements. That will increase the content of SCM in the concrete following the Chinese policies of energy saving and emission reduction. Nevertheless, in China there are several problems affecting the promotion and application of SCM in concrete.

a. The weather conditions and concrete service conditions in China are significantly different from Canada. Since most areas of Canada are located in the cold zone, the anti-freezing abilities of concrete have received much more attention considering the issue of concrete durability. That is similar to the technical requirements in Northeast China. But the most areas of China locates in temperate zone;
b. There are great differences between Chinese standards and Canadian standards about cement types, experimental methods, technical requirements of application, etc. In addition, a large quantity of provincial standards has been developed. The promotion and application of SOS should comply with these Chinese standards;
c. The properties of raw materials in China significantly vary from that in Canada. The categories and properties of SCM are also different. Therefore, the basic databases need to be re-created according to Chinese details to meet the requirements of concrete industry in China;
d. There are also great differences between these two countries on concrete mix proportion technology. The basis of mix design in Canada is the volume method, but in China is the weight method. The SOS applicable in China thus should be researched and developed following the Chinese mix design method.

Based on the agreement of two parties, the objectives of this project are,

a. studying the operating principle, system structure and calculation method of Canadian SOS;
b. investigating the basic data required by SOS all over China according to the current situation of concrete construction;
c. studying and analyzing the major expert guidance and empirical equations about concrete engineering technology;
d. cooperating with Canadian side to adjust and re-develop SOS for China.

4 Research Contents

Figure 4-1 Model of SOS

The model of SOS is given in Figure 4-1. SOS mainly contains four parts, including Databases, Expert Guidance, Empirical Equations and Neural Network Model. Databases include standards and specifications, meteorological data, categories and characteristics of mineral admixtures, concrete components, mix proportion of concrete, application methods of SCM, etc. The most important part is the databases. Every category of basic data is closely related with concrete property. The rationality and reliability of the SOS calculation results directly depend on the quantity and rationality of basic data. Based on the smart system model of SCM and the research and application of Canadian SOS, considering the current situation of concrete construction in China, the research contents of the development and application of **High Volume SCM Smart System** include,

a) Investigation of basic data for the system, which has significant influence on the accuracy of system calculation results;

b) Establishment of the databases. Based on the existing basic data, establish the reliable databases for the system by series of processing;

c) Establishment of the neural network model, which can refer to the Canadian existing research achievements. However, the systematic research should focuses on the characteristics of concrete construction in China and the status of the basic databases;

d) Establishment of databases, network model and calculation method, and their relationship, which is of importance. The scientific relationship between existing basic data and the neural network model should be built up, which directly contributes to the rationality and practicability of the smart system.

The categories of basic data for SOS are shown in Table 4-1.

Table 4-1 Categories and details of basic data of SOS

Item	Category	Details
1	Environmental Data	① Location of concrete construction site; ② local maximum, minimum and average temperature variations; ③ Relative humidity variations over a year; ④ Construction time and weather conditions.
2	SCM	① Origins and distribution of SCM in China; ② Basic properties of SCM, such as chemical composition, mineral composition, fineness, water demand ratio, loss on ignition, activity index, etc; ③ The influence of dosage of SCM on concrete performance.
3	Cementing Materials	① Categories of cements, brands of cements; ② Characteristics of cements, including mineral composition, clinker content, categories and contents of admixtures, mechanical performance, fineness, setting time, chemical composition, etc.
4	Aggregates	① Categories of coarse aggregates and fine aggregates; ② Maximum particle size, grading, crushing index, dust content, crusher dust content, etc; ③ Types of fine aggregates, fineness modulus, dust content,

		crusher dust content, chloride content, etc.
5	Mix Design Data	① Detailed mix design data, including strength class, content of cementing materials, W/B, content of SCM, aggregates percentage, bulk density, type and dosage of chemical admixture, etc; ② Methods of mix design, trial mix, mixture properties, mechanical properties and durability performance of concrete.
6	Standards and Specifications	① The relevant national standards on SCM, such as *Technical specification for application of fly ash concrete GBJ 146*, *fly ash used for cement and concrete GB/T1596*, *Pozzolanic materials used for cement production GB/T 2847*, *Mineral admixtures for high strength and high performance concrete GB/T 18736*, *Ground granulated blast furnace slag used for cement and concrete GB/T 18046*, *Granulated blastfurnace slag used for cement production GB/T 203*, etc; ② The relevant professional standards on SCM, such as *Fly ash for silicate building products JC/T 409*, *Technical specification of fly ash for use in hydraulic concrete DL/T 5055*, *Technical specifications for fly ash in harbour engineering JTJ/T 273*, etc; ③ The relevant provincial standards on SCM, such as *Code for utility technique of granulated blast-furnace slag used in concrete DG/TJ08-501*, etc.
7	Expert Guidance	① Best practices rules recognized by the Chinese Concrete industry to establish the optimum SCM content for different conditions; ② The influences of SCM addition on mixture properties, mechanical properties and durability performance of concrete; ③ The applicable SCM for different structural positions.
8	GHG	① Clinker content of cement, clinker composition, fuel burned,

	Emission	electricity consumption; ② Production technology and production energy consumption of SCM; ③ Cement content and SCM content of concrete, and GHG emission and energy consumption caused by production of cementing materials used in concrete.

5 Road Map

5.1 Overall Implementation of the Project

Because of the huge difference between China and Canada, the databases need be researched and rebuilt before the SOS applies in China. Expert guidance and empirical equations need be confirmed. Neural network model can be based to existing Canadian model. In summary, the Research and development of SOS and its use in China can be done as follows:

a. Translate the SOS software interface in mandarin;
b. Add to the SOS program features not included in the Canadian software but required in a Chinese context according to states of concrete construction in China;
c. Create new datasets with Chinese content to be incorporated in the program database (See Figure 1). This step is the most critical and the most time-intensive. For that reason, it should be started immediately.
d. Neural network model should be developed suitable for Chinese construction industry after databases establishment;
e. Create conjunction method between databases and calculate model. Research interface and function module for the smart system. Develop SOS, by which the optimization SCM content can be calculated.

5.1.1 Create Databases

For the SOS, the veracity and accuracy are determined by the amount of base data. An important aspect is the acquisition of the maximum of properties for a maximum of mix data. The more properties and mix data are entered in the database the more accurate the SOS program will be. The database in table 4-2 can be developed according to Figure 5-1. Whether the information exists in China or needs to be created (See Figure 5-1).

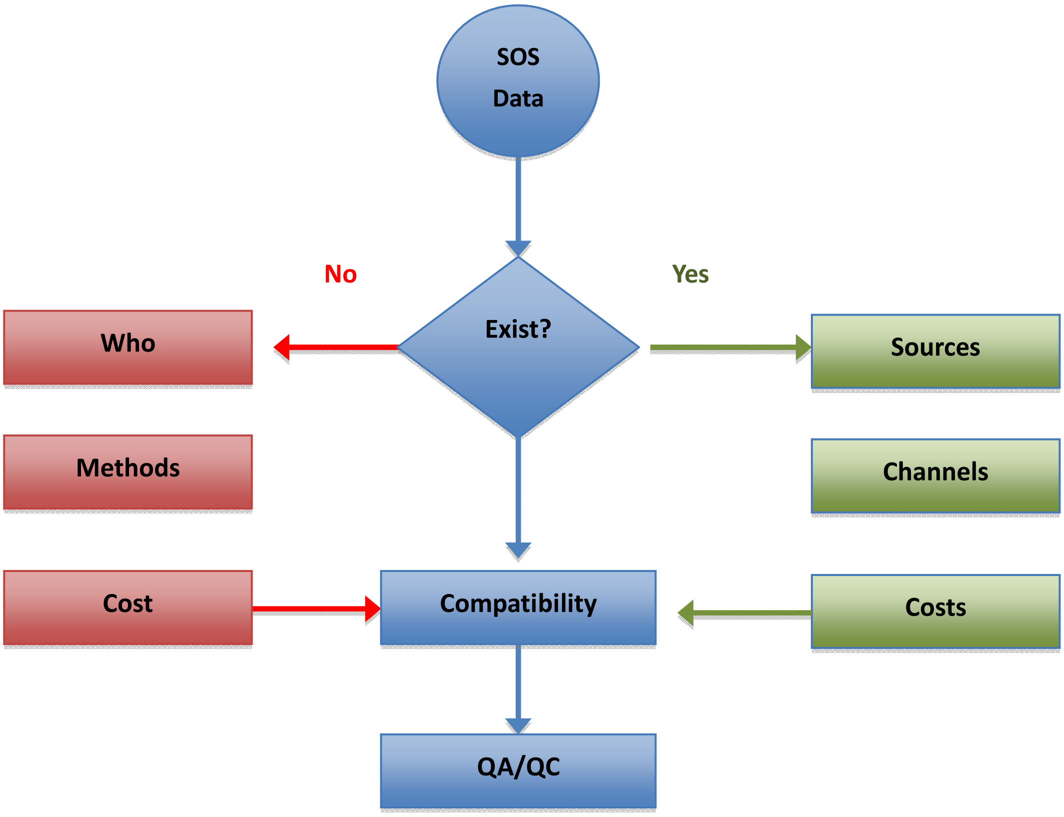

Figure 5-1 Methodology

1) Environmental Data

The environmental data information exists in China and it can be obtained from China meteorological offices. The information is usually in electronic form. The environmental data of typical concrete construction can be developed from construction companies. This information is on paper, so it has to be entered manually. All the information needs be carried on-the-spot investigation.

2) SCM

The information of SCM exists in China, but it needs be developed and analyzed. This information should be available by major cement and concrete companies, SCM companies, Steel plants, coal fired power plants. Most of the information is on paper, thus has to be entered manually.

3) Cement

The information of cement exists in China. It can be developed from cement companies and concrete suppliers. The information is usually on paper, thus has to be entered manually.

4) Aggregate

The information of aggregate exists in China. The properties of aggregate can be developed from concrete companies and aggregate factory. There are lots of local aggregate materials used in China. The information is usually on paper, thus has to be entered manually.

5) Mix proportion

The information exists in China. It can be developed form cement and concrete suppliers, government and private laboratories. But it’s hard to obtain the true mix proportion. It will take a lot of time and money to develop this information. The information is usually on paper, thus has to be entered manually.

6) Codes and standards

The information exists in China. National standard can be developed form standard press. There are a lot of national and provincial standards which will take lots of time to develop in China. The Codes and standards are usually on paper, thus has to be entered manually.

7) Expert guidance

The information of expert guidance doesn’t exist in China, so it needs be created. This can be developed by consulting concrete supplier, concrete construction expert, and college professors. It will take a lot of time to develop the information. Expert guidance developed needs be analyzed and entered manually.

8) GHG emission

The information doesn’t exist in China. It can be developed according to government data, engineering calculation on stochiometric values for combustion and calcinations, data of transport and electricity production. The information needs be obtained form cement companies, SCM companies, concrete suppliers; et al. GHG emission needs be entered manually.

The units, codes and standards are different from China and Canada. The compatibility of information above needs be analyzed with Canadian program. All the information will be developed by on-the-spot investigation to insure quality control of the data. In summary, the data can be obtained according to the following 2 ways. The main sources of databases are shown in Table 5-1.

1) If the information exists, it can be done as follows:
   - Determine what are the sources (construction companies, concrete companies, quality supervision and test center, cement companies, guild organization, et, al).
   - How will the data be accessed and estimate the cost. Determine the Channels to get the data and methodologies such as electronic documents or manual entries et, al.
   - Compatibility requirement with Canadian program (for example different units or standards)
   - Quality Assurance and Control (QA/QC) procedures to ensure data accuracy and reliability
2) If the information does not exist in China, it can be developed as follows:
   - Who will create the information? (construction companies, concrete companies, professional associations, etc.)
   - How will the information be created (for example research program or consult some organization)
   - What would be the estimated cost for creating these additional datasets?
   - Compatibility requirements with Canadian program (for example different units or standards)
   - QA/QC procedures to ensure data accuracy and reliability.

Table 5-1 Mian sources of databases

No.	Category	Sources of databases
1	Environmental data	① Temperature and relative humidity can be got from China meteorological offices； ② Information of typical concrete construction can be developed from construction companies.
2	SCM	① This information should be available by major cement and concrete companies, SCM companies, Steel plants, coal fired power plants. ② It would be worthwhile to develop such inventory nationally.
3	Cement	The properties of cement can be developed from cement companies.
4	Aggregate	The properties of aggregate can be developed from concrete companies and aggregate factory.
5	Mix proportion	It can be developed form cement and concrete suppliers, government and private laboratories.
6	Codes and standards	National standard can be developed form standard press. There are a lot of provincial standards which will take lots of time to develop in China. It would be worthwhile to develop such inventor of all codes and standards in China.
7	Expert guidance	Expert guidance is very important for SOS, but it is hard to develop in China. This can be developed by consulting concrete supplier or concrete construction expert.
8	GHG emission	It can be developed according to government data, engineering calculation on stochiometric values for combustion and calcinations, data of transport and electricity production.

Concrete mix proportion and concrete performance are the most critical data.

They are helpful to seize the property and replacement level of SCM. The mix parameters need be developed are shown in Table 5-2. The type and strength class of concrete should be as much as possible. The kind and replacement level of SCM used in construction need be researched. The grad of aggregate plays an important part in concrete performance, so it should be researched. Database researching is the most critical and the most time-intensive. So it must be supported by enough time and outlay.

Table 5-2 Parameters of concrete need be developed

Category	Unit
Mix Characteristics	
Cement Type	
SCM Class and quality	
Water-binder ratio	%
SCM replacement level	%
Cement Content	kg
Max coarse Aggregate size, grad	mm
Fine aggregate ratio	%
Fine aggregate type, modulus, mud content	
Water dosage	kg
Chemical admixture type and dosage	kg
Fresh concrete properties	
Pump ability (workability)	Yes/No
slump	mm
Setting time Initial	min
Setting time Final	min
Schedule and strength	
Compressive strength at form release	MPa
Compressive strength at post tensioning application	MPa
Compressive strength @ 3 days (design, standard curing, structure)	MPa

Compressive strength @ 7 days (design, standard curing, structure)	MPa
Compressive strength @28 days (design, standard curing, structure)	MPa
Compressive strength @ 56 days (design, standard curing, structure)	MPa
Durability	
Freezing thawing	
Fresh concrete air Content	%
Dynamic elastic modulus and mass damage	%
Charge RCPT Test @ 28 days	C
Charge RCPT Test @ 56 days	C
carbonation depth	mm
Anti-permeability grade	
Cracking	
Heat development (without loss to the outside)	Max temperature °C
Shrinkage Max ×10E-6	
Concrete structure cracking	
curing	
Curing temperature	°C
Curing period	days
Secondary curing period	days

Figure 5-2 Different regions of China for SOS used

China is vast in territory. The climate and concrete raw materials are quite different for different regions. According to SCM application and concrete technology, China can be divided into 7 parts as shown in Figure 5-2. They are northeast (Shenyang, Jilin, Harbin), Northern China (Beijing, Tianjin, Jinan, Shijiazhuang), northwest (Xi'an, Lanzhou), Eastern China (Shanghai, Nanjing, Hangzhou), Southern China (Guangzhou, Shenzhen), Southwest (Chongqing, Chengdu, Kunming, Guiyang) and Central China (Wuhan, Zhengzhou). The development and application of SOS can be carried on in proper sequence as show in Figure 5-3. The project is suggested to start from Beijing. There are two reasons. First, the concrete technology in Beijing region is typical. Secondly, the climate and raw materials of Beijing are nearly the same with Hebei province, Shandong province and Tianjin. The research findings can be used in Northern China.

5.1.2 Development of SOS

Once the database is created, SOS can be developed by Error Back-Propagation Neural Network (BPNN). It can be done as follows.

a. Classify the data in the database. The data can be classified according to the geographical regions. For the data of the same region, they can be classified into environmental data, SCM, cement, aggregate, mix proportion, codes and standards, expert guidance, GHG emission;

b. Create Error Back-Propagation Neural Network model. The model should be created according to the relationship among concrete performance, mix proportion and raw materials. The model can be rebuilt according to Canadian SOS model;
c. Network training and checking. The BPNN is trained according to the concrete data of different regions. The BPNN results are compared with actual engineering data and current standard. The BPNN trained can be applied in given regions first. If the results are perfect, the BPNN can extend to other regions;
d. Deal with input and output system. The results will display graphically in the SOS.

SOS can be established in Beijing (Northern China) first. This could be a typical example for the following regions where SOS need be applied. Once SOS of all given regions has been established, SOS used for China can be created by integrating and future development.

5.2 The next detail work plan and objective

SOS used in Beijing (Northern China) is a demonstration project. Table 5-3 shows the detail work plan, objective and time arrangement.

Table 5-3 Detail work plan and time arrangement of SOS used in Beijing

Year	Schedule	Work plan and objective
2011	2011.4.1~ 2011.7.1	（1） Research the category and applied general situation of SCM in Beijing (Northern China) regions. （2） Research the national standards and provincial standards for SCM in Beijing (Northern China) regions. （3） Research the climate of Beijing (Northern China) regions. （4） Find the SCM suppliers with large scale of production in Beijing (Northern China) regions.
	2011.7.1~ 2011.12.30	（1） Carry on-the-spot investigation in concrete suppliers with large scale of production in Beijing (Northern China) regions,

		such as concrete company of Beijing Urban Construction Group, concrete company of Beijing Construction Engineering Group, concrete company of BBMG Corporation, concrete company of BUCC, Beijing Xinhang Concrete company, etc. The general application of SCM, properties of SCM and properties of concrete raw materials can be obtained. （2） Research concrete engineering data from each concrete supplier. The concrete usage amount should be more than 10,000 m^3 for the concrete construction. The data may include SCM usage amount, concrete strength class, raw materials properties, concrete mix proportion, workability of fresh concrete, mechanical properties of concrete, durability of concrete, etc. These data are mainly tested in library. （3） Research concrete engineering data from concrete construction company according to the data obtained from concrete supplier. The data may include concrete design strength class, structure actual strength, concrete curing condition, weather, structure appearance, concrete durability, etc. （4） Consult to expert about the application and properties of SCM according to different concrete construction.
	2011.7.1~ 2011.12.30	（1） Research the SCM application data in cement factory, such as Lafarge cement group, Jidong cement group, SUNNSY cement group, etc. The data may include SCM type, SCM dosage, properties of SCM, energy consumption and carbon emission of cement production, properties of cement, etc. （2） Develop data from SCM supplier. The data may include properties of SCM, energy consumption of SCM production, optimum replacement level when used in concrete, etc. （3） Consult to experts of Beiing Concrete Association The data may include the general application of SCM, properties of SCM, SCM dosage in concrete, SCM application technology, influence of SCM on concrete, etc.
2012	2012.1.1~ 2012.6.1	（1）Research and analyze the data that has obtained from concrete suppliers, cement factory, construction organization. The data can be classified into SCM type, application field,

		application technology, optimum dosage, etc. （2）Create database used for Beijing (Northern China) SOS on the base of data researched. The data in the database can be updated at any moment to add new technical data. （3）Develop the relationship of data in the database to make sure that the data can be applied scientifically.
	2012.6.1~ 2012.10.1	（1） Research neural network model for the SOS. Meanwhile, add empirical equations into SOS. （2） Create the calculation process for the SOS to make sure that the database could communicate with neural network model scientifically. （3） Create SOS used in Beijing (Northern China) regions. Accomplish the system testing of SOS.
	2012.10.1~ 2012.12.30	（1） Write the report about the database creating and SOS development on the base of researching process. （2） SOS applies in Beijing (Northern China) regions by the generalization of guild, government and some corporations. Economic and social benefits could be obtained.

Once the SOS used in Beijing (Northern China) has been established, SOS used in southwest regions, Southern China regions, Eastern China regions or other areas can be created in the same working process. Finally, SOS used in China can be developed on the base of all local SOS by integration and further updating. The approximate time arrangement of SOS created in China is shown in Table 5-4. Generally speaking, it will take about five and a half years (66 months).

Table 5-4 Time arrangement of SOS researched in China

Schedule	Work plan and objectives
2011.4.1~ 2012.12.30	① Develop database of SOS used in Northern China (Beijing and Tianjin are on behalf of the regions). . ② Develop SOS used in Northern China.
2013.1.1~ 2013.9.1	① Develop database of SOS used in southwest (Chongqing, Chengdu, Guiyang and Kunming are on behalf of the regions). .

	② develop SOS used in southwest.
2013.9.1~ 2014.5.1	① Develop database of SOS used in Eastern China (Shanghai, Hangzhou and Nanjing are on behalf of the regions). . ② develop SOS used in Eastern China.
2014.5.1~ 2015.1.1	① Develop database of SOS used in Southern China (Guangzhou, Shenzhen and Xiamen are on behalf of the regions). . ② develop SOS used in Southern China.
2015.1.1~ 2015.7.1	① Develop database of SOS used in Central China (Wuhan, Zhengzhou and Hefei are on behalf of the regions). . ② develop SOS used in Central China.
2015.7.1~ 2016.1.1	① Develop database of SOS used in northeast (Shenyang, Jilin and Harbin are on behalf of the regions). . ② develop SOS used in northeast.
2016.1.1~ 2016.7.1	① Develop database of SOS used in northwest (Xi'an and Lanzhou are on behalf of the regions). . ② develop SOS used in northwest.
2016.7.1~ 2016.10.1	Develop SOS used in China.

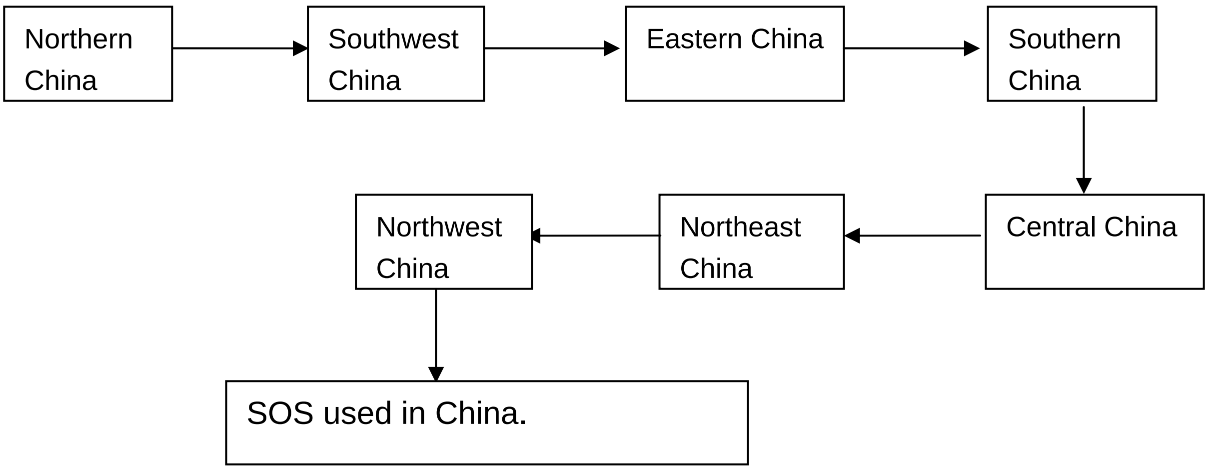

Figure 5-3 The region sequence of the establishments of SOS

5.3. Key technology & technical difficulties

The concrete engineering technology between China and Canada is quite different. The key technology and technical difficulties need be solved during SOS developed and applied in China are as follows.

a. China is vast in territory. The climate and concrete raw materials are quite different for different regions, especially for southwest, northwest and northeast of China. There are lots of local materials in China. The types and application technology of SCM are uneven. There are many provincial standards in China. The technical difficulty is to analyze the properties and application technology of different SCM.

b. How to insure the reliability of concrete engineering data. For the construction market is a little chaotic, there are some interests among constructors, concrete suppliers and engineering project supervisors. It is difficult to obtain real engineering data and concrete mix proportions. The veracity and accuracy of SOS are determined by the database. So it is critical to insure the reliability of engineering data.

c. How to analyze and summarize the expert guidance. It is hard to avoid some fallacious viewpoints for expert guidance is subjective. A lot of literature investigation should be done to improve our professional technology to identify and analyze the expert guidance.

d. How to harmonize the difference of concrete technical level and processing method between China and Canada. There will be many difficulties during the development of SOS in China, because the situation of two countries and concrete technical level are different. How to develop SOS considering the situation of concrete engineering in China on the base of Canadian previous research results is key technology.

6 Expected Achievements and Benefits

6.1 Expected Achievements

The achievements can be obtained from this project are as follows.

a. Create database of SOS used in China. The database may include main SCM suppliers of different regions in China, the general application and properties of SCM used in concrete suppliers and cement factory, application and performance of SCM in typical concrete structure, etc. It also include national and provincial standards about SCM application, concrete mix proportions and properties of concrete, expert guidance about SCM use, properties of concrete raw materials, etc;

b. Develop SOS used in China. The system is developed on the base of Canadian previous research results and database created in China. The optimum replacement level of SCM can be calculated by this system according to the given conditions. The given conditions may include the geographic location of concrete structure, climate of concrete construction, workability and mechanical property requirement of concrete, properties of concrete raw materials, type and properties of SCM, etc;

c. Networked application of SOS can be obtained. By network programming and database technology, SOS can be applied in the net on the base of database created. So people in any place can use SOS to got ideal SCM application technology at any time using the internet. It is a great progress for the application of SCM.

6.2 Economical and Environmental Benefits

SOS is developed on the base of current engineering experience and theoretical foundations. The optimum SCM replacement level can be obtained by this system according to geographic location, technical requirement and raw materials properties of concrete structure. On the one hand, application of SOS could ensure the quality of concrete structure, decrease the risk of engineering accident. On the other hand, application of SOS could improve the using technology level of SCM, reduce the cement dosage in concrete and utilize the industrial waste residue. The total carbon emissions of China in 2010 are about 1.8 billion tons. The cement dosage in concrete may decrease 5%~10% by SOS application. The carbon emissions of concrete could decrease about 100 million tons per year. Meanwhile, 100～200 million tons industrial waste residue could be reused. The environmental and social benefits are notable by SOS application.

Information platform can be built by the SOS. SCM suppliers, concrete raw material suppliers, cement factories, concrete suppliers, concrete construction companies, concrete quality inspect corporation, concrete associations, research institutes and colleges can share technical information about SCM application. For concrete company, optimum SCM dosage can be obtained from SOS without lots of experiments. There are about 3000~4000 ready-mixed concrete companies in China by conservative estimates. According to statistics, there are 202 ready-mixed concrete companies in Beijing at 2008. The number has decreased these years, but it's still more than 150. On the assumption that the royalty of ready-mixed concrete company using SOS is 10,000 RMB per year, the profit of SOS application is more than 30 million in China. The profit of SOS just applied in Beijing regions is more than 1.5 million RMB. Therefore, remarkable economical benefits can be obtained besides environmental and social benefits.

7 Ownership of Intellectual Property Rights

SOS for China can be developed by this project. There are lots of technical data in SOS, including environmental data, SCM, cementing materials, aggregate, mix proportion, codes and standards, expert guidance and GHG emissions. It is the first time to develop these concrete technical data in China. The development and promotion of SOS shall be completed by Chinese and Canadian organisations. Chinese organisations would be responsible for the establishment of the databases of SOS, the research and development of SOS, and the network application. The Canadian organisations would be responsible for providing necessary technical supports on the research and development of SOS, and the network application. The intellectual properties of technical achievements of this project will be jointly owned by Chinese (China Academy of Building Research) and Canadian (EcoSmart), including basic databases of the smart system (SOS), the smart (SOS) system, etc. Chinese and Canadian shall have the equal right to the research achievements and the economic interests. Either party can only use the basic databases or the smart system (SOS) with permission of the other party. Neither party can transfer the basic databases and the smart system (SOS) to a third party without permission in written form.

8 Risk of Project

The project is carried on the basis of previous Canadian researching results, which is strong enough. The research objectives and content are clear. There is a good relationship between China and Canada for this project. The concrete technical level of CABR is high. The working plan and working objectives are feasible. There is little technical risk if the project is supported by enough researching funding.

The cement production keeps growing with large scale infrastructure construction in the last decades. The range and technical level of SCM application can be improved by this researching achievement. The cement dosage in concrete may decrease. This is useful for energy saving and emission reduction, accord with national development policy. The research achievement can be applied in concrete industry, including construction, transportation, water resources, railway, and nuclear power engineering fields. The market risk is small.

9 Research budget & project team members

It will take significant human, material and financial resources to develop SOS used in China. The first step is to develop SOS applied in Beijing (Northern China) regions. The research budget of developing SOS in Beijing (Northern China) is shown in Table 9-1.

Table 9-1 Research budget of developing SOS in Beijing (Northern China)

Budget account	Budget（$\times 10^4$ RMB）	Remarks
Equipment costs	20.0	Buying experimental equipment, software system, database system, network service charge, etc.
Material costs	15.0	Buying experimental materials, doing experiment, etc.
Testing and processing charges	14.0	/
Expenditure on power and fuel	11.0	Buying water, electricity and gas.

Travel expenses (domestic)	25.0	Travel expenses for researching in China
Conference expenses	20.0	Attending conference about SCM application
Corporation and communication cost		
Cost for members study abroad	10.0	Study Canadian SOS in Canada.
Cost for experts overseas	10.0	/
Cost for publication, communication and intellectual property	10.0	Polishing and Patent application
Labor cost		
Domestic labor cost	10.0	
Experts oversea labor cost	10.0	
Cost for consulting to experts		
Domestic expert	15.0	Consulting to expert about the use of SCM
Experts oversea	10.0	
Management cost	10.0	Calculated by 5% of the total budget
Other expenses	10.0	Unanticipated expenses
Total	200.0	

The development of SOS in China will start from the Beijing region. There may be some challenges at the beginning of the project. It will take significant time and financial resources to develop SOS used in Beijing (Northern China) as there are some unforeseen difficulties. The time is about 21 months and the research budget is about 2 million RMB. The project team can improve the skill and gain experience during the stage of developing SOS used in Beijing. Once SOS used in Beijing regions is established, SOS used in other regions can be developed successfully. The approximate time and research budget of developing SOS in China are shown in Table 9-2. The overall time is about five and a half years (66 months) and the research budget is about 10 million RMB. Table 9-3 shows the information and responsibility of project team members.

Table 9-2 Approximate time and research budget of developing SOS in China

Regions	Time spent (months)	Research budget （$\times 10^4$ RMB）
Northern China	21	200
Southwest	8	150
Eastern China	8	150
Southern China	8	140
Central China	6	120
Northeast	6	100
Northwest	6	100
Integration	4	40
Total	66	1000

Table 9-3 Project team members of SOS used in China

Team members						
Name	Sex	Birth date	Duty	Academic rank	Corporation	Diploma
Chinese director						
Leng Faguang	Male	1968.9	Chief engineer	Professor	CABR	Doctor
Chinese participants						
Zhao Xiaolong	Male	1970.11	Institute director	Professor	CABR	Doctor
Ding Wei	Male	1954.10	Department director	Professor	CABR	Bachelor
Ji Xiankun	Male	1983.9	/	Engineer	CABR	Master
Bao Kemeng	Male	1984.3	/	Engineer	CABR	Master
Zhou Yongxiang	Male	1979.10	Executive	Associate professor	CABR	Doctor
He Gengxin	Male	1981.12	/	Engineer	CABR	Master
Tian Guanfei	Male	1978.7	Executive	Associate professor	CABR	Doctor
Wang Jing	Male	1981.4	/	Engineer	CABR	Master
Wang Yonghai	Male	1981.6	/	Engineer	CABR	Master
Tian Kai	Male	1982.4	/	Engineer	CABR	Master
Canadian director						
Michel de Spot	Male		CEO	Professor engineer	Eco SMART	

Reference

[1]http://cache.baidu.com/c?m=9d78d513d9d430df4f9ee3697c10c0111b4381132ba6a1020fa58449e3732a465017e4ac57270775d4d27d1716de4a4b9a842235775d2feddd8eca5ddcc88f357fd86623706bd71c11d913b8cb31749c7f8d0bb4f35fb0e6b62f91b9d5a7de5751ca53057097f7ff5a1714bd35b64b&p=9e6fd01797934eaf53a8c7710b7a&user=baidu&fm=sc&query=%CB%AE%C4%E0%CC%BC%C5%C5%B7%C5%C1%BF&qid=9eab0d9a1b486c5f&p1=12

Acronym

BPNN Back-Propagation Neural Network

SCM Supplementary Cementing Material

SOS Supplementary Cementing Materials Optimization System

GHG Greenhouse Gas

BBMG Beijing Building Material Group

BUCC Beijing ZhuZong Group