EFFECTS OF CORPORATE SOCIAL RESPONSIBILITY FULFILMENT ON THE SUSTAINABILITY PERFORMANCE OF THE CONSTRUCTION PROCESS: A CHINA CASE

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Effects of Corporate Social Responsibility Fulfilment on the Sustainability Performance of the Construction Process: A China Case

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CERTIFICATE OF ORIGINALITY

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Jiang Weiyan

To my families for their endless loves and enduring supports.

ABSTRACT

Recent years have witnessed the aggregation of environmental pollution and many social problems. Contractors are required to put more efforts to both the fulfilment of corporate social responsibility (CSR) and the implementation of sustainable construction. Nevertheless, these two areas interlock with one other and it is time-consuming for contractors to manage the causal relationships between CSR in construction (CSR-C) and the sustainability performance of the construction process (SPCP). While considerable previous studies have been devoted to both CSR-C and SPCP, the causal relationships between them sustain obscure. To fill this knowledge gap, the aim of this study is to investigate the effects of CSR-C on SPCP with an intention of facilitating contractors to conduct sustainable construction practices at the project level.

The concepts, attributes and scopes of CSR-C are presented in detail for the identification of CSR-C activities. Through extensive literature review, interview and questionnaire survey, a set of CSR-C activities are identified and they are further classified into six key areas, namely environment preservation, construction quality and safety, well-being of local community, employees' interests, and CSR institutional arrangement. In appreciating plenty of literature in sustainable construction, literature review and Delphi-type survey are adopted to establish indicators for SPCP measurement and the indicators are restructured in line with an input-activity-output framework. Construction inputs indicators spell out resource efficiency with respect to land, materials, energy, and water.

Construction activities indicators are concerned with the impacts of construction activities on society and the environment. Construction outputs indicators outline three conventional objectives (i.e., quality, schedule and cost) that contractors have to achieve.

The construction process operates as a system composed of a few subsystems. Therefore, a system dynamics (SD) model is developed to detect the ways in which one CSR-C activity changes one SPCP indicator. The proposed model comprises three subsystems, namely construction inputs performance (CIP), construction activities performance (CAP) and construction outputs performance (COP). Each subsystem has a number of parameters.

A large infrastructure construction project in western China is adopted as a case to test the reliability and validity of the proposed SD model. Data collection are well designed and collected in due ways. Based on the case study, it is found that CSR-C makes positive contributions to the attainment of SPCP. Specifically, CSR in the construction industry are embodied with activities in the construction process; the fulfilment of CSR can increase the levels of CIP, CAP and COP; the impacts of CSR-C on SPCP are determined by the weights that contractors utilize to measure the relative importance of the triple bottom lines of sustainability; an increase in initial input for CSR fulfilment may enhance the values of SPCP. Meanwhile, a number of CSR-C activities are simulated with an aim of identifying the manner in which they change SPCP.

To summarize, the research findings contribute to the body of knowledge with an improved understanding on the attributes of CSR-C, its effects on sustainable construction process, and a new perspective to model the relationships between CSR-C and SPCP. However, the study is situated in the Chinese construction sector and the research findings might not completely applicable to other construction contexts. The impacts of CSR-C on SPCP varies with the type of construction projects and the determination of the client. Thus, research works are recommended to generalize the research findings in the future.

KEYWORDS

Sustainable construction, corporate social responsibility, system dynamics, enterprise management, China

PUBLICATIONS ARISING FROM THE PHD STUDY

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Chapter 1. INTRODUCTION

1.1 Background

1.1.1. A growing awareness of sustainable construction practices

It is well recognized that construction activities yield considerable negative impacts on the environment and society such as noise, dust emission, landscape destruction, biodiversity reduction, water and air pollution, and carbon emission (Plessis 2007, Ding 2008, Valdes-Vasquez and Klotz 2013). These impacts have been widely concerned as they are associated with the wellbeing of local community and render much disturbance to the life of citizens (Bentivegna *et al.* 2002). Contractors are thus advocated to make due response to social requirements and expectation when they are undertaking construction works (Lu *et al.* 2016, Croker 2013).

Nowadays contractors have more willingness than before to dedicate resources to the practice of sustainable development. They spend part of working time training manpower to increase the awareness of health, safety and environment on production lines (Jiang and Wong 2016, Loosemore 2015). Working closely with the client favours contractors to understand his/her needs, and this in turn helps them gain confidence in winning competitive bidding (Zitron 2006, Shash 1998).

They take positive attitudes towards new challenges arising from the construction process and are fully committed to successful delivery of final products without producing environmental impacts (Kibert 2012). Meanwhile, the importance of CSR engagement has been recognized to maintain a good reputation in the industry (Croker 2013, Golob and Bartlett 2007). As revealed in previous studies, recognition and commitment from contractors' top management on the fulfilment of corporate social responsibility (CSR) is essential to fortify organizational competitiveness in the construction sector (Lu *et al.* 2016, Murray and Dainty 2009).

1.1.2. Contractors' performance in the implementation of sustainable construction

The construction community is faced with considerable obstacles in the introduction of sustainable practices (Brown and Barber 2012). Many contractors have reached much consensus on the obstacles in terms of type and forms, and adopt sustainable construction paradigms as much as possible (Hochtief 2015), which are viewed as an effective means to renovate conventional development ways (Shi *et al.* 2014). Nevertheless, contractors' efforts in this connection lag behind societal expectation (Kibwami and Tutesigensi 2016). A couple of reasons can be given, but most probably, the wide application of lowest bid price discourages contractors to make extra efforts to cope with unprofitable businesses (Zhao *et al.* 2012).

It is often revealed that contractors' sustainability performance is unsatisfactory and construction firms are required to boost the application of low carbon construction, green buildings, and technologies of recycle, reusing, and reduction (Tan *et al.* 2011). However, contractors are not highly motivated to embrace such changes as expected. First, their main tasks are to achieve project goals (e.g., quality, cost, and safety) within assigned schedules. Second, the pursuit of sustainable construction necessitates the advancement of technologies, the change of management paradigm, well communication within the organization, and full supports from employers (Kibert 2012, Anastasopoulos *et al.* 2014, Hassan *et al.* 2016). With more participation of migrant workers and female employers in the construction process, management of construction activity has become more daunting than before (Zhao *et al.* 2012). Last but not least, the triple bottom lines of sustainability (i.e., environmental, social, and economic) are in nature mutual and interdependent upon each other, suggesting that the trade-off in the daily routine deserves much attention in practice (Kibert 2012).

1.1.3. Interlocked relationships between the elements of sustainable construction

While contractors may have strong determination to improve sustainability performance on construction sites, they ought to understand the essence of sustainable construction and how they could be more efficient. Basically, *sustainable construction* is a broad term that contractors are preferred to including everything that they are doing as its content (Hassan *et al.* 2016, Kibert 2012).

The implementation of sustainable construction is determined by a couple of factors, which may be technical, managerial, cultural, economic, environmental, and societal (Kibert 2012, Peldschus *et al.* 2010). Driven by various claims from stakeholders (e.g., the client, contractors, subcontractors, suppliers, government officials, citizens and financial bodies), these factors have exhibited interlocked relationships, forming a major barrier to the attainment of sustainability (Zainul-Abidin 2010, Pitt *et al.* 2009). Furthermore, the relationships between the elements of sustainable construction are embedded in the interaction of a construction site to the local community (du Plessis 2002). This implies that contractors may not implement sustainable construction efficiently without taking a systems approach.

1.1.4. Interrelationships between corporate social responsibility and the sustainability performance of construction process

Contractors have the responsibility of actualising sustainability (Klotz and Horman 2010). Reduction of greenhouse gases emission, minimum waste generation, recycling and reuse, improving energy-efficiency of residential buildings, adoption of raw materials extraction, protecting local culture, social and environmental ramification mirror all kinds of efforts of contractors in the implementation of sustainable construction. Nevertheless, previous studies have pinpointed that contractors have to make the choices of CSR activities carefully as it can easily give rise to cost overrun as a consequence (Anastasopoulos *et al.* 2014). Meanwhile, internal resistance to changes in both procedures and processes can be confronted in the ways towards the attainment of sustainable construction (Kibert 2012). Therefore, any operatives and site staffs have the importance of comprehending the principle of sustainability and acting in a socially responsible way (Shi *et al.* 2014). This indicates that CSR and the sustainability performance of the construction process (SPCP) may be condensed into a business program.

Many evidences have demonstrated that contractors have little knowledge of how to fulfil CSR in the domain of construction activities (Hochtief 2015, CSCEC 2013). However, managing a construction project in a socially responsible manner is beneficial to risk mitigation and the improvement of both corporate reputation and competitiveness (Croker 2013). In addition, contractors will have viability in a strongly competitive market situation where they reap productivity and profitability, and gain loyalty from the client (Lu *et al.* 2016, Wu *et al.* 2015, Lichtenstein *et al.* 2013).

1.2 A brief literature review

1.2.1. CSR fulfilment in the construction industry

In the discipline of construction management and economics, CSR has attracted closer attention as the publications of research works have been increasing over recent years (Shen *et al.* 2010, Tam *et al.* 2007, Jiang and Wong 2016). Through investigating seventeen large construction corporations in Australia, Petrovic-Lazarevic (2008) found that CSR in the construction sector (or CSR in construction, or CSR-C) refers to the moral obligation of attaining good levels of citizenship, sustainability, reputation, relationships with employees and unions, relationships with suppliers and community representatives, and commitment to CSR reporting. The work by Peter *et al.* (2006) identified six CSR areas in which contractor firms highlight in the UK, namely environment, health and safety, human resources, supply chain management, customers and communities, and governance and ethics. Moreover, CSR-C has been examined under the headings of organizational performance (Peloza 2006), measurement approach (Turker 2009), development of indicators (Zhao *et al.* 2012), reporting systems (Hou and Reber 2011), and stakeholder management (Ye and Xiong 2011). It appears to be that CSR-C is related to the preservation of the physical environment, resource efficiency, and stakeholder management in the sphere of construction activities.

Notwithstanding a wealth of publications, comprehensive critical review on CSR-C has not yet appeared. What are best practices for contractors to become socially responsible? How can them recognise a social problem and take due actions? CSR has been examined in general from an economic perspective of increasing shareholder wealth, to economic, legal, ethical and discretionary strands of responsibility, and to good corporate citizenship (Jamali 2008). Nevertheless, many senior managers and marketers still struggle with the notion of CSR (Maignan *et al.*, 2005). This is true in the construction industry (Zhao *et al.* 2012). The crux of the problem stems from the meaning of the world “social” and how it links to daily construction activities (Wu *et al.* 2015).

Nowadays, construction business has unprecedented pressure of conducting sustainable practices to address social concerns and public expectations (Zeng *et al.* 2015). Win-win benefits from contributing to the improved environment and advanced society are supposed to achieve, and contractors can therefore gain competitive advantages and economic benefits (Hutchins and Sutherland 2008). However, a vast majority of them have lower enthusiasm of undertaking sustainable construction activities (Ye and Xiong 2011). In effect, they are puzzled by why they should do and what they ought to do (Jiang and Wong 2016).

Contractors may respond to societal expectations with reference to some international standards. For instance, *ISO 26000: Guidance on Social Responsibility*, which was developed by experts from over 75 countries and international organizations, offers guidelines for corporations to behave in an ethical and transparent way. The European Commission (2010) sponsored a project entitled *Building Responsible Competitiveness*, which formulates four main CSR areas that contractors are advised to follow, namely health and safety, eco-compatibility, supply, and equal opportunities. There are some other guidelines available to contractors, such as *Social Accountability 8000*, *Global Compact Initiative,* and *ECS 2000 Standard*.

A construction company in Wisconsin USA, Michels Corporation circulated a *2010 CSR Report*. This company allocated 5% of its annual operating budget to CSR activities associated with indigenous relations, health and safety, charitable giving and environmental concerns, trust building, transparency promotion, and other welfare that affects both employees and the public (Michels Corporation 2010). Hochtief (2015) and Vinci (2015), two of top 225 international contractors listed by Engineering News-Records, publicize CSR reports regularly to outline sustainable construction practices. Therefore, whereas having a CSR program is becoming popular in reality, contractors have not reached wide consensus with each other on the approaches to CSR fulfilment. Therefore, a pressing problem with CSR-C fulfilment is to make right decision and to do right things.

1.2.2. Improving SPCP through CSR-C practices

The construction process is composed of many technical and managerial procedures, wherein a wide span of activities emerge and have impacts on the environment and society. As presented above, the attainment of sustainability in the construction process is complicated than imaged. Contractors might encounter some opportunities of fulfilling CSR on construction sites. Trees could be planted outside the fence of construction sites to make local community have more green landscape. Contractors may provide employment opportunities to increase the wealth of local people and in turn receive supports from locals. Furthermore, CSR fulfilment at the project level facilitates contractors to motivate employers. A responsible contractor will equip frontline workers with more confidence and enables them to develop organizational belongings and to reach a higher level of productivity.

CSR strategies are determined by contractors in their own ways, but the outcomes of CSR fulfilment may not be realistic. One of the reasons is that operatizing a CSR program across organizational departments and project management teams calls for considerable unfailed efforts. As presented above, CSR is a part of sustainable construction. The interlocking between CSR and sustainable construction prevents contractors from acting properly in providing services to the client. SPCP improvement is reliant upon the perception that a contractor has on CSR, and how to settle organizational resources for those activities that cannot produce economic outputs. Therefore, it is vital that contractors should be able to elaborate the boundary of CSR on a construction site and synthesise it into the plan of construction management.

1.3 Research aims and objectives

1.3.1. A research gap

As discussed above, CSR and sustainable construction have been examined in isolation in previous studies. Nevertheless, the subject of sustainable construction is all-inclusive and CSR fulfilment could be interpreted under the heading of sustainable construction (Plessis 2005). In reality, approaches to CSR-C engagement are variable and contractors might develop their own one in accordance with their preferences. Although empirical studies have indicated that SPCP is impacted by CSR fulfilment, fewer efforts have been made to combine them effectively. The obscure relationship between CSR-C fulfilment and SPCP fails to support contractors to implement sustainable construction properly.

1.3.2. Research questions

It is important to raise research questions in a logical sequence by comparing the inherence and rationale behind the tenets of sustainable construction, CSR, competitive strategies, and competitiveness. By doing so, the knowledge gap presented above can be filled. Therefore, four research questions are raised below.

(a) Is CSR-C a determinant of SPCP? This research question is worthy of examination to lay a foundation on "yes or no", which should be a basic step of a scientific research. While the answers to this question might be predictable, other factors that determine the engagement of CSR-C and the practices of sustainable construction deserve careful interpretation as well.

(b) If no, what is the reason? If yes, how does CSR-C determine SPCP? This step serves to examine the mechanism that CSR-C fulfilment changes or improves SPCP values. Moderators and other variables would be adopted to outline the whole picture of CSR-C and sustainable construction process. Solutions to this research question can provide insights into contractors' engagement in CSR-C.

(c) To what extent is SPCP determined by CSR-C? Contractors prefer to know whether the level of SPCP will be improved if CSR-C is undertaken properly, and the extent to which SPCP should be resolved by examining the mechanism identified in the second step as presented above. The results could add more knowledge as assumptions over the association between SPCP and CSR-C are introduced.

(d) How can SPCP be improved by CSR-C fulfilment? This step is concerned with the implication of the research findings resulted from the above steps. Competitive strategies and construction schemes are recommended for contractors to undertake sustainable construction activities. The proposed approaches to SPCP improvement should be applicable to other regional construction contexts. Thereby, contractors can follow the shared principle of sustainable construction when they are transferring from one construction market to another.

1.3.3. Research aims

Evidences from the construction industry have given a hint on the impacts of CSR-C on SPCP (Section 1.2.2), and such kind of impacts has not been explored explicitly in previous studies (Section 1.3.1). In an effort to address the aforementioned research questions, this study is thus aimed to examine the effects of CSR-C on SPCP and to propose effective measures for application. By conducting a variety of research activities, the effects are revealed and the research findings can benefit contractors in the fulfilment of social responsibility.

1.3.4. Research objectives

The above research aims are developed with six specific objectives, awaiting for further exploration as presented below.

Objective I: To identify the attributes of both CSR-C and SPCP.

This research objective is to discern the notions of both CSR-C and SPCP with their counterparts in other contexts. The derived attributes help both academics and practitioners fortify a good perception and make due response to external claims.

Objective II: To examine the key areas of CSR-C activities.

CSR-C activities range distinctively between contractor firms and it is of much difficulty in identifying effective strategies shortly. In practice, different contractors may follow different styles in prioritizing those areas they need to pay attention to. Hence, it is very important for them to recognize any key areas of CSR-C activities.

Objective III: To formulate the indicators of SPCP.

Indicators facilitate the measurement of outcomes for a given thing or action scheme. The indicators of SPCP are identified in the study to provide an integral view on sustainable practices on construction sites. Basically, SPCP indicators are too broad and abstract to be followed at the project level. Therefore, the uniqueness of construction business and construction activities in a nation's construction industry are considered in the process of indicator formulation.

Objective IV: To model and validate the effects of CSR-C on SPCP.

The effects of CSR-C on SPCP reflect the mechanism that CRC fulfilment in the construction sector is conducive to the enhancement of sustainability improvement on construction sites. The effects of CSR-C on SPCP are presented using a few quantitative models built on mutual dependence between variables. Data from the industry are gathered to validate the proposed model. A validated model helps achieve the robustness of model development in the fourth step.

Objective V: To propose some approaches to improve SPCP through CSR-C activities.

Many contractors are keen to be taught on how to behave accordingly without spending much time on research and development. This step has the intention of guiding contractors to adopt construction management measures for the practices of sustainable construction. Strategies for this connection are the focus of this step.

1.4 Research significance

The construction industry is characterized by temporal character of construction sites, competitive bidding, high labour intensity and the lifetime of end products (Ofori 1990). With the emphasis on the relationship between CSR-C and SPCP, this research has twofold significance.

1.4.1. Significance to the body of knowledge

First, the research findings are oriented to extend the terminology of CSR to the area of construction business and contribute new knowledge to the discipline of sustainable construction. Prior research related to CSR-C mainly hinders upon the level of company, and a wide scope of issues such as CSR and corporate performance (Lu *et al.* 2016), CSR reporting (Barthorpe 2010), CSR and organizational governance (Wu *et al.* 2015), CSR and organizational competitiveness (Croker 2013), and CSR activities (Jiang and Wong 2016) are presented in the literature. Nevertheless, little attention has been paid to frontline production activities. Although many contractors are engaged in CSR on construction sites, they are unclear about what they are doing and how to motivate employees to improve productivity by virtue of CSR implementation. Findings of this study offer a deeper perception of "CSR in construction" and enrich the main body of knowledge by connecting CSR to sustainable construction. The extension should be valuable as it assists contractors in formulating, developing and implementing socially responsible business.

Second, the concept of CSR-C is presented in detail within the Chinese construction context. The term of CSR is a broad and abstract concept and it requires development in application to a specific context. China is one of the largest developing countries and many of its causes are experiencing transition (Ye *et al.* 2013, Zou *et al.* 2007). In particular, the construction sector in China has the largest size in terms of construction demand in the world (Ye *et al.* 2015), and market players in the Chinese construction industry is characterized by unique demand, expectation, requirements, and the game rule they adopt in determining competitive contractors (Shen and Song 1998). Therefore, examination on CSR-C in China should be placed on the uniqueness of construction business and construction practices, and practitioners' attitudes towards social responsible activities should be well interpreted. In view of this, new knowledge of CSR-C is derived. Furthermore, evidences from the Chinese construction industry are compiled for further debates in the discipline.

Third, the effects of CSR-C on SPCP explored in this study can improve the understandings of sustainable construction in academics. The influencing mechanism of CSR-C on SPCP shed lights on the subjects of both CSR and sustainable construction at the project level. Data gathered from the Chinese construction industry provide a useful reference to other developing countries in addressing same issues. In addition, the mechanism would be helpful for contractors to devise an effective approach in the formulation of competitive strategies in the construction market.

1.4.2. Significance to business development

With benefits of many kinds that large construction firms have reaped, more and more contractors are conscious of the usefulness of CSR to demonstrate organizational competitiveness in bidding for construction contracts (Lu *et al.* 2016). However, contractors' enthusiasm might be fading if their input into the implementation of CSR does not reward anything as expected. An integrated project delivery (IPD) is widely adopted by the client, which accounts for not only those conventional project goals highlighted by shareholders but also a diversity of interests of other stakeholders (Ngowi 1998). The theory and approach of both CSR-C and sustainable construction enable practitioners to own a proper understanding, communication and management of IPD-based projects.

The development of CSR along the construction process is supposed to explain the complexity of construction business. CSR is in essence an approach in which business endeavours to manage the interest of stakeholders including the client, contractors, suppliers, financers, local people, and governmental authority, which is usually not an easy thing to complete. Embracing socially responsible values and concerns of stakeholders into their operation underscores contractors to fulfil and exceed current legal and commercial expectations in the sphere of construction activities.

The research findings offer a few ways for contractors to improve the fulfilment of CSR and sustainable construction practices. Nowadays, contractors still have long ways to go from a right perception of either CSR-C or SPCP to “make right decision” and further to “take right action”. Part of efforts in this study are devoted to the determination of competitive strategies which address the role of CSR in the framework of sustainable construction. The research findings stress the merits and implementation of CSR-C favours contractors to gain positive feedbacks from stakeholders. In addition, by highlighting CSR-C in the discipline of sustainable construction, contractors would know better how to perform effectively on a construction site.

China’s construction industry has become more influential than before in the international arena. According to the Global Construction 2020 report (Global Construction Perspectives and Oxford Economics 2011), China had the world’s largest construction market in 2010, and the industrial size is projected to have a double expansion to a value of US$ 2.5 trillion by 2020. On the other hand, construction business competition in China has been intensifying to an unprecedentedly high level (Zhao *et al.* 2011). To stay competitive means to have more competence in reacting to clients' concern over construction project targets (e.g., schedule, cost and quality) and to be able to align with contractors in maintaining a good social image.

1.5 Methodology

Research methodology in nature describes a series of logical steps adopted to answer predefined research questions (Fellows and Liu 2008). In line with the research aims, the so-called four research questions and the five research objectives presented above, a set of research activities are determined.

1.5.1. Research activities

Objective I: To identify the attributes of both CSR-C and SPCP.

This is a basic step as it offers comprehensive views on the subject concerned. The attributes of CSR-C and SPCP are discussed using the approaches of literature review, case study and interview. The reasons for this are that more and more large construction enterprises have released their CSR annual reports with the headings of either CSR or sustainability (White 2009). Moreover, a large number of international construction firms publishing CSR reports in a regular fashion are targeted and analysed to discern the difference of practices they are executing (Lu *et al.* 2016).

Since case study might not be able to present the latest development or trends in the construction industry, interviews with professionals are appreciated essential to complement the outcomes resulted from the aforementioned case study. For the convenience of interview and data collection, five senior professions in Shenzhen city to be described in Chapter 4 are invited to answer questions as listed below and seven senior researchers in China's universities approached via Email are requested to answer the questions as well.

The questions for interview contain:

(a) What are your understandings on CSR in the construction industry?

(b) Do you think CSR can change SPCP? Please justify.

(c) In what ways can contractors formulate competitive strategies to handle the relationships between CSR-C and sustainable construction at the project level?

Objective II: To examine the key areas of CSR-C behaviours.

This research objective specifies those CSR areas that contractors in China has the necessity of paying attention to. In practice, CSR is usually included in many annual reports of contractors, and part of socially responsible activities are publicized on enterprise websites. In view of data availability, large construction firms in China are targeted. Since these data might be out-of-date, interviews with senior professionals are conducted. The profiles of interviewees are described in Chapter 4 and the questions for interview are as follows.

(d) What are the characteristics of CSR activities that China's contractors are performing?

In order to determine key areas of CSR-C activities, a round of questionnaire survey is conducted to collect practitioners' opinions. The collected opinions are used to extract those activities that contractors should emphasise.

Objective III: To formulate the indicators of SPCP.

The topic of sustainable construction has been researched for decades, leading to many publications about the indicators of sustainable construction for practitioners and academicians to measure (Sahely *et al.,* 2005). The richness in relevant indicators in the literature enables to develop a preliminary list of SPCP indicators. Therefore, Delphi-type survey is adopted to rank the identified indicators, or other indicators are revised in line with the characteristics of construction business in China.

Objective IV: To model the effects of CSR-C on SPCP.

This research objective is realized using a few qualitative and quantitative research methods. The qualitative methods are intended to identify in what form the effects should be, while the quantitative methods aim to uncover how CSR-C activities determine the level of SPCP. Data collected in this step are used to model the effects and a system dynamics approach is adopted therein. In this step, case study is the key to achieving the research objective. Since the approach of case study encompasses a few logical procedures which are fixed with other research methods, interview and field survey are found necessary at the same time.

Objective V: To validate the proposed model.

The proposed model is validated using a large transportation infrastructure project in western China. Literature review is conducted first to gather research findings to demonstrate in part or in whole the relationships between variables of the proposed model. Furthermore, interview with professionals is performed to evaluate whether the proposed model has some efficiency and whether they are applicable to the construction industry nationwide.

Objective VI: To propose SPCP based CSR-C activities.

This step is an application of the outcomes of the aforementioned steps. It is expected that the research findings should be of usefulness to the construction community, and strategies for the fulfilment of CSR-C are finalized. Research activities for this objective include literature review, case study and simulation. First, literature is reviewed to identify key CSR-C activities for simulation. Second, the analysed case is adopted to find out how the contractor's CSR-C activities can change the level of SPCP through simulation. Third, senior managers from the company are invited to give a brainstorming on the way to derive strategies.

1.5.2. Main research methods

The main research methods applied in the study comprise literature review, content analysis, quantitative analysis, interview, and questionnaire survey. Details of these methods are described individually as follows.

Literature review

Research activities in the study are commenced and proceed with literature review from start to finish. Publications related to both CSR and sustainable construction are at the hub of the literature review. Research works revolve around previous relevant research works for three purposes, namely (a) to apply previous research findings as supports; (b) to apply research methodology developed in previous studies; and (c) to utilize the results of literature review as a foundation for theory development. Hence, literature review provides insights into (a) the concepts of both CSR-C and sustainable construction process, (b) the identification of CSR-C activities, (c) SPCP indicators, (d) the relationships between (b) and (c), and (e) CSR strategies for contractors to consider potentially.

Content analysis

The subjects of both CSR and sustainable construction have been researched for long time. The long evolution of research has given rise to numerous publications of technical journal papers and official reports, enabling the application of content analysis in the current study. The rationale for the application of this method is that it favours identifying the significant items that have been acknowledged in previous studies or considered by professionals.

Content analysis, additionally called document analysis, details a systematic examination of records or documents as data sources (Dahlsrud 2008). Analysis using historical data and statistical evidences can supplement the research analysis on the information obtained by other methods such as interview and questionnaire survey (Duffy 1999). In this study, official records and reports, printed forms, published CSR reports and reference books are the materials for content analysis. Content analysis adopted in the study is to recognize key areas of CSR-C activities and SPCP indicators.

Quantitative analysis

Quantitative analysis aims for precise measurement of something and it is used to determine the actuality of events that have occurred or do occur (Cooper & Schindler, 2006). This method can be used to find out "what happened, or how often things happened" (Cooper and Schindler, 2006). In the present study, quantitative analysis is adopted to examine the relationships between CSR-C activities and SPCP using mathematical techniques or statistical models. This method is employed in the present study in line with the theory of system dynamics with respect to the measurement and evaluation of both CSR-C and SPCP.

Interview

The approach of interview is a qualitative approach for defining and resolving research questions (Freire and Alarcón 2002). This method is a bridge connecting theoretical deduction to empirical study, and it carries out the conversation between researchers and respondents in which questions are prepared for obtaining information from interviewees. Face-to-face interview, telephone interview, and directive interview are adopted in the study to obtain practitioners' perceptions.

Interviewees invited should be knowledgeable in the practice of sustainable construction. They are chosen based on work experiences in both CSR and sustainable construction. Interviews with contractors and scholars serve to compare with general managers' views. Each interview lasts about one hour with focal discussion on three questions mentioned above. Notes are taken on site and edited/summarized afterwards, and then sent to interviewees for confirmation. The confirmed notes are compiled into interview minutes, which are deemed as part of evidences to support research activity of content analysis.

Questionnaire survey

Results of literature review, content analysis, and interview as described above produce two sets of indicators to favour the identification of CSR activities and SPCP. To detect the potential relationships between these two indicators sets, a postal questionnaire probably entitled *From CSR to Sustainable Construction Process: A Survey on Professionals* is performed in the Chinese construction sector.

The questionnaire used contains four sections under the headings of introduction, personal information, CSR activities, and SPCP indicators. It consists of a number of closed questions requesting respondents to indicate the significance degree using a five-level Likert scale (1 – extremely unimportant, 2 - unimportant, 3 - neutral, 4 - Important, 5 - Extremely important). To ensure the suitability and readability of the questionnaire, academic supervisors and two professionals are invited to proofread and make comments on the questionnaire. Comments are received and well considered in the revision of the questionnaire. The scales are devised and surveyed in Chinese language, but they are translated into English with the assistance of two construction professionals who are fluent in both Chinese and English for thesis writing. In addition, the translation is emailed to one reviewer who did not see the original Chinese text to ensure an acceptable level of face validity.

1.6 Chapter organization

This thesis consists of nine chapters. Chapter 1 gives a brief introduction to the study. Research background, aim and objectives, methodology and main research activities are described herein.

Chapter 2 presents literature review in accordance with the research aims. The emphasis is placed on the theory of sustainable construction, definitions of the construction process, the theory of CSR, and the attributes of CSR-C. The relationship between CSR-C and the construction process is lastly but not least discussed. This step lays a solid foundation for model development in subsequent research activities.

Chapter 3 describes the background of China's construction industry. A historical review on the Chinese construction sector is presented with the purpose of identifying its characteristics. The characteristics about the Chinese construction industry shed some lights on the identification of CSR-C and CSR fulfilment in China.

Chapter 4 presents an examination on key areas of CSR activities. A couple of research methods are applied including content analysis, interview, and questionnaire survey. The results show six key areas of CSR activities that China's construction contractors often conduct.

Chapter 5 elaborates the formulation of SPCP indicators by virtue of literature review and Delphi-type survey. The construction process is discussed with respect to its definitions and impacts on socioeconomic development. Approaches to formulating indicators for measuring SPCP are compared and determined for the study. The identified SPCP indicators have three dimensions (i.e., economic, environmental and social), but they are restructured in line with an "input-activity-output" framework to match the principle of system dynamics.

Chapter 6 addresses the motivation of system dynamics (SD) to model the effects of CSR-C activities on SPCP. An overview of SD, causal loop diagrams, and stock and flow diagrams are described in this chapter. The application of SD in the construction sector particularly for the issues of construction management and economics is discussed herein.

Chapter 7 describes the procedure of model development in the study. The overall structure of the model is composed of three parts, namely construction inputs performance (CIP), construction activities performance (CAP), and construction outputs performance (COP). The whole SD model consists of three subsystems: CIP, CAP, and COP. The model is proposed in adherence to the principle of system dynamics.

Chapter 8 presents a case study for validating the proposed model. A large transportation infrastructure project in western China is adopted and data are collected. The focus of this case study is in part on the quantification of data and equations development for the computation of the proposed model. Results of the case study are used to test the applicability of the proposed model. A couple of sceneries are simulated to detect how SPCP can be changed by CSR-C activities.

Chapter 9 gives a conclusion to the study. Major research findings are summarized. The research contributions, limitation and recommendation for future studies are presented as well.

Chapter 2. LITERATURE REVIEW

2.1 Introduction

CSR is a broadly concerned concept with a long history of development. The publication by Howard Bowen (1953) entitled *Social Responsibility of Businessman* opened a new era of literature on CSR (Carroll 1999). Since that, the concept of CSR has been evolving, as driven by social concern over environmental stewardship and ecological crises in the globe, closer ontological debates on what business runs for, and the proliferation of CSR research (McWilliams and Siegel 2001, Hopkins 2003, Morimoto *et al.* 2005). The ongoing studies on CSR image academicians' enlarging interest in CSR that has centred not only on "whether CSR is an imperative", but also on "how to make it effective" (Smith 2003).

The construction industry plays a vital role in the attainment of sustainable development (Huang and Lien 2012). Construction activities have multidimensional influences on the physical environment and wider communities (Edmonds 1979, Harvey and Ashworth 1993). This necessitates embracing CSR in the domain of sustainable construction (Myers 2004). While CSR engagement in construction has obtained closer attention over the past decades, contractors are often criticized for their unsatisfactory performance on this matter (Murray and Dainty 2009). It is largely because they have little knowledge of how to implement CSR effectively, and academicians have not provided strong supports at the same time (Barthorpe 2010). In this chapter, the concepts of CSR and sustainable construction are reviewed with an aim of giving a definition to “CSR in construction” (CSR-C) and exploring the inherent relationships between CSR-C and sustainable construction process. In effect, discussion over these relevant concepts is indispensable to model development in the study.

2.2 Concepts of the construction process

The importance of adhering to the principle of sustainability along the construction process is surfacing (Said *et al.,* 2010). A construction project consumes a wide range of resources including fossil fuels, soil, minerals, land, water, plants and equipment. For instance, according to Sjöström and Bakens (1999), 54% of the energy consumed in the USA is related to buildings and construction activities. Although the term *construction process* is often cited in the literature, fewer efforts have been made to give a rigorous definition (Arditi and Gunaydin 1997). Hence, the abstractness of this term has not been rectified significantly. It is vital for this study to present a concept of *construction process* at the very beginning to underscore the identification of CSR-C activities and SPCP indicators.

2.2.1. Two views on the construction process: lifecycle or activity-based

The construction process can be elaborated in two ways. One refers to the whole lifespan of a construction project, and the other specifies onsite construction activities. The former expresses a lifecycle view of construction process, while the latter spells out an activity-based view.

A lifecycle view

As shown in Figure 2.1, the construction process is made up of a few phases that are dominated by actors (e.g., owner, architect/engineer, and constructor): inception (requirements of owner), design (schematic and detailed), compilation of construction documents (plan and specification), construction, and delivery of construction projects. These phases point to three categories of activities: planning and design, construction, and maintenance/operation. Technically, the construction process can be divided into a number of input-process-output procedures managed with the focus on the relationships between actors and the phases of construction. It requires construction project managers to play a predominant role in handling various concerns in a stakeholder management process within limits of the project (Olander and Landin 2008).

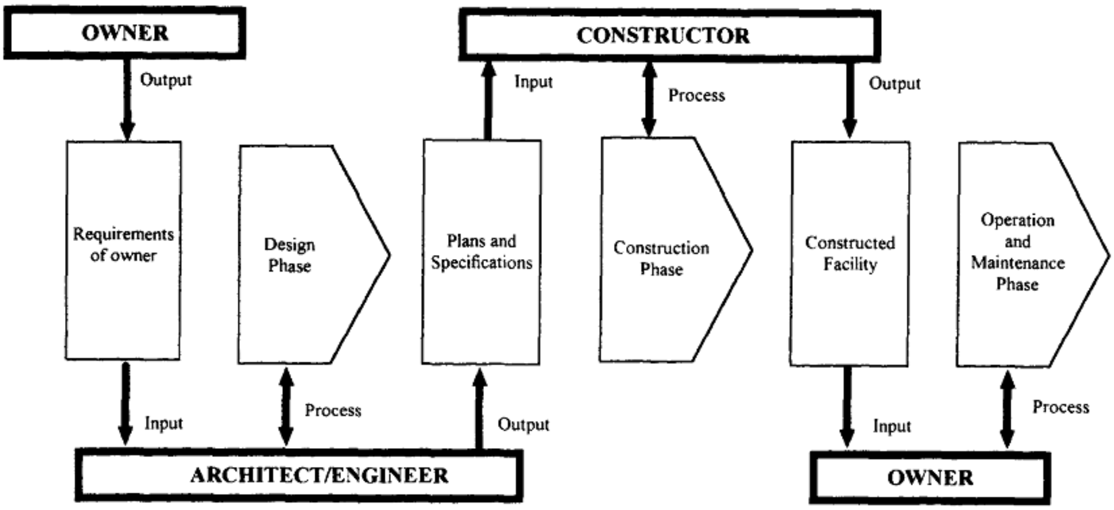


Figure 2.1 Actors and phases of the construction process

(Source: Arditi and Gunaydin 1997)

Previous studies have pointed out that an increase in resource efficiency in all stages of the construction process contributes to the sustainability performance of the construction sector (Taylor 2010). In essence, behind the construction process is an economic logic reflecting the manner in which tasks, parts, and units are organized. In considering a variety of participants and production elements, the construction process can be defined to include not only physical construction activities on the site, but also raw material acquisition, manufacturing and transportation beyond the construction site. The former perception is called a narrow definition, while the latter one is a broader definition. Along this strand of thoughts, managing the construction process in a lifecycle view refers to a development from the narrow definition. While indicators for SPCP measurement may be formulated in line with this understanding, data collection for indicator quantification are usually unapproachable. It is therefore considered to explore the narrow definition of the construction process, which is also cited to be an activity-based view.

An activity-based view

Researchers have pointed out that wastes arise at any stage of the construction process spanning from inception, right through design, construction to operation of the built facility (Teo and Loosemore 2001). The narrow definition of the construction process presented above condenses two phases of construction activities, namely pre-construction and construction execution. In the pre-construction stage, subcontractors are recruited, construction materials and equipment are procured, and construction methods are devised. In the construction execution period, physical activities are carried out in accordance with design specifications, which involve utilization of all types of resources. Meanwhile, managerial expertise, labours, materials, equipment and tools are blended and assembled.

A construction project has some unique natures of construction work, unpredictability of production environment, fragmented nature of project organizations, intense cost, and time pressures (Teo and Loosemore 2001). An activity-based view of the construction process encompasses all of the construction phases shown in Figure 2.1. This phase includes all materials and energy used for onsite activities such as the use of electricity, heat, water and equipment, and transportation of building materials to the site, temporary use of materials, and waste management. Therefore, the construction process transforms all the flows (e.g., materials, labour and equipment) into completed or partially completed products as shown in Figure 2.2.

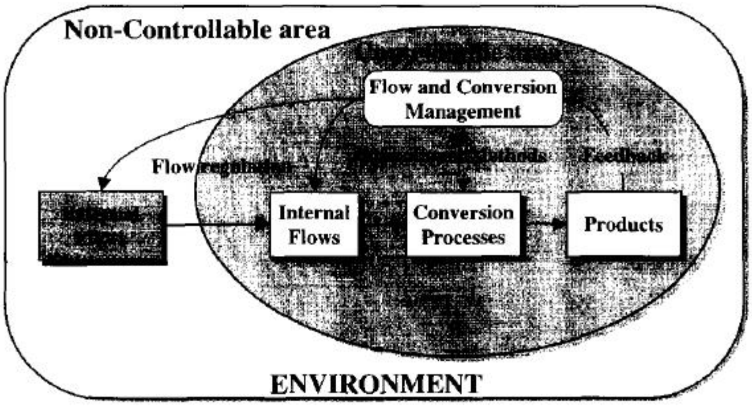


Figure 2.2 A model of the construction process

(Source: Serpell and Alarcon 1998)

The construction process functions like an inflow of production factors (e.g., products, semi-products, labour, materials, and equipment). Once a project is kicked off, the construction project manager will be assigned and a team be formed to conduct construction activities until successful delivery of the built facility. Participants involved in this activity-based construction process are many stakeholders (e.g., the client, main contractor, quantity surveyor, consultants, subcontractors and workforce). The client is the major force steering the construction process. Other stakeholders play as the client's link between business development and facility planning, and oversee the construction process. Traditionally, contractors' work is concerned with foundation, framing, roofing, installation of components, siding, mechanicals (plumbing, electrical, heating, ventilation and air conditioning), insulation, drywall, painting, and interior trim.

Contractors are the main body in managing construction activities, and they are advocated to participate in the construction process as early as possible (Gruneberg and Ive 2000).

2.2.2. Attributes of the construction process

The construction process mirrors a scope of construction activities that start from the client's intention to build something and end with the delivery of a built facility. Therefore, it is shaped in the client's consideration, attitudes and judgment on investment opportunities. The construction process is of complexity as directed to produce a built facility and by doing so the client reaps new development. As presented above, the client plays a predominant role in determining the scope of construction works, time for delivery, and budget of construction expenses (Eriksson 2010). With the possession of construction knowledge, clients of some kinds prefer to undertake part of construction works and leaving the remainder to trade contractors. This happens frequently when the client finds it beneficial to realize project objectives in this way (Eriksson 2010).

The construction process is in nature one-off, dynamic, iterative, and interactive. This attribute is rendered by the interaction of stakeholders no matter who they are. The larger the magnitude of stakeholders, the more complicated the construction project will be. The approaches to which the construction process is operated without compromising the interests of stakeholders could be a work of art. Definitely, different stakeholders express different needs, requirement or expectation across the construction process. Construction project managers under the supports of the client have to satisfy external needs at no extra cost on the principal project goals. The complexity of the construction process would be aggregated if the process takes longer time than usual. For instance, successful development of a mega infrastructure project can be accomplished if only technical challenges are overcome and its construction process has good interaction with the surrounding environment (Ugwu and Haupt 2007).

The construction process is closely enveloped by special environments such as the natural environment, local community, and local infrastructure systems. Once a construction project is commenced, the impacts of construction activities on the environment will last for some periods of time. The sustainability of a completed project depends on whether its construction process is tolerated and accepted by local people. For instance, local transportation system shall be interrupted if the construction process occupies considerable roads. A responsible contractor is to manage the construction process efficiently and make contributions to local community in the meanwhile. In reverse, the support of local community aids contractors in organizing construction activities fluently on construction sites. Therefore, the interlinkage of a construction site to local community ought to be a key factor determining successful delivery of the construction project, providing the rationale for elaborating the effects of CSR on SPCP in this study.

2.2.3. Layers of the construction process

The previous section presents the importance of interaction between the construction process and the surrounding environment. The interaction appears to be multidimensional, depending on which level the definition of construction is based. According to du Plessis (2007), *construction* on a site refers to site activities that lead to the realisation of buildings or infrastructures (e.g., road, bridge or dam). *Construction* at the project level requires activities at each stage to be conducted on a roll. This level specifies the project cycle, of which the key activity comprises feasibility, design, building/construction, operation, decommissioning, demolition and disposal. As a principal economic sector, the construction industry has the responsibility for driving the growth of socio-economy and creation of jobs. Hence, *construction* at the industry level calls for lessening its impacts on society and the environment and its influence on the planet. The fourth level of *construction* is concerned with the broader sense of creating human settlements, of which the process contains planning, design, and implementation.

All of these four levels of construction belong to "the construction process" and they have been examined to a certain degree in previous studies. For instance, the first level is addressed in the work by Tan *et al.* (2011), which reveals that a growing number of clients have found it essential to require contractors, suppliers and business consultants to adopt sustainable policies in the construction process. Basing on the second level, Shen *et al.* (2007) proposed a framework of sustainability performance checklist to assess those factors affecting project sustainability performance across its life cycle. In addition, there exist toolkits for practitioners to implement sustainability initiatives, ranging from benchmarking to build a business case, creating a management framework as well as consideration of issues such as stakeholder engagement, sustainability measuring and reporting guidelines (Paramanathan *et al.* 2004). The UK Government's strategy for more sustainable construction elaborates ten key factors for action by widening these basic objectives (DETR 2000). The major actions include design for minimum waste; applying lean construction principles; minimising energy in construction and use; pollution reduction; preservation and enhancement of biodiversity; conservation of water resources; respect for people and local environment; and setting targets, monitoring and reporting (Addis and Talbot 2001, Cole and Lorch 2004).

2.3 Impacts of construction activities

The impacts of the construction process on society and the environment are by means of construction activities. Economic constraints, environmental degradation, and social disturbances are part of the negative impacts. Well management of these impacts can hopefully result in the betterment of quality of life for present and future generations. In this section, the impacts of the construction process are discussed from three perspectives: environmental, social, and economic.

2.3.1. Environmental impacts

The construction sector has been appreciated to be one of the principal environmental pollutants in the world. For instance, 40% of all wastes in the UK are produced in the construction industry (RICS, 2005). Such large amount of environmental pollution is attributable to construction activities. Construction activities roughly account for 40% of materials flow entering the world economy, with much of the rest destined for roads, bridges and vehicles to connect the buildings (Roodman and Lenssen 1994). Through a literature survey, Dixon (2010) restated that global pollution traceable from buildings includes air pollution (23%), climate change gases (50%), drinking water pollution (40%), landfill waste (50%), and ozone depletion (50%). As estimated by Hawken *et al.* (1999), 80% of the land lost to agriculture, 60% of timber products, and 90% of hardwoods are directly associated with the construction process; 50% of coral reefs destruction and 25% of rain forest destruction are for the reason of buildings and construction.

The environmental effects of construction activities mentioned above permeate through the construction process. As shown in Table 2.1, these effects typically encompass energy consumption, dust and gas emission, noise pollution, waste generation, water discharge, misuse of water resources, land misuse, and consumption of non-renewable natural resources. Currently, most of construction projects are heavily reliant on traditional building materials. The environmental impacts and health threats presented by activities on building sites, especially regarding the loss of topsoil and vegetation, as well as dust and noise pollution and the storage of harmful chemicals (Bon and Hutchinson 2000).

Table 2.1 Environmental impacts of construction activities

Environmental impacts	Description	Potential impacts		
		Air	Water	Soils and land cover
Extracting raw materials	Sand and gravel	Particulate emission	Water courses near quarries are altered	Landscape degradation
Manufacturing building materials	Cement production	Particulate emission CO, Sox and NOx	-	Deposition of dust
Constructing buildings	Transporting materials	NOx and CO_2 emission	-	Taking up new areas of land
	Building sites	Noise, particulate emission	-	-
Using buildings	Energy consumption	CO_2 emission	-	-
	Water consumption	-	Wastewater discharges containing detergents and organic matter	-
	Wear and tear of materials	Asbestos fibres, indoor radon emission	-	-
Demolishing buildings		Noise, particulate emission	-	Demolitions waste to be land filled or reused for sea reclamation

(Source: Majdalani *et al.* 2006)

In accordance with the negative impacts of construction activities on the environment, a holistic and sustainable approach is required to put into practices, such as approaches to integrating planning, design and implementation processes, tools to encourage a synergistic and more ecologically responsible approaches for project delivery. It seems to be that the environmental impacts of the construction process are concerned with four basic natural resources - land, energy, water, and materials (BCA 2005, Chang *et al.* 2016). Therefore, the relationship between construction activities and the environment is multi-dimensional, and more effective methods should be adopted to address such type of impacts and contractors have to implement green construction practices as far as possible (Lu *et al.* 2013)

2.3.2. Social impacts

In many developing countries, development in the built environment has undergone considerable changes, but the physical infrastructure is conspicuously of shortage (Dobers and Halme 2009, Plessis 2007). The operation of poorly maintained built facilities is often appreciated to be a social problem (du Plessis 2002). In particular, major challenges go to the supply of proper housing and necessary infrastructure for transport, communication, waste supply and sanitation, energy, and commercial and industrial activities to meet the needs of growing population. It is assumed that the quality of human life is enhanced by securing sufficient consumption of basic needs. Furthermore, the depletion of natural resources as well as the degradation of environment trigger an increase in public scrutiny on production.

The performance, quality and design of buildings and access to services and recreation undoubtedly affect the quality of life, urban living, and society cohesiveness (Frattari *et al.* 2012). As advised by many researchers, construction activities in developing countries should not follow those paradigms that developed countries have implemented, instead the ways they select must be socially responsible (Ofori 2001). However, the so-called social aspect has been the “weakest pillar of sustainable development” due to the lack of analytical and theoretical underpinning (Croker 2013). The construction process can lead to the disturbance of culture, and thus social self-determination and cultural diversity must be gauged earlier.

Construction is a labour-intensive business and skills training is indispensable to the success of construction project management (Ofori 1990). The construction industry has a poor safety record (Rajendran 2006). Impacts of construction activities on the surrounding society include traffic congestion and delay, disruption of economic activities, excessive generation of pollution and pollutants, damage to sensitive ecosystems, and damage to existing structures and infrastructure systems (Wottrich and Sastararuji 2008). Construction workers have higher possibility of being exposed to pollutants (particulates), noise and air emission (Hendrickson and Horvath 2000). Nearby residents are subject to noise, lighting and air pollution. Therefore, it is very important that a well-organized construction process is able to provide a healthy and safe working platform to protect human health for both construction participants and local communities.

2.3.3. Economic impacts

As pointed out in previous studies, one-tenth of the global economy is dedicated to constructing, operating and equipping homes and offices (du Plessis 2002). A construction project is driven by the demand of the client who identifies some investment opportunities or recognizes the importance of building some facilities to satisfy commercial needs. As a construction project is a good in which various stakeholders utilize the effects of the project on economic development and social needs, the economic aspect of construction activities may embrace financial outcome, investment return, and competitiveness enhancement (Ofori 1994). Arguably, the clients' investment for commercial consideration that ignites the development of a construction project.

For a long time, economic aspects of a construction project have attracted closer attention and contractors' competitiveness is strongly linked to their capability of maximizing profits (Lu *et al.* 2008). In recent years, however, such a business paradigm is gradually criticized due to its less emphasis on environmental impacts of construction activities.

2.4 Attributes of sustainable construction

2.4.1. Theories of sustainable development

A retrospect on the evolution of sustainable development

Sustainable construction is an application of sustainable development in the construction context. Basically, the concept of sustainable development can be traced from the interconnectedness of culture, economy and the environment, which was a snapshot of rapid economic growth after the Second World War (Plessis 2007). Many countries in the 1950s were confronted with the dark side of enormous economic growth (e.g., air pollution, depletion of groundwater, waste of resources, and environmental degradation). Such changes had brought the planet into worsening situations and many countries had to work together to explore solutions in order to improve the quality of development. In 1972, the United Nations Conference on the Human Environment held in Stockholm delineated the rights of human society to a healthy and productive environment. Since that year, *The Limits to Growth* has become popular, which presents the interactions between the Earth's and human settlement with respect to pollution, industrialization, resource depletion, food production, and world population.

In 1980, *the World Conservation Strategy* published by the International Union for the Conservation of Natural Resources asserted that the conservation of nature cannot be achieved without any efforts to alleviate poverty and misery of people. In 1983, the World Commission on Environment and Development (WCED) formulated *A Global Agenda for Change*. In 1987, WCED publicized a report entitled *Our Common Future*, which is additionally named after the Brundtland report. Whilst this report advances the perception of global interdependence on the links between economy and the environment, it acknowledges the complexity of sustainable development that various countries have to explore. As defined in the report, sustainable development means “development which meets the needs of the present without compromising the ability of future generations to meet their own needs”. This definition has been extensively cited in the literature, presenting a basic concept for relevant studies to embrace sustainability in various industrial contexts.

In 1992, the concept of sustainable development obtained further attention at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro. The Conference outlined some global targets for sustainable pattern of consumption and production under the heading of *Agenda 21*. Agenda 21 is exactly a program of action for the environment and development in the 21st century, and it reaffirmed that sustainable development is delimited by the integration of the economic, social and environmental pillars. These decades have witnessed a momentum for rethinking the meaning of sustainable development and its application across sectors. For instance, in 1993, UNCED instituted the Commission on Sustainable Development (CSD) to follow-up on the implementation of Agenda 21. In 1997, the General Assembly dedicated its 19th Special Session to design a “Programme for the Further Implementation of Agenda 21”. In 2002, the World Summit on Sustainable Development (WSSD) convened in Johannesburg to rethink the global commitment to sustainable development. The conference concurred with the Johannesburg Plan of Implementation to put forwards the implementation of sustainable development.

Triple bottom lines of sustainable development

The key to sustainable development is to achieve the balance between the development of economy, societal progress and environmental protection (Lutzkendorf and Lorenz 2005). Previous studies have shown that these three dimensions are equal and the environment can be the dominant dimension setting preconditions for the other two dimensions (Rydin, 2003). There has been a growing recognition of three essentials of sustainable development as indicated in Figure 2.3, which are called triple bottom lines (TBL) of sustainable development.

TBL of sustainable development outlines the interlinking of profit, people, and planet; it has been used widely to measure social, environmental and economic performance of development initiatives. Whilst TBL dimensions have attracted much attention from academics, efforts put to examine the intrinsic relationships between dimensions of TBL are not too many. Some unexpected controversies over the interface between TBL dimensions can thus be appreciated. For instance, CSR belongs to the area of social TBL, while many evidences have shown that the fulfilment of CSR can improve both social performance of TBL and the overall performance of sustainability (Croker 2013). Therefore, an exact definition to the boundary of the research and examining the relationships between CSR fulfilment and sustainable construction in this study can be an effort to broaden the knowledge of sustainable development from a TBL perspective.

Figure 2.3 Triple bottom lines of sustainable development

Sustainability and sustainable development

To address the research questions presented in Section 1.3.2, it is of importance to differentiate the connection between sustainability and sustainable development. The term *sustainability* appears in the literature in parallel to the evolution of sustainable development (du Plessis 2002). While these two concepts are interweaving, they are distinguishable to some extent. As discussed above, the core of sustainable development is to strike the trade-off between socio-economic aspirations and the environmental limits to growth. By definition, sustainability means the continuity of socio-economic aspects of human society in addition to the environmental aspect (Rajendran 2006). Bourdeau (1999) pinpointed that sustainability is representative of minimizing environmental impacts, maximizing economic benefits, and minimizing social impacts.

To summarize, as far as sustainability is concerned, it refers to the intrinsic capacity of something to keep going indefinitely, while sustainable development is simply a means of attaining sustainability (Parkin 2000). Therefore, sustainable construction is instrumental to achieve sustainability in the built environment. In this sense, the effects of CSR fulfilment should be on SPCP rather than sustainable construction.

2.4.2. Definitions of sustainable construction

The nature of both sustainable development and sustainability calls for proactive responses to the challenges of energy efficiency and resource crisis in the construction context (Manoliadis *et al.* 2006). To address sustainability issues in construction, the terminology of “sustainable construction” is defined to stimulate the application of sustainable development in the sector (Irurah 2000). Basically, sustainable construction is intended to mitigate the adverse impacts of built environment over its entire lifespan, to provide safety and comfort to its occupants, and to enhance economic viability in the meantime (Plessis 2007). It has become an issue, a discipline, and one of the key vehicles for the successful delivery of construction projects (Schultmann 2006).

The theme of sustainable construction has been debated heatedly in previous studies, of which a managerial perspective for project procurement (Fernandez-Sanchez and Rodriguez-Lopez 2010), the collaboration between public and private sectors to promote innovation (Bossink 2002), the establishment of body of knowledge for improving sustainability performance (Plessis 2007) are appreciated. Nevertheless, it is often stressed in the discipline of sustainable construction that the improvement of construction activities may be accomplished by adhering to the principle of sustainable development (Pitt *et al.* 2009). The basic ideas of sustainable construction in the opinion of Huovila and Richter (1997) delineate the efforts devoted to minimizing both the use of energy and emission harmful for environment and health in the lifespan of built facilities.

Lanting (1998) pointed out that the operation of a built facility (e.g., residential building) without generating negative health and environmental impacts is an outcome of the practice of sustainable construction. To actualize this objective, close cooperation between developers, investors, professional services, suppliers and other relevant parties towards sustainability is necessitated in addressing environmental, socio-economic and cultural concerns. For instance, they should be able to work together to inhibit waste emission, avoid accidents on sites, minimize energy and resources consumption, control pollution incidents, implement green procurement, adopt prefabrication, follow ISO 14001, and create a far more ethical and sustainability profile (Myers 2005). As a consequence, a holistic approach to sustainable construction favours various participants to work as a team in order to restore and maintain harmony between the natural and the built environment, and to create settlements that affirm human dignity and encourage economic equity (du Plessis 2002).

2.4.3. Drivers of sustainable construction

Previous studies have disclosed that only a limited magnitude of large construction firms are actively involved in sustainable construction practices, while a majority of SMEs are not (Myers 2005). This implies that drivers and obstacles coincide in the implementation of sustainable construction. Whilst the causal relationships between CSR and SPCP to be revealed in this study can hopefully underscore contractors to attain sustainability, they are subject to drivers and obstacles in the same sense.

According to Shen *et al.* (2010), the commitment of efforts from contractors to undertake green construction innovation is motivated by the influence exerted from regulations, stakeholder demands, managerial environmental concerns, and firm size. Shen *et al.* (2010) demonstrated that managerial concerns are the most significant driver for green practices; the relationships between government environmental relationships and firm size within the sphere of green innovation are significant. However, there lack powerful evidences to demonstrate the association of adopting green construction practices with stakeholders' pressures (Lu *et al.* 2013).

Du Plessis (2007) presented three types of drivers of sustainable construction (Figure 2.4): value system enablers, institutional enablers, and technological enablers. It is well recognized that construction activities should be managed from cradle to grave to ascertain that all of the construction processes are stretched in a sustainable fashion. To do so, sustainable construction must be driven by an increase in profitability by using resources more efficiently, opportunities by providing sustainable products, and the improvement of company image and profile by addressing CSR (Abidin and Pasquire 2007). Another driver for sustainable construction is new methods of procurement such as public-private partnership, private finance initiative, and design and build (Manoliadis *et al.* 2006). Increased competitiveness through labels such as "Green Firm" is also a major driver towards sustainable construction (Lu *et al.* 2013). In the meanwhile, some other studies have appreciated the driver of governments in the form of regulations and legislation. The drivers in the view of Zhang *et al.* (2013) are twofold: the rapid advancement of science and technologies, and people's perception of project sustainability. For example, the client can guide practitioners to conduct sustainable construction by virtue of new sustainable tools and techniques.

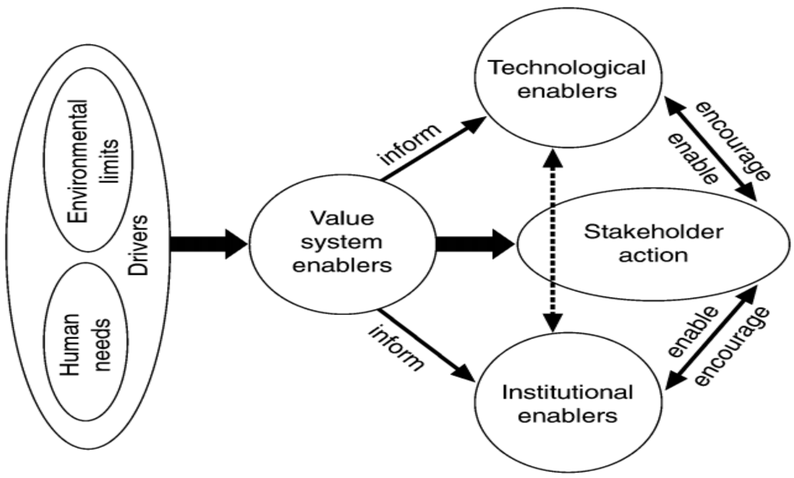


Figure 2.4 A strategy for enabling sustainable construction

(Source: Plessis 2007)

Researchers have offered the drivers for the implementation of sustainable construction as listed in Table 2.2.

The barriers given in Table 2.2 image a multi-dimensional concept of "sustainability in construction" as it spans over a wide range of construction duties. It is very important that the extent to which various objectives are recognized to satisfy stakeholders' need. Therefore, sustainability in construction must be viewed in a lifecycle angle and thereby the principles of sustainable construction are adhered strictly. Moreover, the construction process is to exercise prudence to deal with uncertainty, unpredictability and risk (Goodland 1995). Managing construction activities through targets developing, monitoring, evaluation, feedback, and self-regulation of progress in a process that is iterative and adaptive in nature (Gardner 1989). Hence, a systems approach is supposed to elaborate the interconnections between economics, local communities and the environment.

Table 2.2 Drivers of change of sustainable construction

1	Energy conservation
2	Waste reduction
3	Indoor environmental quality
4	Environmentally-firendly energy technologies
5	Resource conservation
6	Incentive programmes
7	Performance-based standards
8	Land use regulations and urban planning policies
9	Education and training
10	Re-engineering the design process
11	Sustainable construction materials
12	New cost metrics based on economic and ecological value systems
13	New kinds of partnerships and project stakeholders
14	Product innovation and/or certification
15	Recognition of commercial buildings as productivity assets

(Source: Manoliadis *et al.* 2006)

2.4.4. Obstacles of sustainable construction

There are many kinds of obstacles which restrict the generalization of current sustainable construction practices (du Plessis 2007). The construction industry is representative of fragmentation (Egan 1998). The fragmentation nature prevents the shift of contractors from current paradigms to a new one: sustainable construction (du Plessis 2005). In addition, the construction industry is full of numerous homogenous SMEs competing for business against each other. The traditional competitive tendering approach widely adopted in the industry has resulted in low profit margin and contractors have to try every possibility of securing profits for survival. For this reason, SMEs may not resolve sufficient budget for the exercise of sustainable construction (Van Bueren and de Jong 2007). Instead, satisfying minimum requirements posed by the client and reducing cost as much as possible is one of the main instruments to gain competitive edge. Therefore, they might spend less time implementing sustainable practices.

Another obstacle to the implementation of sustainable construction is the lack of capacity in the construction sector. Obstacle of this kind is concerned with both the volume of human resources and skills necessary for construction works. Professionals, tradesmen and workforces shall be trained in due courses to support sustainable construction, especially for those SME firms that rely on outsourcing personnel (Zhao *et al.* 2012). In many developing countries, the outspread use of construction materials such as brick and reinforced concrete indicates that technological inertia could be a major barrier to implement sustainable construction (Sjöström and Bakens 1999). Therefore, technological dependency may hinder the practice of sustainable construction.

Arguably, obstacles to the implementation of sustainable construction as discussed above might also inhibit contractors from fulfilling CSR on a construction site. The detection of the relationships between CSR and SPCP is expected to address such kind of barriers and the contractors can have more motivation to fulfil social responsibility.

2.5 Dimensions of sustainable construction process

Sustainable construction aims for the creation of a sustainable and healthy built environment (Kibert 1994). As a certain level of sustainable construction, sustainable construction process can likewise be addressed using triple bottom lines (i.e., economic, social and environmental). However, behind the so-called sustainable construction process are the linkages of construction activities to a greater community in many ways while addressing issues of planning, architecture, construction operations, operation and building reuse and adaptation, and final disposal is very concrete. Contractors ought to undertake ordinary construction activities following the interdependence between TBL of sustainable construction process. Nevertheless, the reality is that contractors are preferred to conducting one or more types of sustainable construction activities. If such a choice is made, the effectiveness of sustainable construction would be unfolded in different ways. Therefore, discussing the inherent relationships between dimensions of sustainable construction process becomes prominent in this study.

2.5.1. Inextricable links in sustainable construction process

As presented in Section 2.3.1, construction activities consume a large amount of resources (e.g., land, water, materials, energy, and toxics). Part of resources consumed on a site are utilized to construct a physical facility, and part of them are treated as wastes for disposal. Both can generate negative impacts on the physical environment. According to Spence and Mulligan (1995), all environmental impacts resulting from construction activities are complicated but the focus is on the following items:

(a) Use of fossil fuels in the production and operation of buildings. The use of energy in the production phase represents about 10-15% of the total lifetime energy use.
(b) Atmospheric pollution from fossil fuel consumption and cement manufacturing. 8-20% of CO_2 emission of the construction sector goes to manufacturing of building materials.
(c) Depleting of soil and agricultural land.
(d) Shrinking of forests and natural habitats.

In appreciating these impacts, an outstanding issue that contractors have to face is noted, namely how to implement an initial of sustainable construction to maximize resource efficiency? In effect, resource efficiency is frequently highlighted in addition to minimization of environmental impacts in the domain of sustainable construction. For instance, Kibert (1994) summarized seven major tenets of sustainable construction: (1) reduce resource consumption, (2) reuse resources, (3) recycle and use renewable resources, (4) protect nature in all activities, (5) minimize or eliminate toxins, (6) use full-cost accounting, and (7) create environmental quality. Each project has its own unique characteristics, and its impacts on sustainability are inextricable at various stages of lifespan (SHEN *et al.* 2002). This point of view has been echoed in the formulation of indicators for measuring SPCP. For example, eighteen economic attributes, nine social attributes, and eight environmental attributes are formulated in the study by Shen (2010) for SPCP measurement. Zimmermann and Althaus (2005) derived some benchmarks for sustainable construction to identify any requirements to be met by buildings and structures in contributing to the achievement of sustainable society.

Approaches to addressing inextricable parts of sustainable construction process are rich. The *Generic Design and Construction Process* provides a couple of procedures to facilitate effective cooperation between organizations involved in the construction process (Kagioglou *et al.,* 1998). Bourdeau Bourdeau (1999) argued that a sustainable construction framework should cover various processes including urban planning, production development and design, manufacturing and construction, operation and deconstruction. The work by Shen *et al.* (2002) assessed the feasibility of a construction project at the early stage from the perspective of project development sustainability. Based on a dynamic view, Kaatz *et al.* (2006) developed a process protocol to establish a means of streamlining design and construction activities.

It seems to be that the principle of sustainable development is best implemented within the process rather than by being embedded in end products. Likewise, the interdependence between triple bottom lines of sustainable construction process is dependent upon those entities or individuals involved (e.g., the client, designers, contractors, subcontractors, suppliers and labours) (Zainul-Abidin 2010). As presented in this subsection, sustainable construction process has inextricable links of economic, social and environmental aspects. To offer a precise definition, it is essential to discuss these three aspects individually.

2.5.2. Environmental dimension of the sustainable construction process

Previous studies have revealed that nearly 70% of construction companies are aware of the urgency of tackling environmental problems, but they might not have strong willingness to do environmental protection (Wong and Yip 2004). As given in Figure 2.5, the construction process has considerable impacts on the environment through consuming materials, generating waste and dust, and incurring pollution of air and water (Ngowi 1998). Sev (2009) pointed out that the construction process is related to raw material consumption, land use change, clearing of existing flora, energy use and emission of greenhouse gases, waste water generation, and increased transport needs. Fossil fuels used in the process can result in loss of soil and agricultural land, forests and natural habitats. The impacts of the construction process on the environment are all-pervading and they deserve well-designed solutions considering the uniqueness of construction projects and much fragmentation in the construction industry (Ahn *et al.* 2010).

The work by Shen *et al.* (2002) identified a couple of approaches for the assessment of environmental performance in the construction process including the Environmental Performance Assessment Method, Eco-Quantum, and the Life Cycle Analysis Rating Method. These approaches measure the level of environmental performance contributed by a construction product, and thus to promote environmentally friendly construction practice. In practice, construction activities are often criticized for poor performance on environmental protection (Ballesteros *et al.* 2010). Many kinds of emission in the construction process have resulted in further environmental problems. For instance, the exposed surfaces resulting from excavation generate air and dust emission, causing soil erosion, and undermining fauna and natural waterways (Lapinski *et al.* 2006). The impacts of the construction processes on the physical environment are typical when excavation is conducted.

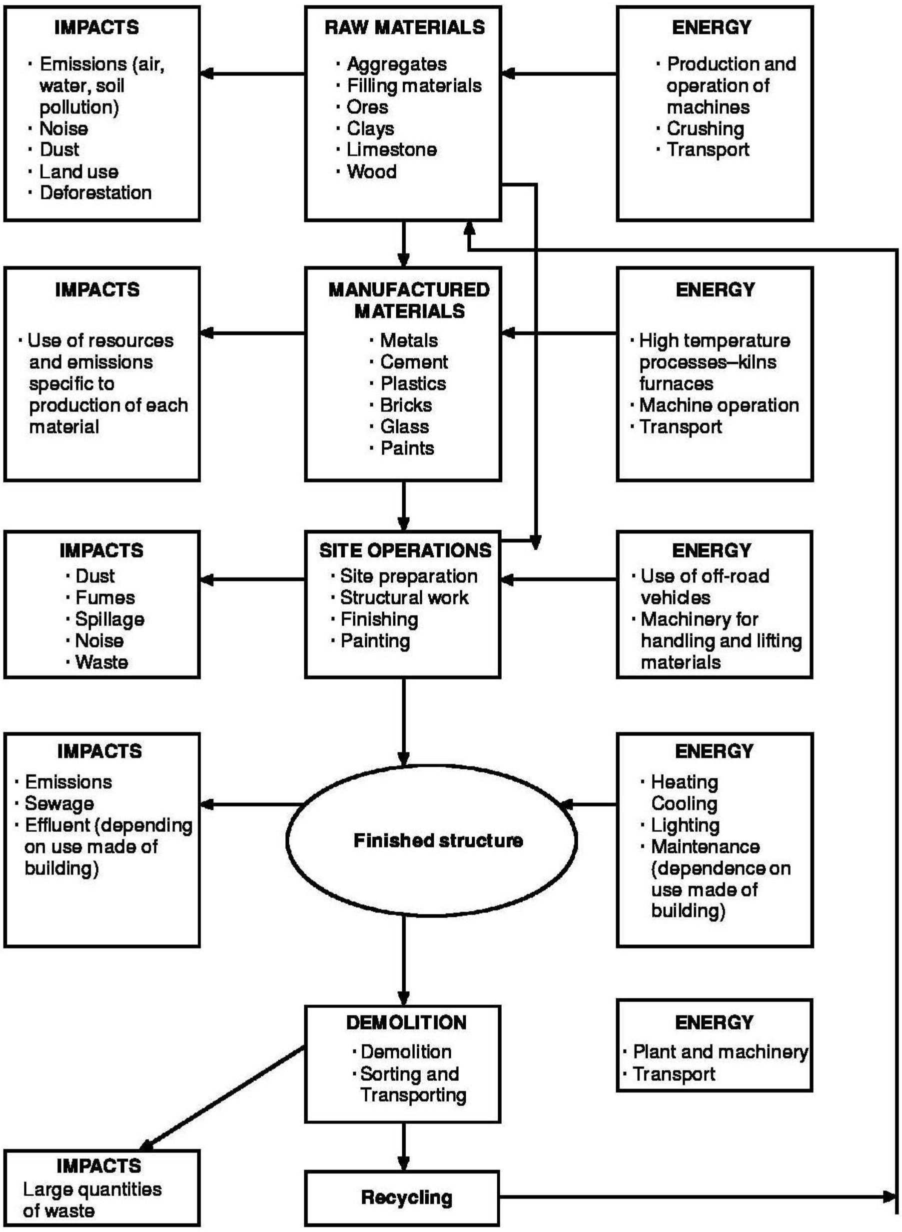


Figure 2.5 The environmental impacts of the construction process (Source: Ngowi 1998)

2.5.3. Economic dimension of the sustainable construction process

As presented above, recent years have witnessed a magnitude of environmental challenges that contractors have to deal with (Shen *et al.* 2010). Sustainable development agenda usually forms the cornerstone of built environment activities, and the environmental dimension becomes a key aspect of sustainable construction (Edum-Fotwe and Price 2009). However, this does not simply imply that contractors can overlook the significance of economic performance of the construction process. The economic aspect of sustainable construction is a conventional goal securing a stable growth of economy. It means working within the capacity of the natural environment, adopting measures from fair and rewarding employment to competitiveness and trade (OGC 2007). Thus, the economic sustainability provides the momentum for the industry to constitute national capital investment, the creation of enterprises in various sizes, and the provision of employments.

The construction industry has the potential to contribute to economic prosperity. However, a general perception is that improving the construction process for sustainability would increase cost and shrink profit due to additional procurement of machinery, equipment and professional services. Meanwhile, it is noted that the introduction of sustainable construction process is associated with saving resulting from efficient resource use, higher productivity and reduced risk. Using data collected from 17 Fortune 100 owner corporations, Beheiry *et al.* (2006) demonstrated that senior management’s commitment to sustainability facilitates sustainable project planning, which in turn helps achieve better project outcomes. Begum *et al.* (2010) examined the economic feasibility of waste minimization in Malaysian construction project, and concluded that 2.5% of the total budget can be saved by adopting waste minimizing strategy like recycling and reusing materials. Contractors have to find solutions to capitalise on these potential benefits of sustainability to increase profitability. As stated by Shen *et al.* (2010), sustainability is usually interpreted as environment oriented in the construction industry, starving for sustainability may cause a conflict between long-term environmental benefit and short-term economic operational goals.

2.5.4. Social dimension of the sustainable construction process

As presented in Section 1.3.3, the aim of this study is to present the impacts of CSR-C on SPCP. Since the construction process has many impacts on society and CSR-C belongs to the area of social dimension of construction process, it is vital to present the social dimension of sustainable construction process.

The social dimension of sustainable construction has been widely aware for decades (Hill and Bowen 1997). One of the main reasons is that the construction industry has a reputation for greed, corruption and unfair labour practices (Ngowi 1998). Consumption behaviour of people is seen as what drives the utilization of natural resources, which is in turn about social equality if resources are allocated unfairly and inefficiently (Edum-Fotwe and Price 2009). End-users' operation cost will be higher if the built facilities are not delivered in due course. In addition, contractors are required by governments and environmentalists to improve performance to satisfy new societal demands driven by the goals of sustainable development (Loosemore 2015). There are a number of interested and interlinked parties external but associated with the construction process. Given that a construction project can underpin many facets of socio-economic relations, enhancing social sustainability through the construction process deserves much attention. Therefore, the construction industry has to engage in social responsibility to minimize the negative impacts on social environment (Opoku and Fortune 2011).

Construction activities are labour-intensive (Ofori 1990). Construction workers are the main force driving the construction process and they should be regarded as the most valuable resource (Morton *et al.* 2011). Consequently, fostering a healthy and safe working environment forms a basic step to health, safety and occupational management on a construction site (Quinn *et al.* 1998). Basically, to improve social dimension in the sphere of construction activities is to secure fairness and justness that are appreciated positive to human development and offer people with opportunities for self-actualization and quality of life (Jones *et al.* 2006). The social sustainability of the construction process guides contractors to examine the demands of local people and to enhance customer satisfaction and work closely with the client, suppliers, employees and local communities (Curwell and Cooper 1998).

2.6 A review on CSR theories

2.6.1. CSR: outside-in or inside-out?

The essence of CSR has been debated heatedly over the past decades (Holmes 1976, Wood 1991). The debates over CSR span from a broader view – “actions that appear to further some social good, beyond the interests of the firm and that which is required by law" (McWilliams and Siegel 2001) to a narrow one – "maximizing shareholder wealth" (Becchetti *et al.* 2012). However, a universally agreed upon definition is still unavailable in the literature (Jiang and Wong 2016). Since the whole society of which business is a part keeps changing, CSR is subject to being perceived in vague, intangible and highly subjective terms (Jones *et al.* 2006).

CSR addresses the overall contribution of business to societal sustainability (United Nations 2007). A hybrid way is usually outlined in CSR plans that firms formulate to resolve the trade-off between economic, social and environmental goals (Carroll and Shabana 2010). Two perspectives can be outlined to present the meanings of CSR. One is an outside-in perspective, in which a socially responsible firm ought to "make a profit, obey the law, be ethical, and be a good corporate citizen" (Carroll 1991, pp 43); the other is an inside-out angle, in which CSR spells out corporate commitments in contributing to improving the interests of both employees and their families, local communities and society (World Business Council for Sustainable Development 2000). Given the inherent relationships between business and society, three questions await detailed discussion in the present study.

First, should the natural or man-made environments (hereafter name it "the physical environment") be treated as a component of CSR? There is one opinion that the physical environment should be separated from all dimensions of sustainability (Jiang and Wong 2016). Business exists at the pleasure of society, and its scope and methods need to accord with the guidelines set by society (Bowen 1953). This view of points has been echoed by Wang and You (2008) on the scope of CSR, which is found to be functional, legal, economic, ethical, cultural, and public welfare responsibility. An alternative viewpoint claims that the domain of CSR must integrate the natural environment with society as they have some shared environmental, economic, and social concerns (Haigh and Griffiths 2009). For instance, Davis (1973) asserted that in addition to traditional economic orientations, firms ought to respond to those beyond narrow economic, technical, and legal requirements to accomplish social and environmental benefits.

Second, what kinds of stakeholders must be included in CSR practices? Stakeholders refer to those groups or individuals that affect the achievement of an organization's objectives, and those who are affected by the achievement of the objectives (Freeman and Reed 1983). Business has diverse relationships with identifiable stakeholders rather than with society at large. In this sense, stakeholder management is instrumental to consolidate mutual dependence between business and society (Zhao *et al.* 2012). Traditionally, shareholders' profit maximization was set as the goals of CSR fulfilment. However, there is a contemporary view holding that CSR serves to manage a multitude of stakeholders no matter how their interests are impacted or might be impacted by the corporation. Hence, stakeholder management enables to achieve the balance between diverse stakeholders and builds a bridge between corporations and general society (Mitchell and Wood 1997).

Last but not least, should CSR be placed on a voluntary or mandatory basis? Friedman (1956) pointed out that the business of business is business. However, business has unequal obligations to society, being unlimited to mere profit-making (Godfrey and Hatch 2007). CSR has four dimensions - economic, legal, ethical and discretionary (Carroll 1991). The discretionary responsibility presents any voluntary or philanthropic needs carried out by the organization to contribute to the good of society. According to ISO, transparent and ethical behaviours are a means of CSR engagement because of the impacts of its decisions and activities on society and the environment (Swider 2013). Although CSR activities are not governed by legislation or subject to any statutory control, certain aspects of CSR might be due to become mandatory (Barthorpe 2010).

2.6.2. Attributes of CSR

As discussed above, CSR means differently to different people. On the basis of 37 definitions given in the literature, Dahlsrud (2008) identified five dimensions of CSR, namely environmental, social, economic, stakeholder, and voluntariness. Business as a part of society ought to accord their activities and practices with the guidelines set by society (Bowen 1953), and thereby has the predominant social accountability to maximize business profitability. This gives the hint that business should embrace those actions that are not stipulated by law, extend beyond explicit transactional interests of the firm, but aligns with social welfare (McWilliams and

Siegel 2000). Therefore, stakeholders involved in CSR distribute widely across sectors than expected.

Friedman (1962) offered a narrow economic perspective of business entity that is responsible to its stockholders. However, some other researchers claimed that a firm's stakeholders are not confined to stockholders. In the construction industry, for instance, stakeholders exist both within and outside a firm, which probably include customers, employees, communities, owners/investors, government, suppliers, competitors, and the local community (Hopkins 2003). Firms act in a socially responsible manner when they embark on two main activities - not hurt the main stakeholders within which they are engaged and they must rectify it whenever they bring harms to stakeholders (Campbell 2007).

CSR means taking responsibilities towards the environment and acknowledging the social dimension of sustainability which is often overlooked in many industries (Hutchins and Sutherland 2008). Most of CSR activities are voluntary. A voluntary activity view on CSR highlights that firms integrate social and environmental concerns with business strategies and the interaction with stakeholders should be placed on a voluntary basis (Steurer *et al.* 2005). While CSR is expected to conceptualize from both management philosophy and business operation perspectives, the crux of CSR controversies probably stems from the meanings of "social" and how it links to daily construction activities.

By examining the aforementioned views, therefore, CSR attributes can be summarized below:

(a) CSR has an important element of philanthropic community investment and environmental impacts mitigation.
(b) CSR accounts for the effects of firms' activities on community and environment, and
(c) It could be embraced as core activities and decision-making of contractors.

2.6.3. Categories of CSR based on need hierarchy

Maslow's hierarchy of needs is useful to construct the layers of CSR. As stated by Tuzzolino and Armandi (1981), the role of business in satisfying physiological and safety needs is to ascertain accountability to stockholders, in satisfying its affiliative needs to its peers, and in self-actualizing to react to its claimants. In light of the hierarchical needs theory, firms ought to upgrade from social responsibility to social responsiveness by adapting corporate behaviours to social needs. Along this trajectory, the spectrum of CSR has two dimensions - internal and external. The internal dimension is concerned with human resources management, health and safety at work, adaptation to change, and the management of environmental impacts and natural resources. The external dimension addresses the interests of investors, local communities, business partners, suppliers and consumers, human rights and global environmental concerns.

The needs hierarchy lays a solid foundation for scholars to propose three levels of analysis on CSR - institutional, organizational and individual (Wood 1991). According to Thompson and Ke (2012), the institutional level delineates those issues related to regulations, standards, certification demands, stakeholders; the organizational level elaborates firms' instrumental and normative motives, firms' mission and values and governance structure; and the individual level is concerned with supervisory commitment to CSR, values, needs, and awareness regarding CSR. In addition, there are three circles of CSR. The inner circle is for economic function (e.g., products, jobs, and economic growth), the intermediate circle - for a sensitive awareness of changing social values and priorities (e.g., environmental conservation, hiring, and relations with employees); and the outer circle for more involvement in actively improving the social environment (e.g., poverty and community welfare).

2.7 Definitions of CSR-C

As presented in the above section, CSR addresses ethical behaviours related to the environment, society, and economy (Hutchins and Sutherland 2008). Business has to take responsibilities towards the environment and acknowledge the social dimension of sustainability (Hutchins and Sutherland 2008). In the discipline of construction economics and management, many researchers (e.g. Henricsson *et al.,* 2004; Shen *et al.,* 2006; Lu, 2006) have tried to give a definition to CSR by imitating the definitions as informed by previous studies. The richness of CSR definitions paves a way for discussing its attributes through investigating the interdependence between construction and society, which offers a clue for this study to detect the effects of CSR fulfilment on SPCP.

2.7.1. CSR studies in the construction management literature

Literature is surveyed in the current study with the intention of identifying those themes of both "CSR in general" and "CSR in construction" (CSR-C) that were presented in previous studies. The results are shown in Table 2.3. As shown in this table, 24 themes are derived. In the meanwhile, the world leading journals in the discipline of construction management and economics such as Journal of Construction Management and Economics, Journal of Construction Management and Engineering, Journal of Management in Engineering, Journal of Cleaner Production, International Journal of Construction Management and International Journal of Project Management were scanned carefully to identify whatever papers that present the subject of CSR. As a consequence, there are totally 16 papers identified, and each one is further examined in length to examine the keywords they represented.

Table 2.3 Key themes of CSR studies in the literature

No.	Key Themes	References
1	Audit	Kemp *et al.* (2012);
2	Attitudes	Brammer *et al.* (2007);
3	Consumers' interest	Ramsey and Yeung (2009);
4	CSP[1]	Carroll (1979); Gond and Crane (2010);
5	Definition & attribute	Carroll (1979); Dahlsrud (2008);
6	Drivers & obstacles	Carroll and Shabana (2010);
7	Education	Matten and Moon (2004);
8	Ethics	Bond (2009);
9	Corporate Performance[2] & profitability	Cochran and Wood (1984); Tang *et al.* (2012);
10	Marketing	Vaaland *et al.* (2008);
11	Measurement & benchmarking	Tuzzolino and Armandi (1981); Wood (2010);
12	Governance	Jamali *et al.* (2008);
13	Implementation methods	Nijhof *et al.* (2008);
14	Organizational culture	Maon *et al.* (2010);
15	Public policies	Albareda *et al.* (2007);
16	Reporting	Du *et al.* (2010);
17	Risk management	Husted (2005);
18	Social issues	Wood (1991);
19	Industrial background	Sobhani *et al.* (2012)
20	National background	Yu and Bell (2007)
21	Stakeholders	Jamali (2008);
22	Strategic management	Asif *et al.* (2013);
23	Supply chain	Andersen and Skjoett-Larsen (2009);
24	Sustainability	Montiel (2008);

Note: 1-Corporate social performance; 2-corporate performance;

As shown in Table 2.3, CSR research spreads over a wide range of themes, such as stakeholders, measurement, reporting, and financial performance. By comparison, the relevant studies in construction are centred on three themes, namely industrial background, national background, and implementation. It seems therefore that academicians' concerns have been over "how to make CSR effective", while studies in construction highlight "whether CSR is an imperative".

The three themes identified above show that CSR-C research has just been kicked off. The three themes indicated in Table 2.4 suggest that the difference of CSR attributes in construction from that in other sectors has been recognized in previous studies, which might lead to the establishment of CSR-C theories. Thus, the nature of construction business deserves well consideration when CSR-C is compared with counterparts in other sectors. Meanwhile, China implemented a socialist market economic system. The characteristics of national backgrounds such as the dominating market position of state-owned enterprises and the Chinese traditional culture can enable CSR to become different. It seems therefore that prior research on CSR-C is focused on the application of generic theory to construction business, while little attention has been paid to enriching the body of CSR knowledge.

CSR-C research attaches less importance to other seven themes that general CSR studies have outlined including audit, ethics, marketing, organizational culture, risk management, strategic management, and supply chain. Since CSR research in construction has just been at infant, it is very important to discuss the attributes of CSR-C and CSR-C fulfilment along the construction process.

2.7.2. Attributes of CSR-C

Interdependence between construction and society

The effects of construction activities on the surrounding environment are double-edged, dynamic, complex and comprehensive (Hendrickson and Horvath 2000). On one hand, construction activities consume numerous resources and energy, and the negative impacts on the physical environment and society such as dust and carbon emission, noise, waste generation, and air pollution are usually blamed (Tam *et al.* 2007). In addition, labour-intensive utilization and high exposure to accident risks and injuries have highlighted the importance of health and safety on construction sites. Furthermore, a built facility generates considerable negative impacts on society and the environment in the lifetime.

Table 2.4 Key research themes of CSR-C

References	Key research themes in general																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Myers (2005)		√											√		√				√	√				√
Petrovic-Lazarevic (2008)												√	√			√			√	√				
Peter *et al.* (2006)																		√	√	√	√			
Barthorpe (2010)					√								√			√			√	√				
Willetts *et al.* (2011)													√			√		√	√	√				
Griffith (2011)													√						√					
Patricia *et al.* (2011)							√												√	√				
Oo and Lim (2011)		√	√												√				√	√				√
Huang and Lien (2012)									√		√								√	√				
Kornfeldová and Mysková (2012)		√									√		√						√	√				
Zhao *et al.* (2012)											√		√						√		√			
Barnes and Croker (2013)		√											√						√	√				
Lichtenstein *et al.* (2013)		√							√		√								√	√				√
Liu *et al.* (2011)				√															√		√			
Wottrich and Sastararuji (2008)						√							√						√	√	√			
Croker (2013)		√				√							√						√	√				
Total number	0	6	1	1	1	2	1	0	2	0	4	1	10	0	2	3	0	2	16	13	4	0	0	3

On the other hand, the construction industry is a main driver of civilization by creating buildings, industrial plants and infrastructures to society (Ofori 1990). A social style and structure can be changed when the physical environment is forming or reforming. Therefore, construction firms' efforts put to CSR fulfilment ought to align with the quality of life and the relationships between all living beings, communities, the built environment, and the natural environment (Kaatz *et al.* 2005, Birkeland 2002). In addition, the construction industry is a huge labour employer as numerous work opportunities are supplied, and practitioners engaged in the production chain are considerable (Ofori 1990). Subject to societal concern over sustainability challenges, construction practitioners are often reminded to respond to any increasing claims from governments and the general public (Zhao *et al.* 2012). By doing so, the industry can engage in a coordinated relationship with society.

A management tool

Although business is accountable toward society at large, individual business can be deemed to be responsible only toward stakeholders, or the definable agents with whom it interacts. A construction firm is knitted by a wide array of stakeholders who have dissimilar interest and demand interlinked in the construction process (Yang *et al.* 2011). They may claim for either economic or social interests, or both. Ineffective stakeholder management for CSR might be accompanied with serious problems. For instance, poor response to financers' social expectations would undermine the mutual trust and results in insufficient financial supports to construction organizations.

CSR-C could be treated as a management tool in the construction process. In the construction industry, however, the lack of involvement and transparency can result in conflicts between stakeholders. If construction workers are subject to unnecessary health and safety risks, accidents and death would become a serious problem, and the project goals might not be actualized in due ways. Poorly managed disruption, such as noise and restricted access, will lead to nuisance and congestion. By virtue of CSR-C, project managers are able to be flexible in dealing with those issues that are non-technical.

A wide span of activities

CSR activities refer to those policies or actions that recognize a company as being concerned with society-related issues. In many areas, CSR contains: (1) the environment, (2) affirmative action programs, (3) equal employment opportunity policies, (4) community involvement, (5) product safety, (6) policies toward South Africa, (7) energy policies, and (8) social responsibility disclosure (Roberts 1992). The works by Griffith (2011) identified five core features of CSR, namely social accountability, associations of stakeholders, compliance with law and regulation, ethically sound operational practices and business sustainability. It is therefore arguable that CSR-C is not limited to a certain type of social or environmental activity.

2.7.3. Dimensions of CSR-C

Construction is an unique business due to its active interaction with local community, many negative impacts on local infrastructure system, creation of working opportunities, and resolution to disastered area reconstruction. In effect, CSR-C activities span extensively from those social issues that project teams identify on sites to other social matters that are beyond the expectation of the client.

While CSR engagement in construction has become popular, main contractors are criticised for poor performance in the area (Murray and Dainty 2009, Myers 2005). The poor performance is attributable to several facts. The most influential one probably refers to the lowest price tendering mechanism, which has formed a strongly competitive business environment and it has resulted in low profit margin. To survive from fierce competition, contractors have to spend considerable time in satisfying clients' primary concerns over construction schedule, cost and quality. Firms are assumed to take due roles in social affairs such as disaster recovery, cleaner production, work security, and the development of local communities. Nevertheless, if inputs into these sorts of business cannot generate economic profit in the short run, contractors would have insufficient incentive to do rather than some minimum legal requirements of CSR.

Contractors are advocated to embed CSR implementation in the construction process. In effect, as one of the hottest topics in the discipline of construction management (Zhao *et al.* 2012), CSR has been considered from the narrow economic perspectives of increasing shareholder wealth, to economic, legal, ethical and discretionary strands of responsibility to good corporate citizenship (Jamali 2008). The well-grounding of CSR in the literature facilitates researchers to investigate how to develop a framework of CSR implementation in the construction process.

As presented above, the work by Dahlsrud (2008) collated 37 definitions from 1980 to 2003 by means of a comprehensive literature review, and five dimensions of CSR were identified, namely environmental, social, economic, stakeholder and voluntariness. Taking into account the attributes of construction activities, four dimensions of CSR in the construction process can be recognized as follows:

(1) An economic dimension: business has the predominant social accountability to maximize the value and profit of the company for its stockholders (Friedman 1962).

(2) An environmental/social dimension: those actions that are not required by law but that appear to further some social good and that extend beyond the explicit transactional interests of the firm (McWilliams and Siegel 2000).

(3) A voluntariness dimension: CSR behaviours are voluntary (Manne and Wallich 1972) on that companies integrate social and environmental concerns in business

operation and in the interaction with their stakeholders on a voluntary basis (van Marrewijk 2003, Steurer *et al.* 2005).

(4) A stakeholder-based dimension: stakeholders of a firm should be treated ethically. Stakeholders exist within and/or outside a firm including customers, employees, communities, owners/investors, government, suppliers, competitors and the local community (Hopkins 2003).

CSR mirrors the interdependence between business and society (Carroll and Shabana 2010) and all construction businesses are expected to engage in CSR practices. Nevertheless, what inspires construction firms to embrace CSR activities, and what prevent a vast majority of SME firms from CSR duties? A proper understanding of CSR-C underscores the formulation of relevant activities in the present study.

2.7.4. Motivation of CSR-C fulfilment

According to Aguilera *et al.* (2007), drivers for business to fulfil CSR are three-dimensional: instrumental, relational and moral. The instrumental drivers refer to self-interest that CSR is beneficial for business to enhance competitiveness and legitimacy (Bansal and Roth 2000). A business plan might centre on CSR if resources input into this area can add values to the firm. The benefits include the improvement of financial performance, brand image and reputation, sales and customer loyalty, productivity and quality, stability of workforces, capital access, benefits to community, and product durability and functionality, while business operating cost stays lowly in the meanwhile.

A contractor is more likely to engage in CSR when its governance structure is strongly built on external relationships with larger communities. Corporate governance structures such as the inclusion of outside directors broadens the focus of the firm to go beyond the exclusive interest of shareholders. Furthermore, the moral driver is based on a concern with ethical standards and moral principles. Firms are motivated by normative reasons such as a sense of responsibility and duty (Bansal and Roth 2000), following a higher order or morals (Aguilera *et al.* 2007). Hence, the rational driver lies in the relationships of business with society.

As described above, numerous construction firms might not comprehend all demands from stakeholders and fail to realize how much they value CSR. This suggests that CSR-C fulfilment has been inhibited by some obstacles. Subject to the abstractness of CSR in nature, the obstacles arguably contain the lack of awareness, the lack of organizational buy-in and commitment to CSR, the difficulty in integrating CSR with organizational values and practices, and the lack of sufficient time and financial resources (Barnes and Croker 2013). In addition, the incompleteness of CSR strategy may constitute another obstacle of CSR-C fulfilment (Croker 2013, Barthorpe 2010).

Human resource is another major obstacle that construction firms have to process in the engagement of CSR-C. To implement CSR-C activities, recruiting/training staff with may prioritize the determination of CSR initiatives. A major concern for construction firms is to determine codes of conduct that might be competing among customers. The nature of business can in part impede managers from adopting more socially responsible actions. For instance, construction firms have to move from one project to another and thereby using external resources to construct a project has brought much difficulty to contractors in the implementation of CSR-C. When an organization finds it difficult to make a business case for CSR or to link it to core organizational operations, it will be reluctant to commit and allocate resources to the practices. Furthermore, construction firms are constantly encountering the problem of budgets caused by CSR implementation, which might not return profits in the short term. Therefore, most of them are unable to spend money on CSR initiatives.

Liu *et al.* (2011) pointed out that contractors in many building projects care much about the client, forming a barrier for them to embark on CSR activities. They also argued that the nature of project work as having "power-based opportunism towards self-orientated profitability…among participants" means that CSR is seldom realized. Similarly, Green (2009, p.49) blames the industry's "obsession with narrowly defined efficiency" as being a hindrance to developing concerns outside of profitability. Petrovic-Lazarevic (2008) found that construction companies' approach to CSR is predominately a one-sided communication with the company communicating its values and policy with little or no community input. She also notes that none of the companies interviewed had a representative of suppliers or community on its board of directors.

As discussed above, the growing value of striking the trade-off between social equity, environmental degradation and ecological crisis highlights the importance of treating CSR-C as an ingredient of sustainable construction. As shown in Table 2.4, CSR-C in research is concerned with three key themes (i.e., implementation, industrial background, and country background) and there are twenty themes that previous studies in construction have not attracted much attention. This implies an infant stage of CSR-C research and researchers have to make unfailing efforts to synthesize CSR into routine construction business management.

2.8 Embedding CSR-C fulfilment into the construction process

2.8.1. Evidences from the construction industry

Subject to the impacts of construction activities on the physical environment and society, sustainable construction has been put highly on agenda since the Rio Earth Summit of 1992 (Myers 2007). It was reported that the built environment shares approximately 40% of total energy consumption, 40% of global material deployment and 25% of global waste (Mokhlesian and Holmén 2012). The Environmental Protection Agency (EPA) in the U.S. revealed that the construction industry generates the third highest Greenhouse Gas (GHG) emission among various industrial sectors. Such negative impacts of the built environment have unavoidably confronted construction firms with overwhelming pressure to pursue sustainable development. For instance, MWH, a global construction contractor, employs cost-effective construction methods to meet clients' needs while do its best to preserve resources and to control pollution simultaneously. While contractors have taken some actions, it seems that they have not many ideas of how to attain sustainability in the construction process.

A construction process consumes considerable energy and resources compared to other production processes (Sjöström and Bakens 1999). Most of the resources consumed on construction sites are non-renewable and some of them may even generate negative environmental effects at the early stages (Griffith 2011). A few approaches have been proposed to improve SPCP. Koo and Ariaratnam (2008) devised a sustainability assessment model to determine the most sustainable option for a water main replacement project, and highlighted the importance of exploring all factors affecting sustainable construction process through its long life cycle. Ogwu *et al.* (2006) established a mathematic model for evaluating the sustainability of infrastructure projects in Hong Kong, and shed light on the pedagogical dimensions (e.g. knowledge, problem analysis, and application) of designing and constructing for better sustainability. Dasgupta and Tam (2005) synthesized the sustainability indicators of civil infrastructure system by using a multi-objective decision approach to facilitate the choice of practical alternatives. Furthermore, the study by Shen *et al.* (2007) demonstrates that a good concession time period underpinning infrastructure sustainability must deal with the benefits, authorities and responsibilities between various project parties.

Industrial cases demonstrate that (a) CSR includes philanthropic community investment and environmental impacts mitigation; (b) CSR must be integrated into decision making of a company as well as core activities, and (c) CSR should be accountable for the effects of any of their actions on their community and environment (CSCEC 2013). There are far more construction firms fulfilling CSR in the construction process in a similar way. For instance, Herbsthofer Austria works closer in the local region, reaching that 80% of its customers/suppliers are within 50 km from the company site. CITIC Limited, a top Chinese international contractor, won a strongly competitive bid of an expressway project in Algeria in 2008 due to its excellence in corporate social performance. As reported by the media of Phoenix (2009), CITIC is well recognized as submitted a CSR-based bid highlighting that their CSR behaviours would extend to the development local community beyond the construction site. The efforts of both Herbsthofer and CITIC can show that CSR at an organizational level can cascade to a broader construction site and improve SPCP as a consequence.

Basically, the construction process contains a multitude of technical and managerial activities on some known construction sites. These activities usually generate environmental and social impacts on local communities. As pinpointed by Bowen (1953), businesses exist at the pleasure of society and their activities and methods must follow the guidelines set by society. Following Bowen's perception, academic efforts to improve the understanding of CSR and to give a precise definition have not discontinued (Joyner and Payne 2002, Carter and Fortune 2007). *The Agenda 21 on Sustainable Construction* stresses the significance of socio-cultural and economic dimensions of sustainable construction and the need for an explicit treatment of these non-technical issues in construction policies and management practices (Sjöström and Bakens 1999, Kaatz *et al.* 2006). Griffith (2011) found that a contractor needs a socially responsible organisational approach which structures both corporate and operational management functions and applies them to the delivery of its business processes. Thereby, the vision, values, policies and objectives of CSR can be configured and embedded within routine business operation.

2.8.2. A framework for CSR-C implementation in the construction process

The above four dimensions of CSR-C overlap with each other (Section 2.7.3), in which two views can be employed to explain as follows:

(a) A narrow view. This view outlines that CSR-C refers to those efforts that firms put to resolve some social and ethical problems concerned with the relationship between business and society (Eells and Walton 1961). Business decision and actions are usually beyond the firm's basic economic or technical interest (Davis 1960, Piacentini *et al.* 2000).

(b) A broader view. Business has not only economic and legal obligations, but also certain responsibilities to society which extend beyond these obligations (McGuire 1963). In line with the definition by Jamali (2008), CSR-C develops from the conventional economic perspective of increasing shareholder wealth, to economic, legal, ethical and discretionary strands of responsibility to good corporate citizenship in the construction context.

As pointed out by the World Business Council for Sustainable Development (2000), CSR is corporate commitment to contribute to sustainable economic development, employees and their families, local communities and the whole society. The business is required to meet or exceed social expectations of industrial and commercial institutions in the ethical, legal, commercial and public areas. CSR is known to take responsibilities towards the environment and acknowledge the social dimension of sustainability which is often overlooked (Hutchins and Sutherland 2008). Corporations act in a socially responsible manner when they undertake two key activities - not harm their key stakeholders within which they operate, and they must rectify it whenever they bring harms to stakeholders (Campbell 2007). While ongoing efforts are expected to conceptualize CSR from both management philosophy and business operations perspectives, the crux of CSR controversies probably stems from the meanings of the world 'social' and how it links to daily construction activities.

Based on the above discussion, a conceptual framework is proposed as shown in Figure 2.6.

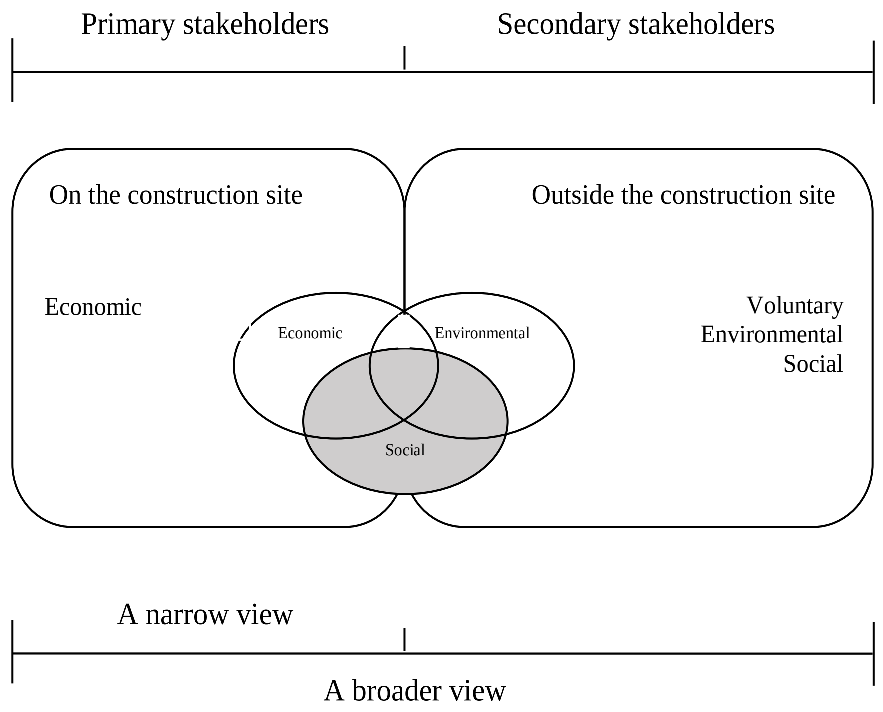


Figure 2.6 Embedding CSR in the construction process

To interpret Figure 2.7 as follows: (a) CSR efforts at a firm level can improve SPCP from the perspective of a larger construction site. (b) CSR efforts related to primary stakeholders can improve the economic performance of construction process. (c) CSR efforts related to secondary stakeholders can improve the social performance of construction process. (d) The environmental performance of construction process can be improved by attaching CSR efforts to both primary and secondary stakeholders.

2.8.3. A construction process oriented approach for CSR-C fulfilment

Contractors might implement a CSR initiative in their own ways. In general, they can follow the instruction raised by Global Reporting Initiative (GRI) to enhance any sustainability performance. GRI circulated a supplementary guideline for the construction and real estate sector. Contractors may adopt green technologies on construction sites to improve their sustainability performance. Part of their enterprise resources might be assigned to help local community to build recreational facilities and embark on disaster area redevelopment by remedying a broken road infrastructure. Conducting education or training for local people to improve their knowledge and skills can be considered a means of CSR fulfilment.

The construction industry is demand-driven and business competition in the market is very strong on many occasions. Contractors have to face with fierce competition and the way for them to outperform counterparts is quite simple, determining a lowest price while convincing the client to trust their competency in future project delivery. The suggestion is that contractors might not be able to respond to the expectation of society on those issues outside construction sites when they are interacting with the client prior to the commencement of the construction process. In addition, with the aggregating specification of construction business, the construction market becomes more fragmented (ENR 2008). This means that contractors usually spend most of their time in coordinating project participants to ensure that the project is undertaken efficiently. Therefore, a project management organization has to concentrate on construction management issues within or beyond expectation of the client.

A construction project is managed by a temporary team established by a construction company to actualize predefined goals. The team is composed of different staffs who might be from different organizations but they ought to work as a team. In fact, most of construction projects are conducted by a team but the team is under the leadership of construction enterprises. It is often the case that CSR is arranged completely by the construction company and the project management team implements part of CSR activities accordingly.

An effective mode for CSR fulfilment is to implement CSR initiatives on construction sites. This approach is a bottom-up approach to synthesize those socially responsible activities by taking into account construction activities. It presents different arrangements between a construction company and its project management team. The company focuses on the formulation of CSR strategies, CSR reporting and decision-making, while its project teams implement CSR on construction sites. The construction process has a time chain with a diversity of project participants. A few phases can be derived, such as briefing, design, preparation, construction, and delivery. Contractors have to manage and utilize resources differently in different phases. The main task of construction process-based approach for CSR fulfilment is to determine what kinds of issues that could be addressed when contractors have come to a certain stage of construction process. For instance, contractors procuring materials and equipment need to consider those local and matching the requirements of green construction. They can make contributions to local community by improving the situation of local built facilities, and build some facilities such as school building and community recreational centre.

2.9 Summary

CSR is subject to an abstract definition in general and difficulty in application in many industries. In this chapter, the development of CSR in the construction sector is discussed with respect to its concept, drivers, obstacles and potential approaches for formulating CSR-C activities. The discussion is also placed on the relationship between CSR-C and sustainable construction to highlight the importance of embedding CSR-C fulfilment in the construction process. Based on this, a framework for embedding CSR-C fulfilment in the construction process is proposed. The proposed framework is expected to lay a solid foundation to model the relationships between CSR and SPCP.

Chapter 3. CHINA’S CONSTRUCTION INDUSTRY

3.1 Introduction

As presented in Chapter 1, business of Chinese contractors will be examined and data from China’s construction industry be collected to investigate the effects of CSR-C activities on SPCP. It is essential to understand the nature and characteristics of this industry and the practices of contractors in the fulfilment of CSR-C nationwide. Basically, contractors’ decision-making on business competition is based on market conditions they have (Ye 2009). By investigating the features of China’s construction industry, factors that determine contractors' decision-making on CSR-C and SPCP indicators can be detected.

This chapter first gives a brief review on the development history of China’s construction industry. The characteristics of the construction industry will then be described with reference to the structure-conduct-performance paradigm in the discipline of industrial economics (Wang 2004). Thereafter, an overview of CSR-C practices as well as the implementation of sustainable construction in China is given eventually.

3.2 Development history of China’s construction industry

China's construction industry was known for its low efficiency and effectiveness before the 1980s. Delay in schedule, cost overrun, quality problems and environmental destruction happened nationwide during the period of time (Shen and Song 1998, Zou *et al.* 2007). As pointed out by researchers, the reason could be that construction firms were state-owned enterprises and contractors had no need to take responsibility for such unsustainable issues.

With an increase in market efficiency after the introduction of competitive bidding systems, the Chinese construction sector has been expanding rapidly over the past three decades. The industry sustains expansion in size with the contribution rate to GDP growth increased from 3.8% to 8.0% (Ye 2009). The industrial long-time prosperity coincides with an unfailing inflow of foreign investment, advanced technologies and managerial expertise from developed countries (Ling *et al.* 2005). The influx of foreign capital and technology into the construction industry drives the shift of traditional business paradigm to an internationally competitive one (Zou *et al.* 2007).

The development of China's construction industry can be divided into several stages in order to review whether there exist some factors that can be adopted to present CSR practices.

Phase I: 1949 ~ 1978

Within thirty years since the foundation of the People's Republic of China in 1949, urban residential housings were owned by the Central Government which was responsible for funding all construction projects and distributing all built facilities across various departments through corresponding work units (Wu *et al.* 2012). However, low efficiency of this system had resulted in severe housing shortage and little improvement of dwelling situations. During this period of time, housing investment occupied only 1.5% of GDP, which was far smaller than the level of maintaining basic housing conditions as recommended as 3% by the United Nations (Lin 1991).

China during this period of time made a series of political efforts to explore a more suitable economic system. The time that the Chinese government took responsibility for all economic activities, reimbursed all construction costs, and allowed no competition between business firms had arrived (Shen and Song 1998). The demand-and-control regime became the prevalent approach for clients to obtain construction business. Construction services providers were state-owned firms which were founded to favour the construction of many nationwide major projects. Construction clients usually formed temporary project management teams to engage themselves in construction activities.

Phase II: 1978 ~ 2001

Economic reform was triggered from the year of 1978. Incremental, sequential, and experimental procedures were taken to enable reformation nationwide. With the implementation of the open-door policy, the purely planned economic system was translated into a market-oriented system in order to expedite economic growth. More and more construction firms were allowed to isolate from governments at various levels and could charge their services from market demanders. Privatization and commercialization were at the core of reformation, and housing units became commercial commodities and can be transacted (Shen and Song 1998). This period of time set the scene for the construction industry to proliferate and the process can be called the socialization and modernization of construction business (Lu *et al.* 2013).

An external force moving construction business modes to change could be triggered from the World Bank, the Asian Bank and some other kinds of foreign investors that took the lead in loaning projects construction in China. The Lubuge Hydroelectric Project, the first one funded by foreign institute, offered a hallmark for and demonstrated effective in applying international codes to project development. On this project, briefing, feasibility study, schematic design, procurement and construction management were a must. Thereafter, the construction sector did not cease growing as a result of a series of industrial events, such as the enactment of law concerning construction supervision system in 1988 as well as the founding of China Engineering Consulting Association in 1992.

Phase III: 2002 ~ now

The current status of China's construction industry mirrors an accumulative effect of long evolution of national reform and open-door policies. China's entry into the World Trade Organization in 2001 has been speeding up the transformation process from a traditional economic system to a socialist market economy (Wang 2004). Property developers in China grow rapidly, from one firm in 1980 to 66290 firms according to the Book Operation and Management Status of Chinese property developers released by China's Real Estate Industry Association and Rand Consultation in 2010.

This period of time has seen the dramatic development of the construction sector. The effectiveness of reform on construction business over this period of time was more significant. In 2001, construction firms were developed to be more technological and encouraged to erect modern enterprise management system. After decades of development, construction firms have become diverse to include the businesses of engineering, architecture/design, contracting services and consultancy. A large number of megaprojects were kicked off in the past decades such as Ertan hydride project, Three Gorge Project, West-to-East National Gas Transmission Project, Qinhai-Tibet Railway project. China has thus been the largest construction site in the world (Jiang and Wong 2016).

3.3 Characteristics of China's construction industry

The brief review presented above describes a rapid development of China's construction industry. Business competition among contractors has become stronger than before. On one hand, contractors are apt at finding business opportunities for survival in the home market. On the other hand, they attempt to adopt “going-out” strategies to operate business in the international arena. To understand those competitive strategies that contractors adopt in an industry is to know in depth the industry they are faced with (Tan *et al.* 2010).

3.3.1. Enormous market size

In the discipline of economics, the so-called market size is defined to be the number of buyers and sellers in a given market (Devine *et al.* 1985). A small market has less likeliness to support a high volume of goods, while large markets may bring in more business competition (Ye 2009). For this reason, contractors in different market sizes show different attitudes towards the fulfilment of corporate social responsibility and the implementation of sustainable construction. For instance, a significantly fluctuating market situation requires contractors to act proactively and uses less resources to conduct those activities that cannot generate profits in the short term.

The expansion of China’s construction market could be a result from the rapid urbanization as indicated in Figure 3.1. It appears to be that the urbanization rate almost sustains an annual growth of 1%, which has created tremendous market demands for contractors to compete. Huge demand for housing and infrastructure in parallel with such large scale of urbanization triggers fast development of the construction sector, which consolidates the industry as major engines for China’s economy. As of 2015, the total output has increased to 18.75 trillion Yuan as shown in Figure 3.2.

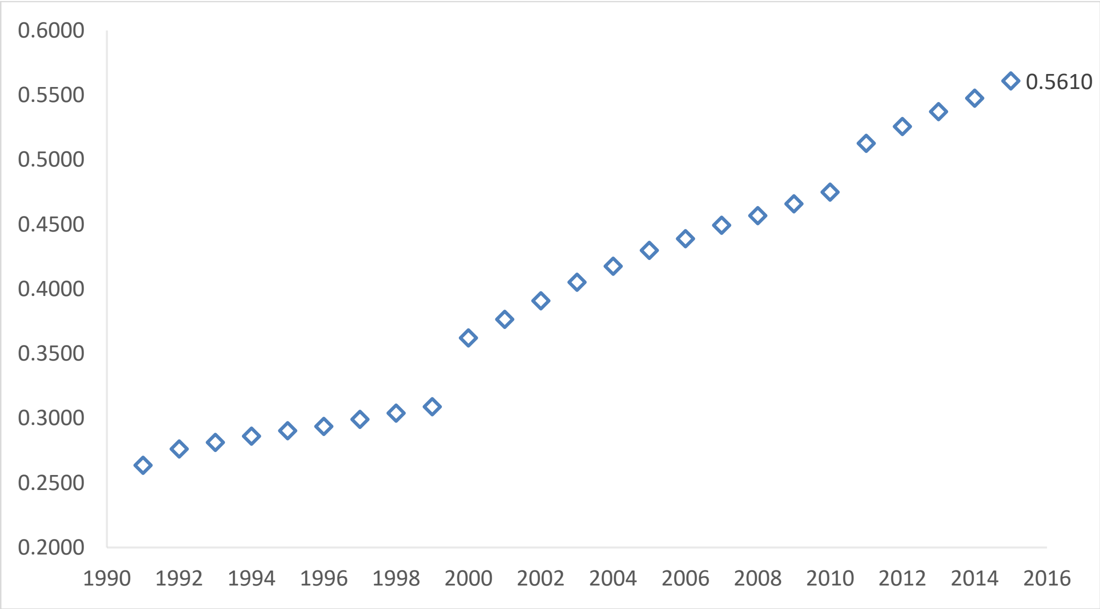


Figure 3.1 Urbanization rate of China

Source: National Bureau of Statistics of China at http://www.stats.gov.cn

The rapid urbanization rate in China is one of the force driving the construction industry to become the largest construction market in the world (Zou 2007). However, recent years have witnessed a significant change of the Chinese construction industry in prosperity in parallel to the slowdown growth of GDP. Many contractors find it more difficult to secure construction contacts. In this situation, contractors ought to rethink their business strategies. Furthermore, some private construction firms are actively competing against those state-owned construction firms that are usually supported by governments and awarded contracts of public works first (Shen and Song 1998).

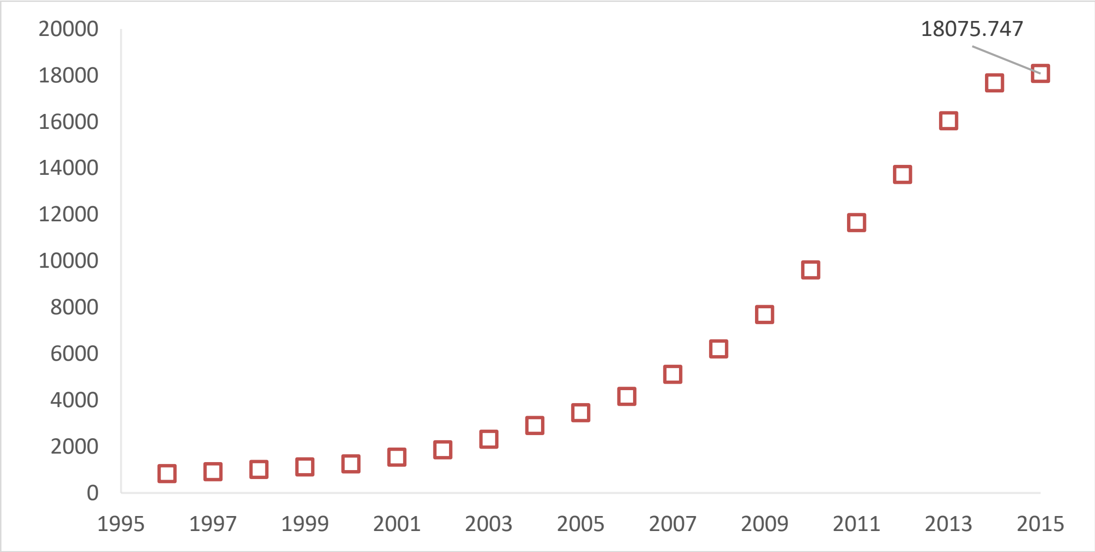


Figure 3.2 Total output of China's construction industry (Unit: 100 million Yuan)

Source: National Bureau of Statistics of China at http://data.stats.gov.cn/visualchart/view?c=01

3.3.2. Competitive business environment

Despite the industry's great achievement with respect to high growth rate and provision of considerable built facilities to support economic development, many serious challenges are surfacing. As shown in Figure 3.3, there were in total 80911 construction firms with a total of 5.093 million employers in 2015. The construction industry in China is composed of a majority of SME that are homogenous (Wang 2004). As stated above, the construction industry is one of the primary sectors that introduced reformation policies in China. While at the early stage, in addition to the existing construction bodies that attached to different departments of the state council, numerous private firms crowded into this industry (Ben and Yi 2009), which had given rise to the proliferation of construction firms. As a result, business environment in the Chinese construction industry is characterized with stiff competition.

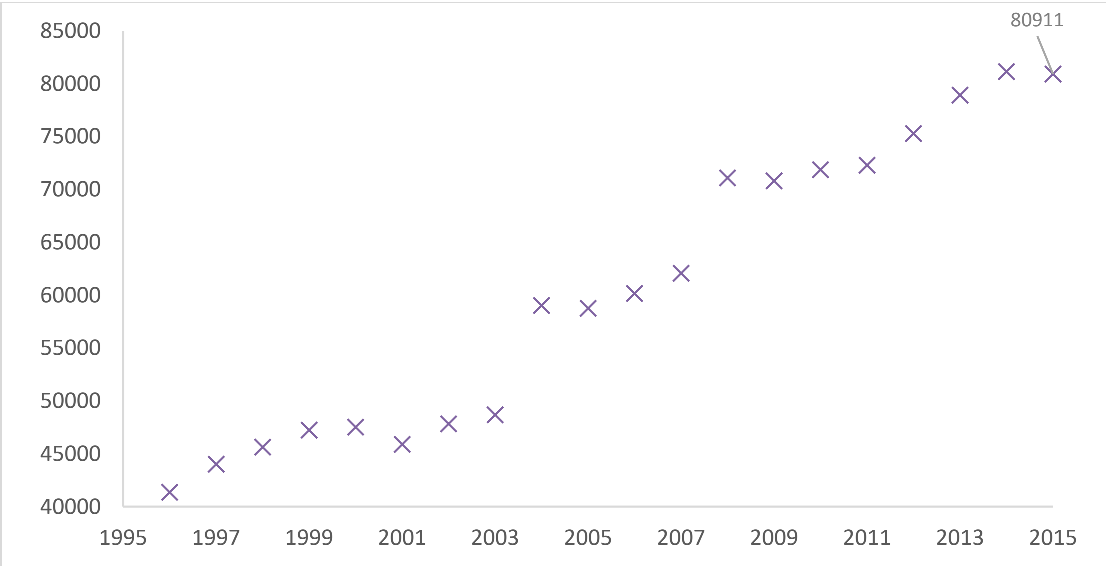


Figure 3.3 Firm number

Source: National Bureau of Statistics of China, at http://data.stats.gov.cn/visualchart/view?c=01

In such an increasing business competition situation, contractors in China are more selective in the determination of CSR matters. On one hand, less inputs into CSR-C fulfilment could be adopted by whatever size a construction firm might be. Therefore, construction firms can focus on competitive strategies. Meanwhile, smaller construction firms exhibit more reluctance to conduct CSR-C either at the project level or at the firm level. On the other hand, large contractors are more active than before in erecting organizational competitiveness. They are more likely to spend enterprise resources on CSR activities and to improve their competitiveness as a consequence.

3.3.3. Hierarchical market structure

Market structure refers to the number and size distribution of competing firms (Brain 1968). The measurement of market structure is usually undertaken by virtue of concentration ratio, which reflect the uneven distribution of market shares in mirroring the market structure in the Chinese construction industry. A construction market is considered to be fragmented if the size of the largest firm thereof is very small in correspondence to the whole market. As found by Wang (2004), the concentration ratios of China's construction market are very small, indicating that the largest Chinese contractors have lower competitiveness or market power than their counterparts in the developed countries (e.g., Japan, UK and USA).

The market structure of the construction industry in China is undergoing rapid transition. Previous studies have pointed out that the domestic turnover of the top 10 Chinese contractors make up about 10% of the total output of the construction industry (Xia *et al.* 2009). This indicates a low level of market concentration and the large number of construction firms can lead to fierce competition and low profitability. Under this circumstance, contractors should establish their competitive strengths in the construction market and maintain good operating conditions. While this feature of the Chinese construction market is a cause leading to competition intensity (Ye 2009), it also suggests that contractors might be indifferent in CSR-C fulfilment.

3.3.4. Low industrial profitability

Although industrial profitability is determined by multiple factors such as market condition, innovation, and cost level, fiercer competition in the construction market can lower business profitability in the industry (Yee and Cheah 2006). It has been revealed that many construction markets have low profitability due to high competition (Choi and Russell 2005).

Figure 3.4 shows that the industrial profit rate of construction business waves around 3%, which is at a low level and indicate a highly competitive business environment in the construction industry.

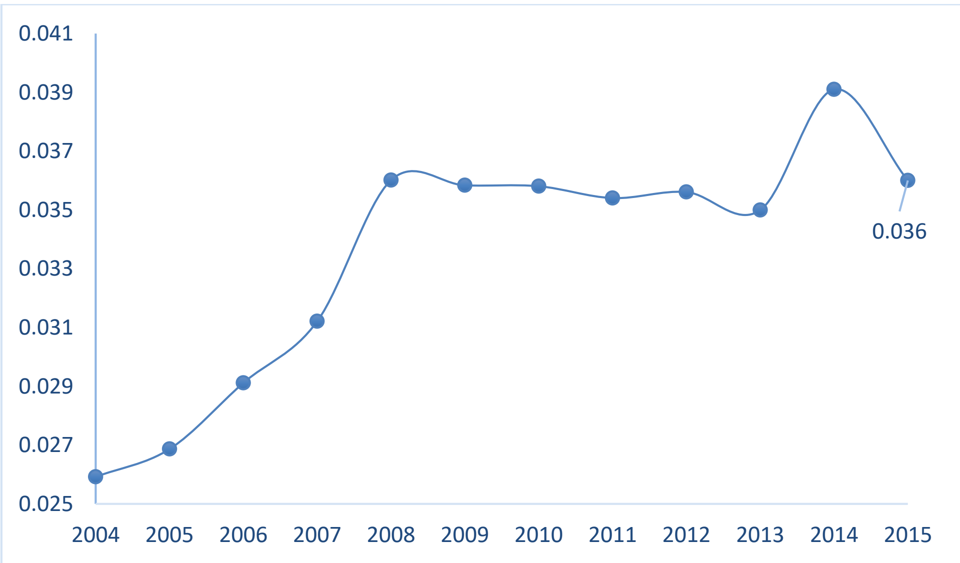


Figure 3.4 Industrial profit rate of China's construction industry

Source: National Bureau of Statistics of China, at http://data.stats.gov.cn/visualchart/view?c=01

Profitability is a key factor determining the awareness, attitudes and strategies in the fulfilment of CSR, although this issue has been debated for decades and extensive consensus on the relationship between CSR fulfilment and business profitability is a lack. A low rate of profitability prevents contractors from making efforts to engage in CSR. It is reasonable that construction firms are inclined to do more contributions to CSR activities if their businesses go well. Therefore, assuming the fulfilment of CSR depends on the industrial situation that construction firms are faced with.

3.4 CSR practices in China's construction industry

3.4.1. Status quo of CSR engagement

As presented above, China implemented a planned economic system before the 1980s. Under this old economic system, CSR was extensively practiced as all businesses were owned by the State Council and they had to take certain degree of social responsibility (Jiang and Wong 2016). Over the period time of 1979-2000, the old economic system was gradually replaced with a socialist market-oriented one permitting corporations to make profits. Only after China's joining in WTO in 2001, CSR was undertaken seriously nationwide due to the happening of social irresponsible behaviours of business in China and the criticism from overseas. By far, a number of laws/regulations are thus enacted as shown in Table 3.1 to guide CSR practices in China.

Table 3.1 CSR related laws/regulations/codes in China

Title	Content	Type
Customer Protecting Law (1993)	Protecting legal rights of customers including the right to get respect in product purchase, to monitor products or services exchange activities, and to enjoy an equal and independent decision, etc.	Legislation
SA8000 Implementation of basic workplace rights (2001)	Assessment methods for employees' rights and relationships in terms of illegal employment, a suitable working time length, and a reasonable remuneration for workers.	Voluntary
China Social Compliance 9000 for Textile & Apparel Industry (2005)	As one of earliest industrial CSR codes in China, it describes general requirements for companies' CSR business and shows them the way to establish an effective CSR fulfilling system.	Code/ Standard
Corporations Act (2005)	The first CSR law in China about organizational obligation to conduct CSR instead of pure profit-making.	Legislation
GRI's Sustainability Reporting Framework (2006)	Guidelines for organizations to report their sustainability performance in terms of social, economic and environmental performance.	Voluntary
Social Responsibility Instructions to Companies Listed in Shenzhen Stock Exchange (2006)	Including employee interests, interests of suppliers, customers, environmental protection and sustainable development.	Instruction
Guidelines to the State-owned Enterprises on Fulfilling Corporate Social Responsibilities	The State-owned Assets Supervision and Administration Commission (SASAC 2007) circulated a code that state-owned enterprises should follow to cultivate a coordinated and sustainable relationship between the enterprises, society and environment.	Regulation
Labour Contract Law (2007)	Protecting legal rights for employees: the obligation for corporations to enter contracts with employees, and to treat employees equally if disputes happen; guiding employee union to protect the interests of employees actively.	Legislation
Guidelines on CSR Fulfilment for State-owned Enterprises in China (2008)	For state-owned enterprises' CSR fulfilment with respect to awareness, implementation, business credits, resource saving and environment protection.	Regulation

ISO 26000 (2010)	Guidelines for corporations to undertake CSR with the focus on stakeholder management and sustainable development; emphasize organizational responsibility, transparency, ethics, respect for profit, laws, international standards, and human rights.	Voluntary

The enforcement of these laws/regulations/codes guides business to behave in a socially responsible manner. According the 2012 White Book of Chinese CSR Reports, which was documented by Chinese Academy of Social Sciences, 1006 companies issued CSR reports in 2012 compared with only 32 issued in 2006. The Fortune magazine releases a list of Top 100 Chinese CSR corporations in line with corporate social, environmental and governance performance (Fortune CHINA 2011). According to the Report of CSR of Chinese firms in 2009, there were over 400 firms release annual reports of corporate social activities. Whereas CSR attracted increasing attention in the past decade, it is still at its infant stage in the mind of Chinese people. A recent survey has revealed that only 37% Beijing (the capital of China) locals know the term CSR (Chinese Academy of Social Sciences 2009). Yu and Bell (2007) opined that Chinese small-and-mediate enterprises have a perplexing attitude towards social responsibility; they convey a high level of awareness but carry little engagement.

3.4.2. CSR practices of contractors

In China, the problems of construction pollution and wastes have been more critical than before. It is found that the average annual growth rate of 9.7% in China' GDP could be ascribed to a high rate of resource consumption and pollutants generation (Zhao *et al.* 2012). About ten thousand square meters of construction area produce 500-600 tons of solid waste, while in developed countries (e.g., the US), the figure is just 180 (Ye *et al.* 2015).

CSR has been examined in the context of developed countries such as Europe, the US and Australia, but CSR practices in developing countries have not been investigated fully (Belal 2001). This is the case in the Chinese construction industry. More and more Chinese contractors believe that they should make decisions and conduct business both transparently and ethically, and assume responsibility to all stakeholders (Zhao *et al.* 2012).

Prior to the 1980s, business system in China was based on a non-competition mode. The state owned all firms in whatever size they were and deemed them as governmental branches sharing the obligation of supplying products/services to society. Nevertheless, this old system suffered from low efficiency in industrial resources allocation (Shen and Song 1998), and it was replaced gradually by a socialist market-oriented one during the period 1979-2000. The upgraded economic system is representative of the market competition mechanism wherein firms compete against each other. Under this new system, however, firms might vanish if they fail to fortify a certain level of competitiveness effectively, and firms usually give lower priority to those negative impacts they impose on society and the environment to cut off production cost (Zhong *et al.* 2009).

In parallel to China's reformation as well as the introduction of international practices, CSR has gained much recognition nationwide. Despite this, the notion of CSR still seems to be an infant in the mind of Chinese people (Chinese Academy of Social Sciences 2009). Yu and Bell (2007) found that Chinese SMEs have some perplexing attitudes towards social responsibility, a high level of awareness but little engagement. Furthermore, Shen *et al.* (2010) found a number of performance indicators, namely economic, social and environmental indicators that project owners often use to gauge project feasibility. They claimed that project owners should attach more importance to those social and environmental aspects.

The dramatic changes of China in the past decades have confronted the country with an important decision to make on how to yield high economic growth at no extra cost of the environment and societal progress. Irresponsible corporate activities that can be gauged at the business level can lead to some outstanding industry wide problems. The fact is that China generated 29% of the world's municipal solid waste, of which construction activities contributed nearly 40% (Wang *et al.* 2008), while the situations seem to be much better in developed countries (e.g., the US) (Yuan 2011). Chinese governments at various levels have to deal with those environmental and societal threats on the construction industry in order to improve the industry's sustainability performance. For instance, the Ministry of Commerce of China commissioned the Chinese International Contractors Association China International Contractors Association (2012) to compile *A Guide on Social Responsibility for Chinese International Contractors*. Nevertheless, there is much still to be done by Chinese construction firms.

3.5 Sustainable construction practices in China

3.5.1. Policies and regulations

The construction industry in China is appreciated to be an engine for the attainment of sustainability. On one hand, it functions like others in making positive contributions to society by providing numerous employment opportunities and yielding built environment to satisfy the demands of both individuals and society (Ofori 1998). The construction industry contributed 22.6% of GDP to macro-economy and provided 36.7 million employment opportunities in 2009 (National Bureau of Statistics of China, 2010). On the other hand, sustainability issues such as energy efficiency and waste management have become outstanding and they have posed challenges onto the construction sector. Furthermore, the buildings stock occupies 30% of total energy consumption (Chinese Construction Industry Association, 2010) and generates 25 per cent of greenhouse gas emission (Center for Housing Industrialization, 2010).

The construction legal system of China is composed of five tiers - laws, administrative regulations, departmental rules, local regulations and local department rules. Laws of sustainable construction in China include *Environmental Protection Law* (1989), *Prevention and Control of Pollution from Environmental Noise* (1997), *Prevention and Control of Atmospheric Pollution* (2000), *Cleaner Production Promotion Law* (2003), *Evaluation of Environmental*

Effects (2003), *Prevention of Environmental Pollution Caused by Solid Waste* (2005), *Energy Conservation* (2008), *Prevention and Control of Water Pollution* (2008), and *The Circular Economy Promotion* (2009). The administrative regulations of sustainable construction include *Regulations on Prevention and Cure of Ambient Noise Pollution* (1989), *Regulations on Construction Project Environmental Protection* (1998), *Regulations on Construction Project Production safety* (2004), *Regulations on Energy Conservation of Civil Building* (2008) and *Regulations on Evaluation of Environmental Effects* (2009). In addition, departmental rules of sustainable construction contain *Stipulation for Environmental Protection Design of Construction Project* (1987), *Stipulation for Management of Urban Construction Garbage* (2005), *Technical Guidelines for Green Building* (2005), *Stipulation for Energy Conservation Management of Civil Building* (2006), *Measures on Supervision and Management of Conservation Quality in Civil Building* (2006), and *Green Construction Guidelines* (2007).

China has been experiencing rapid development but has been at an important crossroad in deciding how to continue to grow at no cost of environmental quality in the meanwhile. Many provinces have adopted some responsive actions to deal with the unsustainable problems that local construction industries have. A typical instance is the framework of sustainable construction for the Shanghai World Expo 2010 as given in Figure 3.5. As indicated in this figure, sustainable construction should be conducted across five stages, namely inception, design, building, operation and demolition, and contractors share the responsibilities of implementing sustainable construction.

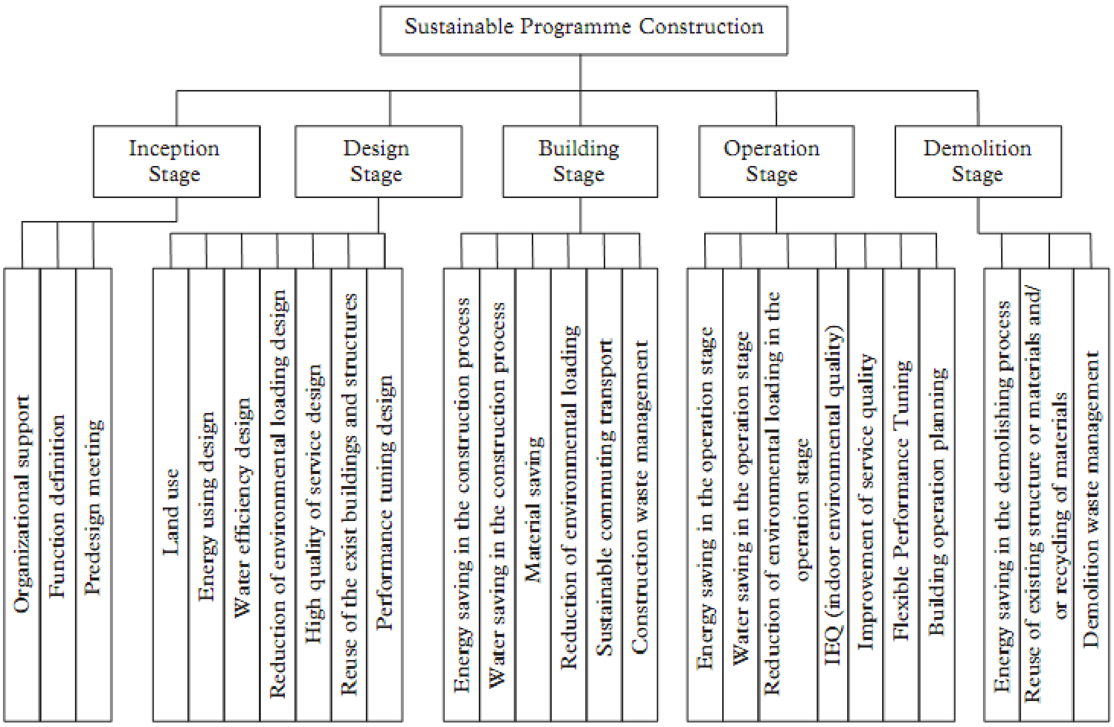


Figure 3.5 Basic guidelines for sustainable construction for the Shanghai World Expo 2010

The case of Shanghai World Expo is a snapshot of sustainable construction nationwide. In effect, China is a large country with the shortage of resources. The rapid pace of development in the Chinese construction industry presents some new and urgent challenges, such as balancing the social and environmental needs, creating more productive, healthy and safe ways for working, conserving and sustaining natural resources and reducing vulnerability to natural hazards (Zou *et al.* 2007). However, as pointed out by Plessis (2007), developing countries have met great challenges of finding a holistic approach to guarantee sustainable development of construction industries.

3.5.2. Deficiency in CSR-C implementation in China

In China, about 25% of energy is consumed in the process of producing building materials and implementing construction activities (Shen *et al.* 2005). As revealed in Shen's (2010) research, eighteen economical, nine social and eight environmental performance attributes are usually addressed in feasibility study reports in China. However, focus is placed on economic performance than those social and environmental attributes. There is a need to shift the traditional approach of project feasibility study to a more inclusive one to embrace the principles of sustainable development.

The work by Zhang *et al.* (2013) developed an SDA prototype model that incorporate the effects of dynamical factors on project sustainability and indicates that sustainable construction depends on two major drivers: the rapid advancement of scientific and technological progress; and people's perception of project sustainability. A case study was cited to illustrate the model's application and it was revealed that project sustainability can change due to impacts of various dynamic variables, particularly those relating to technical measures and people's perception. Therefore, while sustainable construction in China has been widely conscious nationwide, few efforts have been put to outline the role of social sustainability in practice, and the fulfilment of CSR-C in contractors' regular operation is less known.

The interaction between triple bottom lines of sustainability suggests that treating sustainable construction without adopting a comprehensive view can lead to inefficiency in the attainment of sustainability. The social dimension of sustainable construction appears to include everything; it plays a key role in the determination of sustainability performance at the project level. This dimension has won much consideration from practitioners, but fewer attempts have been put to present its interdependence on other dimensions.

3.6 Summary

The characteristics of China's construction industry suggest that contractors have their own ways in determining approaches to sustainable construction. Although Chinese governments whatever national or provincial have circulated a number of regulations and policies in guiding contractors to perform sustainable construction, little attention has been paid to present the social dimension. The uniqueness of China's construction industry as a result of decades' development outlines a specific context that CSR-C has to be situated in. It is thus considered that different CSR activities might be derived even though the approaches presented in Chapter 2 are applied in the same way.

Chapter 4. IDENTIFYING KEY AREAS OF CSR-C ACTIVITIES

4.1 Introduction

CSR has a broad, hierarchical and multidisciplinary nature that corporations often struggle with its authentic meanings (Maignan 2001). The crux of this problem is attributable to the abstractness of the word "social" and its links to daily production activities. For this reason, the process of determining CSR activities might be time-consuming. The abundance of previous studies has promoted the understanding of CSR and its links to construction business in developed countries. However, corporate social activities suitable to construction business in developing countries have not been explored explicitly. It goes without doubt that CSR-C activities in developed countries could not be absolutely effective in developing countries if any revision is not made.

This study therefore investigates this by conducting an extensive literature review on CSR activities. The results are refined by doing content analysis on CSR reports of eight Chinese major construction enterprises and subsequent interviews with five senior professionals in the country. A snowball-based survey is eventually conducted to collect practitioners' opinions to sort out key activity areas of CSR-C. Findings of the study are useful to those contractors who are running construction business or want to excel in corporate social performance in China.

4.2 Main theory for identifying CSR-C activities

According to a stakeholder view on CSR (Mutti *et al.* 2012), CSR-C has likewise two levels of analysis. One refers to stakeholders at the project level, which contain four types namely the client, project leader's organization, outside services, and invisible team members (Briner *et al.* 1996). The other refers to stakeholders at a firm level, which can be classified in several ways (Cleland 1995). A typical approach is to classify them as policy-makers, building officials, investors, financiers, developers, owners, architects and designers, engineering professionals, specialist consultants, product manufacturers, project managers, builders/contractors, sub-contractors, facilities managers, users, tenants, and teachers/educators (Bakens *et al.* 2005).

Various stakeholders might claim for interests in a construction project, whatever contradictory or complementary. Managing these interests is prerequisite to the fulfilment of CSR-C. In fact, CSR-C is often reported by many large construction enterprises and many of its activities fall into the domain of construction sites. It is thus imaged that these two levels of stakaholder analysis deseves synthesis in designing a few approaches to addressing CSR-C issues.

A stakeholder approach

The stakeholder approach to CSR fulfilment is concerned with the determination of right stakeholders, the way they influence and are influenced, and the relationships between stakeholders in the relevant area. According to Friedman (1962, 1970) who offered an economic perspective of a business entity that is primarily responsible to its shareholders, business has in nature exclusive social responsibility to maximize value and profits. Nevertheless, the key point is to embrace those actions that are not required by law but appear to further some social good (McWilliams and Siegel 2000). As such, part of CSR engagement must be voluntary (Manne and Wallich 1972). A voluntary behaviour-based CSR leads corporations to explore solutions to whatever social and environmental problems while their business performance concurs with the interest of stakeholders (Croker 2013). Fundamentally, CSR aims to maintain both the relationships with suppliers and local community and the relationships with employees and unions (Knox *et al.* 2005). Business is known to take its responsibilities towards the environment seriously and acknowledge the social dimension of sustainability (Hutchins and Sutherland 2008).

A social issues management approach

Society is the soil for business to flourish, but business is in turn expected to address social and ethical problems for the welfare of society (Eells and Walton 1961). This suggests that some corporate actions might be beyond those conventional economic or technical interests (Davis 1960, Piacentini *et al.* 2000). In appreciating the influence of social issues such as consumer protection, environmental and discretionary on business operation, an approach called "social issues management" (SIM) (Sethi 1975) was proposed for business to improve enterprise governance. SIM is characterized by interdisciplinary thoughts covering economics, sociology philosophy and anthropology. Its main idea is connecting business to society straight and thereby motivating enterprises to achieve a better quality of life. The core of the SIM approach is to understand the intricate interweaving of business with society, and to address CSR activities from an interdependence perspective. SIM spells out the tenets of CSR, which is as good as it could be, not only as good as it is with questions on business activities, social mechanisms for controlling business behaviour, and the resulting corporate social performance.

A social value chain approach

As discussed above, business has economic and legal obligations as well as certain responsibilities to society that extend beyond these two (McGuire 1963). The richness in CSR activities hints high involvement of corporations in the social value chain. According to Porter and Kaplan (1985), the interdependence between a corporation and society takes on two forms. One refers to the impacts of business on society through its daily operations. Virtually every activity in a corporate value chain touches on the community in which the corporation operates, creating positive or negative social spill-over. The other is the influence of external social conditions on business. Every corporation operates in a competitive context, which can affect its ability to implement its strategy. In light of the rationale for these dual linkages, Porter and Kramer (2006) employed a value chain approach that is traditionally used and can be re-interpreted in order to analyse corporate processes and its strategic approach, so as to make their effects more explicit. In effect, business is required to meet or exceed social expectations of industrial and commercial institutions in the ethical, legal, commercial and public areas.

4.3 Identifying preliminary CSR scopes

An extensive and thorough literature review is conducted with a view to identify general areas of CSR activities. The literature is searched in line with two criteria - the journal is indexed in popular databases such as Science Citation Index and Engineering Index Compendex database, and the topics of publications selected are highly related to CSR fulfilment. As CSR has a couple of synonyms, those terminologies such as corporate citizen (Sadler 2004), social accountability (Roberts 2006, Kemp *et al.* 2012), and ethical business (Rose 2007) are included in the literature survey. Much attention is paid to selecting the right keywords to retrieve papers. Critical and in-depth review and analysis on the selected papers is then conducted to identify CSR activities which may be specific to an industry but has some potential implications to the industry. As a consequence, 60 kinds of CSR activities are derived.

4.3.1. Content analysis

Enterprises usually start CSR reporting with enterprise belief, attitude, decisions and actions, and it has become an effective tool for them to communicate with stakeholders and society. In considering that some of the activities identified above might not suit the Chinese construction industry, CSR reports from contractors are intended and the method of content analysis is adopted. Corporate cases were selected carefully from the ENR's ranked international contractors in 2013 (ENR 250). As shown in Table 4.1, all of the selected contractors have nationwide business and reputation, and their CSR reports over the past three years are available for examination. In addition, CSR report (2011/2012) released by China's International Contractors Association (CICA) was included in the content analysis.

Table 4.1 Profiles of eight major construction corporations in China

Company	2013 ENR ranking	Data resource
China Communications Construction Group	10	Annual report
Sinohydro Group Ltd.	20	Annual report
China State Construction Group	24	Annual report
China National Machinery Industry Corporation	25	Biannual report
China Railway Group Ltd.	34	Annual report
CITIC Construction Co., Ltd.	43	Annual report
Metallurgical Corporation of China Ltd.	51	Annual report
China Railway Construction Corporation Ltd.	53	Annual report
Chinese International Contractors Association	N/A	Annual report*

* In accordance with the Guide on Social Responsibility for Chinese International Contractors compiled by CICA commissioned by the Ministry of Commerce of China.

According to the procedure of content analysis (Gao 2009), the authors and two research students are grouped to analyse and code the data from CSR reports. Participants are trained and given 15 randomly selected and identical items and made an initial analysis in an independent way. Participants' judgments are compared, and disagreements are discussed until agreements are reached. Inter-coder reliability is 97% of all the items coded, which is considered acceptable

(Kassarjian 1977). The coders subsequently analysed the rest of items over three days, coding a total of 936 data items. One week later, participants are invited to re-analyse 5% of the items and the test-retest agreements are 99%. By conducting content analysis on the aforementioned CSR reports, 60 CSR activities are finally expanded to 83.

4.3.2. Interview

The list of CSR activities is reviewed by five senior professionals whose profiles are given in Table 4.2. The professionals are three enterprise managers and two project managers. For the reason of time limit and the convenience of conducting research activities, the professionals are interviewed in Shenzhen city. The professionals have good work experiences in CSR management and sustainable construction nationwide, and the semi-structured interview is thus considered appropriate. Each interview lasts about one hour with focused discussion.

Table 4.2 Profiles of interviewees

Position	Enterprise			Particular	
	Name	Type	Year established	Work year	Expertise
General manager	Shenzhen Municipal Engineering Corp.	State-Owned Construc-tion Enterprise	1983	12	Project management, tendering, strategy management
Project manager	Shenzhen First Construction Engineering Co., Ltd.	State-Owned Construc-tion Enterprise	1983	16	Civil engineering, project management, planning
Vice-president	Shenzhen Yuezhong Construction & Engineering Co., Ltd.	Private Construc-tion Enterprise	2000	20	Project management, electricity, construction marketing
Project manager	Shenzhen Yuezhong Construction & Engineering Co., Ltd.	Private Construc-tion Enterprise	2000	8	Construction management, enterprise management, architectural
Project manager	Shenzhen Huarun Construction company	State-Owned Constructi on Enterprise	2006	5	Construction management

Note: Names of the interviewees are not shown for privacy.

4.3.3. Tentative results

As a result, a list of CSR activities is formulated as shown in Table 4.3.

Table 4.3 Contractors' CSR activities in the Chinese construction industry

Code	Activity	Source		
		Reference	CSR report	Interview
B01	Applying/optimizing a management system for occupational health and safety	(Mercer 2003, Lai and Lam 2010)	√	
B02	Applying/optimizing a confidentiality system for customers' information	(Luo and Bhattacharya 2006)	√	
B03	Applying/optimizing a customer satisfaction management system in responding to customers' claims	(Luo and Bhattacharya 2006)	√	
B04	Applying/optimizing an environmental impacts assessment and precaution system prior to construction	(Reinhardt and Stavins 2010, Shen *et al.* 2010)	√	
B05	Applying/optimizing an equal employment system (e.g. recruitment and promotion)	(Lichtenstein *et al.* 2013)	√	
B06	Applying/optimizing precaution mechanism for safety management	(Peter *et al.* 2006)	√	√
B07	Applying/optimizing a "win-win" based procurement and subcontracting system	(Petrovic-Lazarevic 2008)	√	
B08	Applying/optimizing a products and services system to meet customers' quality, safety and environmental demand	(Peter *et al.* 2006)	√	
B09	Applying/optimizing a safety training scheme to improve employees' safety awareness and skills	(Petrovic-Lazarevic 2008)	√	
B10	Applying/optimizing a training and education system for occupational skills	(Peter *et al.* 2006)	√	√
B11	Applying an environmental performance evaluating system (e.g. setting up environmental goals and plans, regular inspections)	(Peter *et al.* 2006)	√	√

B12	Applying environmental technology and green energy to promote energy saving and emission reduction	(Peter *et al.* 2006)	√	
B13	Applying evaluation mechanism for collaborators to implement CSR	(Petrovic-Lazarevic 2008)	√	
B14	Applying green supply chain management	(Peter *et al.* 2006)	√	
B15	Applying a humane salary and welfare system	(Peter *et al.* 2006)	√	
B16	Applying pollution emission control systems (e.g. gas, dust, noise, sewage and waste)	(Zhao *et al.* 2012)		√
B17	Applying a post-construction service system and providing customers with proper post-construction services		√	√
B18	Applying quality management certification	(Ng 2005)	√	
B19	Applying a saving and recycling system for resources and energy utilization	(Shen *et al.* 2010)	√	
B20	Applying a selection, management and supervision system for sub-contractors		√	
B21	Applying a strict quality inspection system for material and equipment procurement		√	
B22	Conducting CSR implementation monitoring and evaluation			√
B23	Conducting green office			√
B24	Conducting occupational health and safety training for employees	(Petrovic-Lazarevic 2008)	√	
B25	Conducting research development and technological innovation to improve quality and safety management level	(Shen *et al.* 2010)	√	
B26	Contributing efforts to industrial development by	(Shen *et al.* 2010)	√	

	formulating industrial standards			
B27	Disclosing CSR information adequately and reasonably	(Hou and Reber 2011)	√	
B28	Disclosing product information to customers timely and adequately	(Peter *et al.* 2006)	√	
B29	Donating money to community and social charity and public welfare and supporting staff to participate in public activities	(Petrovic-Lazarevic 2008)	√	√
B30	Employing legally (e.g. do not use child or forced labour, sighing legal contract with all employees)	(Petrovic-Lazarevic 2008)	√	
B31	Enforcing intellectual property rights and respecting for partners' property protection claims		√	
B32	Engaging in urban renewal and rural development programs		√	
B33	Establishing and applying a collaborators training and education system		√	
B34	Establishing/improving a CSR management system		√	√
B35	Establishing/improving employer-employee communication and negation mechanism (e.g. labour union)	(Petrovic-Lazarevic 2008)	√	
B36	Establishing effective communication channels with local community	(Petrovic-Lazarevic 2008)	√	
B37	Establishing regular and effective communication mechanism with customers	(Croker 2013)	√	
B38	Establishing strategic cooperative relationships with collaborators to share resources, complementary advantages	(Peter *et al.* 2006)	√	
B39	Formulating/applying an operation plan for			√

	shareholders' long-time and continuous benefits			
B40	Formulating/implementing CSR crisis precautionary and response mechanisms		√	√
B41	Formulating/implementing a CSR training scheme	(Peter *et al.* 2006)	√	
B42	Giving priority to the procurement of local products and services	(Peter *et al.* 2006)	√	
B43	Guiding/encouraging customers to pursue green products and services	(Croker 2013)	√	
B44	Guiding employees in career development and establishing employee promotion mechanism	(Petrovic-Lazarevic 2008)	√	
B45	Implementing/optimizing environmental training scheme to improve employees' environmental awareness and skills	(Petrovic-Lazarevic 2008)	√	
B46	Implementing/optimizing a quality management system to strictly prevent quality accidents			√
B47	Implementing/optimizing quality training to improve employees' quality awareness and skills	(Peter *et al.* 2006)	√	
B48	Implementing/optimizing a safety management system to prevent safety accidents	(Lai and Lam 2010) (Zhao *et al.* 2012)	√	
B49	Implementing crisis evaluation, inspection and precaution for health and safety			√
B50	Implementing disaster prevention/ relief activities for the society and local community	(Petrovic-Lazarevic 2008)	√	
B51	Implementing emergency mechanism and scheme for environmental pollution accidents	(Croker 2013)	√	

B52	Improving investors relationship management and disclosing information to shareholders timely and adequately	(Petrovic-Lazarevic 2008)	√	
B53	Competing for business in a fair and ethical way	(Peter *et al.* 2006)	√	
B54	Inspecting/eradicating business corruption and other unfair competition practices	(Peter *et al.* 2006)	√	
B55	Keeping credit records and transparency to collaborators	(Petrovic-Lazarevic 2008)	√	
B56	Optimizing corporate governance and guaranteeing shareholders' interests for participation in corporate decision	(Peter *et al.* 2006)	√	
B57	Optimizing an environmental management system and applying environmental management certification	(Peter *et al.* 2006)	√	
B58	Organizing/supporting occupational skills training programs for local community	(Petrovic-Lazarevic 2008)	√	
B59	Paying taxes in duly		√	√
B60	Promoting community and social employment (especially university graduate students and rural migrant workers	(Petrovic-Lazarevic 2008)	√	
B61	Protecting biological diversity and ecological systems	(Heras-Saizarbitoria *et al.* 2011)	√	
B62	Respecting and protecting cultural tradition and heritage of the community	(Petrovic-Lazarevic 2008)	√	
B63	Setting up special division(s) for CSR management		√	
B64	Setting up special units or/and positions to conduct daily environmental management			√
B65	Signing legal and fair contracts with customers and developing and delivering projects in accordance with the contracts		√	√

B66	Strengthening communication with collaborators and improving collaboration space and efficiency	(Peter *et al.* 2006)	√	
B67	Supporting the development of infrastructure and public services of local community	(Petrovic-Lazarevic 2008)	√	
B68	Taking care of employees and their families and help employees to achieve work-life balance	(Petrovic-Lazarevic 2008)	√	
B69	Taking care of low-income groups (e.g. Build-transferring low-income housing without charge)			√

4.4 Questionnaire survey

A questionnaire survey is conducted to collect practitioners' opinions on those items shown in Table 4.3. The questionnaire contains three parts, general information regarding respondents and organizations; respondent's views on the overall CSR implementation in China's construction industry; importance judgment on areas of CSR activity.

4.4.1. Questionnaire design

The third section for respondents to judge the importance of each area of CSR activity consists of a number of closed questions requesting respondents to indicate the significance degree through a five-level Likert scale (1 - Negligible, 2 - Less important, 3 - Average, 4 - Important, 5 - Extremely important). To ensure the suitability and good readability of the questionnaire, academic supervisors and several professionals are invited to help proofreading and make some comments on the questionnaire. Comments are well considered in the revision of the questionnaire.

According to the Regulation on Qualification Management of Construction Firms (Ministry of Housing and Urban-Rural Development of the People Republic China, MOHURD, 2007), construction firms in China are classified into various grades, and only those contractors who meet the requirements in terms of technology, capital, credit grade and firm size can be listed as first-two group (FTG) contractors (Ye *et al.* 2010). FTC contractors are allowed to conduct construction business nationwide, and they are considered having good knowledge of CSR and sustainable practices. The questionnaire is formulated toward the middle-top management staff from FTG contractors in China as they are expected to have comprehensive knowledge and experiences over CSR practices.

4.4.2. Data collection

As construction firms engaged in CSR practices are expanding in terms of number, it is quite difficult, if not impossible, to recognize the entire population precisely in this study. Thus, the method of snowball sampling is employed to collect respondents' opinions as much as possible. A small pool of initial informants is invited to nominate through their social networks other participants who have knowledge/experience of CSR and sustainable construction. To avoid too many friends being recruited into the sample, informants are asked to send the questionnaire to professionals they know in other regional sectors. The respondents are encouraged to return their feedbacks by mails and by filling in an online questionnaire.

Consequently, 116 questionnaires are received. Of all the returned questionnaires, 93 are found valid. The respondents participating in the survey have an average of 13.2 work years, and 45% of them hold a manager position or above. 93 respondents are from major provinces/municipalities, including Beijing (10), Chongqing (12), Guangdong (10), Jiangsu (5), Shandong (3), Shanghai (9), Sichuan (9) and Zhejiang (8). Although it is very hard to appraise the representativeness of the respondents, the sample distribution helps mitigate bias and prejudice on CSR activities.

4.5 Data analysis

4.5.1. Factor analysis technique

The technique of factor analysis has the efficiency in identifying a relatively small number of individual factors which are useful to elaborate the relationships among sets of interrelated variables (Norusis 2002). This technique can be used to reduce or regroup those individual factors identified from a larger number to a smaller and more critical set. In this study, the number of key areas of CSR activities should be able to represent a set of data are determined by examining the total percentage of variance explained by each individual CSR activity. To this end, principal components analysis is consequently used to identify the underlying grouped activity types because of its simplicity and its distinctive characteristic of data-reduction capacity. Furthermore, in order to obtain a clearer image, extraction with Promax rotation and Kaiser normalization is conducted using the Statistical Package for Social Sciences (SPSS) FACTOR program.

4.5.2. KMO and Bartlett's Test of Sphericity

The sampling adequacy using Kaiser-Meyer-Olkin (KMO) and Barlett's test of sphericity are used to evaluate the appropriateness of the data for factor analysis (Fox and Skitmore 2007). In the present study, the KMO test gives 0.874 and Bartlett's test of sphericity is high at 2958.951 (with a probability value of 0.000), suggesting that the data are acceptable for factor analysis.

Factor loadings refer to the correlations of variables under the heading of a factor. Eigenvalues and the percentage of variance are used to determine the magnitude of factors. Factors with relatively large eigenvalues are retained and those with relatively small eigenvalues are removed. The eigenvalue for a factor should be greater than 1.00 and all the factors extracted should account for at least 60% of the total. Therefore, a six-factor solution is produced finally, explaining 71.96% of the total variance. The factor grouping based on factor loading and the rotation are given in Table 4.4, in which 37 variables are derived, each belonging to one factor.

Table 4.4 Internal consistency analysis, KMO and variance explained

Factors extracted	Factor loading	Corrected Item-total correlation	Eigenvalue	Explained variance percentage	Cumulative percentage
Factor 1			15.844	16.054	16.054
B64	.573	.609			
B45	.748	.697			
B04	.727	.712			
B19	.703	.694			
B16	.747	.707			
B12	.717	.754			
B51	.666	.763			
B61	.716	.695			
B23	.659	.664			
Factor 2			3.804	15.607	31.661
B18	.774	.551			
B46	.852	.502			
B47	.763	.601			
B21	.763	.647			
B20	.714	.632			
B48	.847	.537			
B06	.714	.531			
B25	.598	.621			
Factor 3			2.108	15.503	47.165
B13	.631	.658			
B36	.772	.734			
B58	.724	.660			
B42	.812	.657			
B62	.704	.663			
B50	.812	.769			
B67	.782	.660			
B69	.718	.607			
Factor 4			1.690	8.806	55.970
B10	.635	.648			
B44	.748	.552			
B35	.685	.605			
B68	.707	.592			
Factor 5			1.471	8.609	64.580
B03	.739	.541			
B02	.608	.686			
B37	.793	.579			
B17	.562	.717			

B66	.602	.565			
Factor 6			1.425	6.617	71.196
B63	.815	.401			
B41	.773	.428			
B40	.765	.407			

Cronbach's alpha indicates the internal consistency among the items within a factor. The alpha coefficient should normally be larger than 0.7. As listed in Table 4.5, the alpha for the six factors ranges from 0.847 to 0.944, all exceeding the acceptable 0.7 level. The percentage of variance explained by each factor is distributed over the range (65.535%, 72.659%). The KMO test suggests that all factors are reasonable as the values vary from 0.693 to 0.913. The item-total correlation that tests convergent validity for all variables within the six factors ranges from 0.401 to 0.769 (Table 4.4), obeying the rule that variables with an item-to-total correlation score lower than 0.4 can be removed (Park and Kim 2003).

Table 4.5 Internal consistency analysis, KMO, and explained variance of critical factors

Factor interpretation	Cronbach's alpha (reliability）	Explained variance (%) (unifactorial）	KMO (unifactorial)
Factor 1	0.937	66.892	0.913
Factor 2	0.927	66.814	0.912
Factor 3	0.944	72.175	0.906
Factor 4	0.847	68.669	0.795
Factor 5	0.868	65.535	0.831
Factor 6	0.810	72.659	0.693

Results of the factor analysis are listed in Table 4.5. As shown in this table, the cumulative contribution percentage is 72.659%, suggesting that the vast majority of the variance can be interpreted by the six factors.

4.6 Key areas of CSR-C activities

Results of the data analysis suggest that CSR activities can be condensed into six key factors or key areas. The key factors identified are discussed below to elaborate their differences and implications.

Environment preservation (F1)

F1 indicates the importance of environmental protection in the domain of CSR-C. Environmental degradation can be found easily on surrounding construction sites. Due to the influence of construction activities on the physical environment and contractors' passive attitudes towards environmental sustainability (Oo and Lim 2011), the construction industry has become one of the targets of environmentalists and governments (Petrovic-Lazarevic 2008). The identification of this factor echoes with previous studies (Tabassi *et al.* 2016, Kibert 2012) on the obligation that contractors have the necessity of protecting the physical environment. In effect, the negative impacts of construction activities on the environment is the evidence that environmental preservation should be included as a key area of CSR activities. This is the case in China as the lowest-price competitive system has driven a vast majority of firms to prioritize environmental deterioration lowly (Zou 2007).

Construction quality and safety (F2)

This factor concurs with the *Code of Green Construction* enforced by the Ministry of Housing and Construction China, and agrees with previous studies on the significance of quality and safety in the construction industry (Zeng *et al.* 2015, Zhao *et al.* 2012). In fact, quality and safety are a fundamental requirement of production activities, which have likewise been outlined in other industries such as manufacturing and services (Fadul 2004, Yotsumoto 2002, Mercer 2003). According to the variables clustered under this factor, it can be found that contractors should implement a strict management system to maintain efficiency in managing construction activities.

Well-being of local community (F3)

This factor specifies the contributions of construction business to the welfare of local community. Construction projects have tight relationships with local communities. Impacts on the local environment and infrastructures might continue until the completion of construction process. The built facilities serve local community with whatever production or services. This factor suggests that contractors are supposed to do whatever they can to improve the social welfare and contribute efforts to the development of the local community. To this end, two ways can be appraised, such as providing employment opportunity to the local community and donating money to social charities. The identification of this factor echoes with previous studies on that business has close relationships with local communities (Petrovic-Lazarevic 2008).

Employees' interests (F4)

This factor is concerned with the continuing professional development and job satisfaction of employees and its importance has been stressed in previous studies (Lichtenstein *et al.* 2013). As a main supportive production factor on construction sites, employees' interests should be respected to a certain degree that they are motivated to guarantee productivity. Contractors are thus often claimed to provide sufficient training and education opportunities to improve employees' competence. As such, organizational competitiveness can be fortified (Lu *et al.* 2008). For instance, equal opportunity should be set out to deal with the non-discrimination of people, regardless of gender, origin, ethnicity, age and others.

Clients' interests (F5)

Clients' interests are articulated in bidding documents and described in contracts that contractors should endeavour to actualize. In reverse, work contracts may be suspended if the client is aware of the possibility that their interests are plaguing due to contractors' unexpected behaviours. Previous studies have unveiled the usefulness of this factor in various construction contexts, and highlighted that CSR can be treated as a management tool in delivering business to customers (Luo and Bhattacharya 2006). This is extremely pertinent within the construction industry where contractors must meet a plethora of client requirements (Griffith 2011). This factor is made up of a satisfactory management system, requires contractors to disclose product information to clients, and establish regular and effective communication with clients.

CSR institutional arrangement (F6)

This factor emphasizes that corporate governance paves a way for meeting CSR objectives. Campbell (2007) pointed out that business needs to develop institutional mechanisms to fulfil CSR in due ways. However, there are relatively few organizations in China that incorporate and institutionalize CSR. Being a responsible business partner and adhering to the rule of business is prerequisite for a contractor to gain social recognition in any industry. Contractors are thus recommended to provide some training and education to employees on CSR fulfilment as a means of contribution towards sustainable construction.

4.7 Findings and discussion

4.7.1. Approaches to identify CSR activity

The above research findings have some implications for construction firms to improve the fulfilment of CSR in practice. CSR has been considered much more in the context of developed countries such as Western Europe, the USA and Australia, while less in emerging countries (Belal 2001). Same case happens in the Chinese construction industry. China CALXON Group probably released the first CSR report among property developers in 2007, and thereafter many firms in the construction industry often report their CSR practices. Although the socialist market system enables construction firms to achieve a higher operating efficiency than before, unethical corporate activities such as air pollution, hazardous food, resource wastes, environment destruction and poor quality of projects often spring to social attention nationwide at the same time (Jones *et al.* 2006)**.** It appears to be that the social issues management approach and the social value chain approach has the potential of resolving such social issues in China. In fact, more and more Chinese contractors believe that they should make decisions and conduct business both transparently and ethically, and assume responsibility to all stakeholders (Ye and Xiong 2011). As inspired by this, using the stakeholder approach is considered more useful to CSR practices in China's construction industry.

Truly, it is interesting to rethink about the identified six key areas of CSR activity from the perspective of stakeholder management. The stakeholder approach to CSR means that a managerial framework should be put into place for business to synthesize those concerns, interests and claims of stakeholders into a CSR package (Miles *et al.* 2006). Stakeholders exist both within and outside a firm, including customers, employees, communities, owners/investors, government, suppliers, competitors, and the local community (Hopkins 2003). Stakeholders of a construction firm should be treated ethically. By transforming CSR agendas into daily activities that are responsive to some known stakeholders, construction contractors' CSR can be fulfilled more effectively. Behind the key areas of CSR activities are a set of stakeholders that contractors ought to manage appropriately. In this study, it is found that the stakeholders involved in CSR implementation are shareholders, employees, clients and the public. These stakeholders are at the construction firm level, and interact with each other around the construction process.

4.7.2. Characteristics of CSR activities in China

The research findings disclose that CSR activities in the Chinese construction have some unique characteristics with those in developed countries, and they offer new evidences for academicians to debate the subject of CSR-C. Specifically, the key factors F1 and F2 suggest that CSR-C is embedded in the construction process, and the environment should be particularly accounted for. The factor F3 signifies that CSR-C is at large on a voluntary basis. Furthermore, F4 and F5 show that not all stakeholders play an equal role in the area of CSR-C. The work by Petrovic-Lazarevic (2008) revealed that CSR in Australia's construction industry encompasses broadly including being a good citizen, attaining sustainability, having good relationship with employees, suppliers, and community, and effective CSR reporting. According to Peter *et al.* (2006), many leading contraction firms in the UK have dedicated CSR to environmental protection, health and safety, human resources, suppliers, clients, communities, and governance and ethics. Notably, the scope of CSR-C activities in China is almost identical to that one in both Australia and the UK. This could indicate that the areas of CSR-C activities are commonly characterized by the construction process. However, a key CSR-C activity in China can have a different importance level, which may arguably be ascribed to the effects of Chinese unique construction business.

4.8 Summary

The crux of CSR engagement is to determine a set of activities that can be executed accordingly. In this chapter, six key areas of CSR-C activities are identified, namely environmental protection, quality and safety, local community, employees, clients and CSR administration. These activity areas address a wide concept of CSR as both environmental and societal concerns are included and contractors are required or expected to make due response. The key areas of CSR activities provide useful guidelines for implementation in the Chinese construction industry. With reference to the key areas, contractors who are operating or are to enter the Chinese construction industry can find it helpful to behave in socially responsible manners, and for other contractors to consider in other construction industries. As stated in Chapter 1, the derivation of CSR-C activities is a key step for examination in this study. Future studies are oriented to investigate whether these activities can have impacts on SPCP and in which way the effects are most significant.

Chapter 5. ESTABLISHING INDICATORS FOR SUSTAINABILITY PERFORMANCE OF THE CONSTRUCTION PROCESS

5.1 Introduction

The construction industry plays a vital role in resolving a multitude of social issues such as urbanization, poverty, inequity, productivity, economic crisis and environmental degradation (Ofori 1990). One of the main instruments is through providing tremendous housing and infrastructure to satisfy human demands (Irurah 2001). Nevertheless, the negative impacts of construction activities on society and the environmental have not significantly been improved (Shi *et al.* 2014). As revealed in previous studies, construction activities have exceeded environmental limits of the planet and many countries have to make due reaction to unsustainability challenges (Spence and Mulligan 1995, Aye *et al.* 2000). Therefore, construction activities together with environmental policies ought to be addressed by adopting some sustainable practices (e.g., waste reduction, materials reuse and recycle) (Irurah 2001).

The principle of sustainability has brought the built environment into sharp relief (CSCEC 2013, Dasgupta and Tam 2005). Probably for this reason, views and interpretation on sustainability along the construction process are divergent in the literature (Bossink 2002, Shi *et al.* 2014), which embrace kinds of activities that are technical, social, legal, economic and political (Bon and Hutchinson 2000, Bossink 2002, Costantino 2006, Ding 2008). Since the relevant studies devoted to

SPCP indicators is plentiful, this chapter presents the formulation of the indicators by way of literature review and Delphi-type survey. The chapter starts with reconsideration over established indicators for sustainable construction. Approaches and main theory for formulating SPCP indicators are then presented. The chapter proceeds to present the identification of indicators and they are eventually restructured in line with a new framework.

5.2 Reconsidering indicators for sustainable construction

Rethinking indicators for sustainable construction means making a review on the scope, effectiveness and efficiency of established indicators bearing in mind the research aims. This step frames the backbone of identifying SPCP indicators for model development in the next step.

5.2.1. Definitions of indicators

Indicator is defined as a parameter or values detailing information about a phenomenon or an object (Guy and Kibert 1998). Indicator facilitates the comparison of goals, targets, and benchmarks (Guy and Kibert 1998). To this end, the usefulness of an indicator should be relevant (action oriented) and valid, representative, repeatable, responsive to change, and reasonably simple for interpretation (Lema and Price 1996). Since a single indicator might not be able to outline a whole picture of an object, a number of indicators are usually combined to form an indicators set to provide all-round measurement results. By doing so, key characteristics of subsystems or the overall system of concern can be identified completely.

An indicators set has multiple functions, purposes and approaches for application in practice (MacDonald, 1996). This is true in the area of construction management. Researchers have established a set of indicators to examine competitiveness (Shen *et al.* 2004), project maturity (Henjewele *et al.* 2014), project risk and uncertainty (Chan and Au 2009), time performance (Chan and Chan 2004), and satisfaction (Maloney 2002). The choices of an indicators set in terms of number and coverage lie in the intention of assessment and the attributes of project type (Ugwu and Haupt 2007). It can be used to mirror a dynamic process or an outcome about the application of sustainability principles in the domain of construction activities. By virtue of an indicators set, the measurement is expected to shed some lights on the encouragement of construction employers and the stimulation of changes by reviewing performance objectives.

Development of an indicators set has been appreciated effective to measure the progress of sustainable construction in a simplified and readily understandable manner (Guy and Kibert 1998). In this study, the aim of an aggregated indicators set is to image the efforts towards sustainable practices along the construction process, which is considered to be the system of concern. A user-friendly set of indicators helps to assess SPCP in both efficiency and effectiveness.

5.2.2. Hierarchy of indicators for "sustainability in construction"

Sustainability in the construction context has been interpreted in a handful of ways, depending on which perspective is adopted to examine the requirements of stakeholders as well as the phase of the project life cycle (du Plessis 2005). Basically, *sustainability in construction* means engagement among employees, local communities, clients, and the supply chain in an effort to meet the needs of current and future populations and communities in the built environment (Irurah 2000). For instance, community involvement approaches (e.g., public hearings) favour local government to make right decision on major issues arising out of construction sites. A truly sustainable construction project ought to address not only social issues for end users but also impacts on the surrounding community, safety, health and education of the workforce.

The criteria for sustainability indicators development in the construction sector must be comprehensive, integrated/linked, with long-term perspective and consider various needs of stakeholders (Guy and Kibert 1998). While such kind of criteria sustains advancing, SPCP indicators have become more inclusive and all-encompassing than before. Figure 5.1 gives an indicators set for measuring project sustainability, of which three tiers are constructed to describe the opinions of investors on an infrastructure project. A lifecycle analysis on the sustainability performance is adopted therein, and this step matches the functions of indicators as presented in Section 5.2.1. Likewise, sustainability indicators for the construction process have the importance of elaborating the responsibility of contractors in attaining sustainability (du Plessis 2002), namely to meet the client's needs while contractors' success in an increasingly competitive and constrained operational environment cannot be sacrificed.

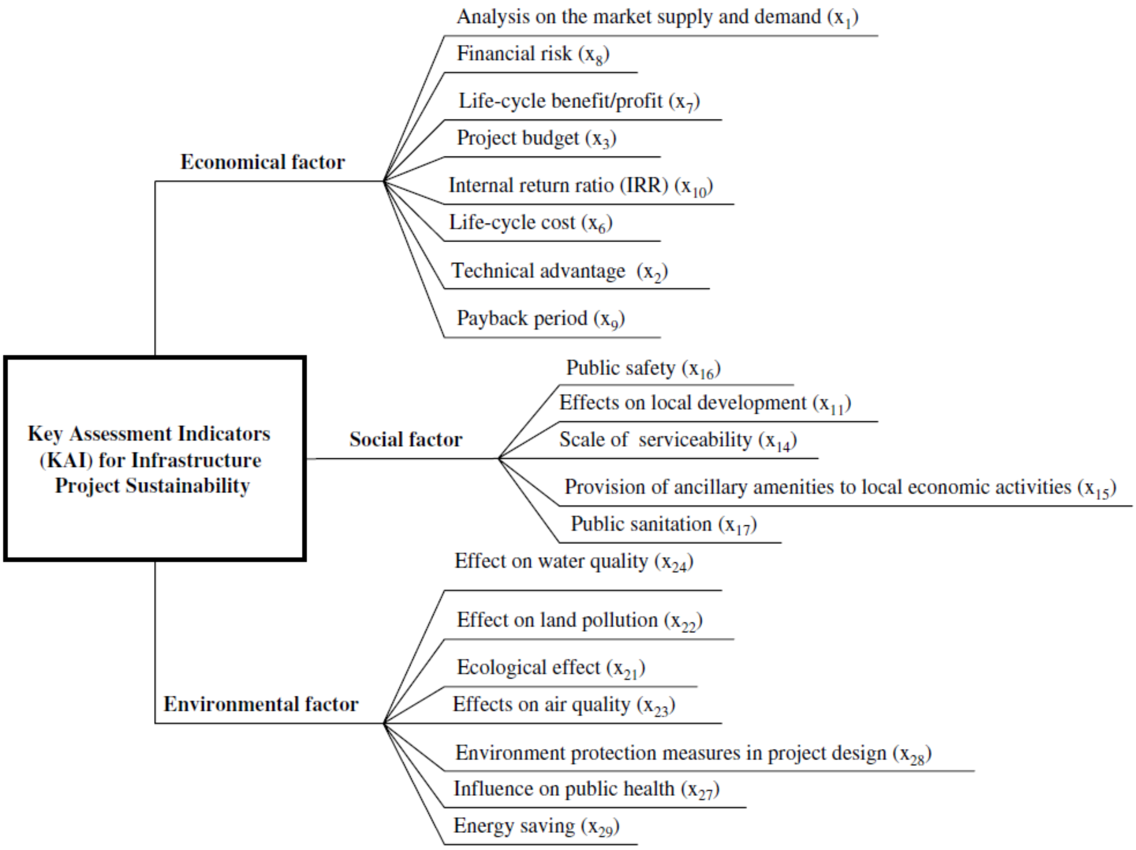


Figure 5.1 Key assessment indicators for an infrastructure project's sustainability

(Source: Shen *et al.* 2011)

5.2.3. Integration of sustainability indicators

Enriching the goals of construction project management with the tenets of sustainable development calls for innovating the composition of sustainability indicators for the construction process. As shown in Figure 5.2, a traditional paradigm for the construction process is endowed with three predominant goals (i.e., cost, quality and time). With the increase in recognizing the negative impacts of construction activities on the environment, many factors such as resources utilization, emission and biodiversity have been included in the field of construction management (Jiang and Wong 2016). Nowadays, a more inclusive approach of construction management is surfacing in academic studies, guiding construction contractors to explore a holistic approach to manage the construction process (Kok *et al.* 2001, Jones *et al.* 2006).

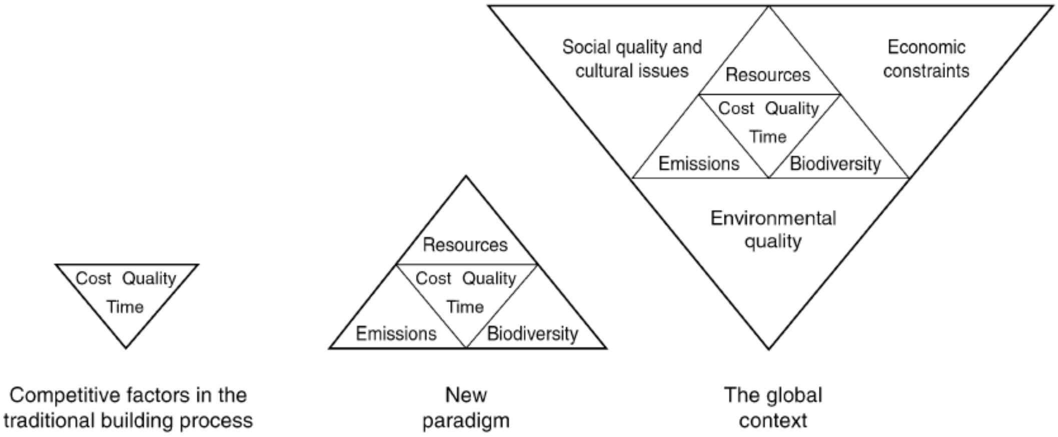


Figure 5.2 Evolution of construction project goals

(Source: Costantino 2006, Sjöström and Bakens 1999)

An expanding diversity of construction project goals outlines the necessity of integrating indicators for measuring the outcomes. As given in Figure 5.3, sustainability measurement in construction consists of six modules, namely analytic hierarchy process (AHP), real cost estimation, pollution estimation, energy estimation, time estimation, and natural resource depletion impacts analysis. It seems therefore that the formulation of a SPCP indicators set might be quantitative or qualitative, and quantifying economic indicators is easier than quantifying those indicators that are social and environmental.

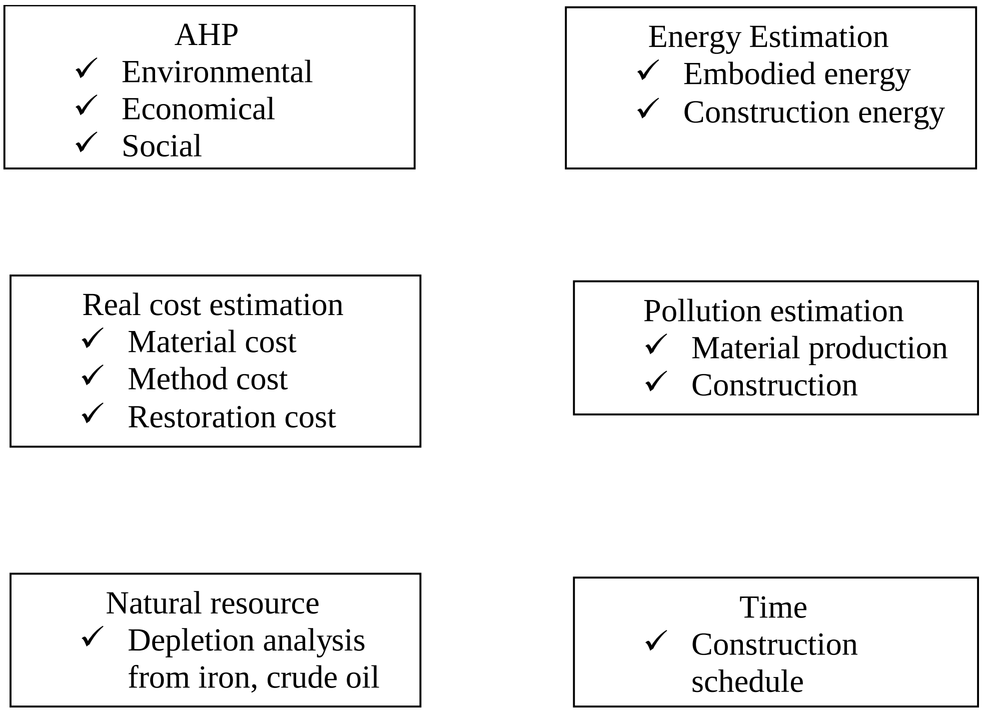


Figure 5.3 Modules for measuring sustainable construction performance

(Source: Koo and Ariaratnam 2008)

5.3 Understanding multiple dimensions of sustainable construction performance

Notwithstanding the environmental impacts of construction business, the link of construction activities to SPCP is covert and sophisticated (Chen and Chambers 1999). As given in Figure 5.4, sustainable construction performance may be measured using an indicators set rather than an indicator. The indicators set comprises three parts (i.e., economic, environmental and social), each having a number of items. Since a proper perception of the construction process favours the formulation of sustainability indicators, this section will present an understanding of sustainability indicators with the emphasis on multiple dimensions.

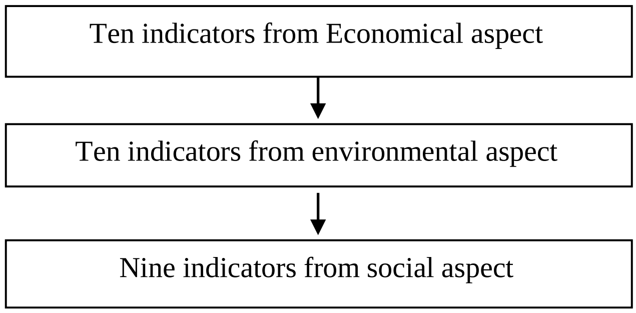


Figure 5.4 An indicators set for measuring sustainable construction performance (Source: Koo and Ariaratnam 2008)

5.3.1. Environmental dimension

Environmental degradation is an all-pervading phenomenon over the globe (Shen *et al.* 2007). The built environment is responsible for 50% of the total UK energy consumption; of which 45% is used for heat, light and ventilate buildings and 5% for construction (Pitt *et al.* 2009). Since the environmental impacts of construction activities take place frequently, an unfailed monitoring process to appreciate contractors' environmental efforts is often considered (Shen *et al.* 2005). Basically, environmental impacts caused by construction activities are concerned with air, waste, water, noise, land, and the nearby community (Table 5.1). Land degradation (erosion, aridity, desertification, drought, flooding, alkalization and salinization), shortage of fresh water, deforestation, air and water pollution and pressure on existing infrastructure are cited as outstanding environmental impacts of a construction project of infrastructure (du Plessis 2002). Such environment-related problems can be traced back to the construction process and they are extraordinary in the developing countries. For instance, considerable developing countries have been confronted with fragile environments (e.g., high levels of land degradation, acute shortage of fresh water, loss of forests), and the rapid urbanization in the past decades have become an issue due to the problems of air and water pollution and dust emission (du Plessis 2002, Melchert 2007).

Table 5.1 Environmental indicators for construction project sustainability

First level	Second level
Environmental aspect	Recyclability of scraped material
	Waste after decommissioning
	Construction nuisances (noise, vibration, visual impacts, etc.)
	Job site disturbance and restoration
	Disruption of the ecosystem during construction endangered and threatened species on the site
	Selection of the construction method and impacts to the existing environmental hazards
	Likelihood of landslides, erosion, and sedimentation (environmental hazards) potential
	Long-term water pollution
	Long-term local air pollution
	Long-term ground/soil contamination

(Source: Koo and Ariaratnam 2008)

Construction activities can weaken the ability of the biophysical environment in the process of delivering life-support services to the human being (Plessis 2007). Many construction-related factors can be outlined such as materials selection, specification for building materials, selection of construction technologies, control of toxic chemicals, disposal of dangerous wastes, recycling of construction wastes, reuse of construction components, environmental control law, and environmental education (Wu *et al.* 2004). The study by Ugwu *et al.* (2006)

proposed an indicator system used for measuring the sustainability of an infrastructure project, in which the environmental indicators spell out land use, water, air, noise, and waste - solid (construction material, dredged/excavated material) and liquid (toxic, non-toxic). Environmental indicators used in previous studies include water pollution, noise, air pollution, emission, soil damage, solid wastes, loss of forests and wild lands, loss of non-renewable energy sources, sewage, loss of non-renewable materials, traffic, health hazards, and loss of biodiversity (Hill and Bowen 1997).

5.3.2. Social dimension

The construction process is additionally a social process (Abowitz and Toole 2010). A major characteristic of the construction sector is embodied by actors participating in a variety of construction activities, from development phase to deconstruction or demolition phase through the operation phase of each component of the built environment. As listed in Table 5.2, the expectation, requirements and interests of these actors in the domain of construction management may be addressed under the heading of social sustainability.

Table 5.2 Social indicators for construction project sustainability

First level	Second level
Social aspect	Workers safety
	Requirement of utility relocation due to the project development
	Limitation of accessibility (causing segregation of community)
	Public support of the project (acceptance)
	Social and cultural impacts due to the project
	Preservation of historical and archeological assets
	Social impacts due to the resident relocation
	Public safety
	Vulnerability of infrastructure from vandalism and sabotage

(Source: Koo and Ariaratnam 2008)

Business is assumed to dedicate more resources for the attainment of social sustainability. This is particularly the case in the construction sector as construction activities are in nature labour-intensive and the industry has the potential of alleviating poverty (Sjöström and Bakens 1999). Improving the welfare of employees at work will in turn improve their personal lives, which can further influence their families, friends and wider community. Due to unsafe work conditions, it is very important that construction workers are provided with necessary protection. The surrounding society from traffic congestion and delays, disruption of economic activities, generation of pollution and pollutants, damage to sensitive ecosystems, and damage to existing structures and infrastructure systems are entering the eyesight of construction practitioners (Gilchrist and Allouche, 2005).

A number of indicators have been offered in previous studies to measure the social sustainability of a construction project. The indicator system proposed by Ugwu and Haupt (2007) assesses societal sustainability of infrastructure projects with (a) cultural heritage - complaints from local parties/villages; (b) public access - extent of diversion, extent of blockage; and (c) public perception - Fung Shui. Similarly, the work by Shen *et al.* (2011) established an option list of indicators for measuring the social performance of infrastructure projects including effects on local development, provision of employment opportunities, project function, scale of serviceability, provision of ancillary amenities to local economic activities, public safety, public sanitation, land use and its influence on the public, protection to culture heritage, and promotion of community development.

According to Shen *et al.* (2010), the social performance attributes of construction project include the following items: influence to local social development, provision capacity of employment, provision capacity of public services, provision capacity of public infrastructure facilities, and provision of infrastructures for other economic activities, safety standards, improvement to the public health, cultural and heritage conservation, and development of new settlement and local communities. With reference to a number of studies focusing on social sustainability in the construction context, Zuo *et al.* (2012) attributed social sustainability in construction to traffic, quality of life, ecological impacts, health and education, security, cultural diversity, economic contribution, equity, employment, cultural heritage, infrastructure provision, and macro social performance. Therefore, the development of indicators for social sustainability has the importance of responding to social matters on a construction site.

5.3.3. Economic dimension

As presented above, the construction process consumes materials and causes air pollution by releasing dust and toxic fumes during the production and transportation of materials. To ensure successful delivery of construction projects, measures are often adopted on construction sites including erecting fencing, managing security, providing means for the disposal of hazardous materials, managing traffic conditions, providing covered walkways for pedestrians, arranging times and locations for delivering materials to the site, and providing safe storage for materials on sites (Zuo *et al.,* 2012). Minimizing impacts and disturbance to local community in the construction and demolition stages is perceived as extremely important to the implementation of sustainable construction (Zuo *et al.,* 2012).

As described in Table 5.3, the construction process has economic benefits arising from better relationships with clients, local community and other stakeholders. According to Shen *et al.* (2011), indicators for measuring economic performance of infrastructure projects include project budget, project financing channels, project investment planning, life-cycle cost, life-cycle benefit/profit, financial risk, payback period and internal return ratio. Overemphasis on economic performance of a construction project can easily be found in the construction industry. In order to achieve economic targets, contractors often attempt to lower unnecessary cost and to enlarge any potential income as much as possible.

Table 5.3 Economic indicators for construction project sustainability

First level	Second level
Economic aspect	Construction material quality
	Quality of the completed infrastructure structure
	Land and space availability for future development after the project
	Selection of an effective procurement method
	Selection of an effective contract type
	Potential legal dispute
	Infrastructure service fee escalation due to the project funding or tax
	Economic benefits/effects to the local community from the project development
	Social cost due to the project development
	Capability of proper operation and maintenance during the life cycle

(Source: Koo and Ariaratnam 2008)

The economic effect of the construction process is easily subject to misinterpretation. Any type of benefits and impacts may be valued in economic (money) terms, "willingness to pay", or insofar as considerable construction activities are a useful angle to image the prosperity of the economy. Nevertheless, evidences have shown that this kind of practice may not always lead to the saving of construction cost.

The effectiveness of sustainable construction methods is unsatisfactory in practice. One of the barriers is that people have not much confidence in the attainment of sustainability in terms of its contribution to improve project value such as improved quality of output, productivity, profitability, reduction to life cost and business enhancement (Abidin and Pasquire 2007). This limitation is partly due to profit-driven culture in the industry where cost, time, and quality have been the determinants ensuring maximum benefits to the client. The construction process also creates some other economic impacts as fiscal impacts, which can affect government revenues by expanding or contracting the tax base.

5.4 Justification for a new set of SPCP indicators

The richness of prior research in the area of sustainable construction lays a useful foundation for this study to look at whether it is necessary to formulate a new set of indicators for SPCP measurement, and in what ways the indicators set can be developed properly. To answer this, strengths and weakness of established indicators are discussed below.

5.4.1. Strength of the established indicators

The established indicators set for sustainable construction measurement is well grounded on the definition for sustainable construction. The term sustainable means lasting for perpetual (du Plessis 2002), while sustainability means "… that which is capable of being sustained; in ecology the amount or degree to which the earth's resources may be exploited without deleterious effects" (Chambers 1993). In line with this definition, sustainable construction is often deemed to be a chain of activities which starts as early as the planning and design stages and continues after the construction team leaves the construction site (Bon and Hutchinson 2000). The quality of human life ought to be improved within the carrying capacity of supporting ecosystems in adherence to the principle of sustainability (Hill and Bowen 1997). As indicated in Section 2.4.2, indicators for mirroring sustainability in construction must account for those construction activities that can present social, economic, biophysical and technical impacts (Hill and Bowen 1997).

The established indicators set is reflective of the construction process. The construction process is dominated by a population of individuals and they represent some interest groups or organizations. A well-managed, skilled and motivated workforce plus attractive working conditions add values to the success of a construction project. Good health and safety practices enable contractors to improve efficiency and avoid accidents, and save both management time and legal cost. Initiatives to improve staff skills, job satisfaction and motivation must have positive business benefits in improved efficiency and productivity. Accordingly, a set of indicators should have its promotion for interdisciplinary collaboration and multi-stakeholder partnerships. This concern has been echoed in the established indicators set. For instance, it is stressed that sustainability aspects include natural resource, environmental quality, biodiversity, social equity, cultural conservation, and economical benefits (Koo and Ariaratnam 2008).

The established indicators set could be an embodiment of *Agenda 21*. Many of the problems and solutions being addressed in *Agenda 21* have their roots in the construction process (Guy and Kibert 1998). The understanding or interpretation of sustainability in the construction sector has undergone substantial change over years. In the beginning the emphasis was on how to respond to the challenge of limited resources such as energy, and on how to mitigate the adverse impacts of human activities on the natural environment. It was later on shifted to more technical consideration such as materials, building components and construction technologies. Such considerations were extended to the phase of planning and design. Currently, non-technical issues have gained closer attention and a larger number of practitioners also realize that a couple of “soft” issues are the core of sustainable construction (Sjöström and Bakens 1999). For instance, the protection of cultural heritage has been recognized as prominent issues and both governments and business have reached consensus on it (Ugwu and Haupt 2007).

5.4.2. Weakness of the established indicators

Researchers have stated that the extent to which the construction industry is able to decrease energy consumption and greenhouse gas emission is reliant on the procedure of construction process (Shen *et al.* 2007). However, sustainability choices made in the process are often criticized for inefficiency and ineffectiveness as they rarely view the construction process from a lifecycle perspective (Shen *et al.* 2007). Construction projects in different sizes differ from each other in complexity, and the construction process might last shortly for a few months or long enough for decades.

Solow (1993) pointed out that sustainability means more than just the preservation of natural resources. Hence, a comprehensive and pragmatic approach to “sustainability in construction” should be devised in due ways (Chen and Chambers 1999). Koo and Ariaratnam (2008) offered forty-seven sustainability indicators for measuring the sustainability performance of an infrastructure project by using the approaches of interviews and surveys of experts. The survey was structured with questions for respondents to rate the significance of each sustainability issue - economic, environmental, and social. However, the assessment process was demonstrated only by using a case study approach. The indicators adopted in these previous studies for project sustainability assessment are fragmental, and very few methods incorporate the three dimensions embodied in sustainable development principles. They assessed the indicators using Likert scale, evaluating the magnitude of sustainability relevance through multiple project stakeholders.

A few sustainability assessment techniques for building development have been summarized such as the leadership in energy and environmental design (LEED) method. LEED rates sustainability by accumulating scores from multiple categories including economic performance, resource use, environmental impacts, energy conservation, and long-term operation and management (USGBC 2009). The LEED method is known to be an effective method; however, it is limited to housing and building applications rather than infrastructure systems.

Furthermore, these indicators sets that are based on project management outcomes cannot support dynamic feedbacks to improve construction project management timely. Stakeholders such as government, consultants, contractors, non-government organizations and the public in the construction process are participatory, interactive and consensual (Gardner 1989). Stakeholder management is weakly supported from these indicators sets and thus stakeholders might not be satisfied even though sustainable construction practices are implemented properly.

5.4.3. Implications for formulating a new SPCP indicators set

According to the above discussion, the diversity of established indicators for measuring the performance of sustainable construction does not request for a completely new set of indicators for SPCP measurement. Instead, the established indicators can be improved to satisfy some predefined research aims. In this study, the improvement is placed on the strengths of established indicators while the weakness of them are rectified in the meanwhile. As the present study is intended to investigate the effects of CSR-C activities on SPCP, a new SPCP indicators set is supposed to demonstrate the dynamic mechanism of this process in which the impacts of social responsible activities on sustainable construction can be observed and detected efficiently.

The attributes of the construction process (Section 2.2.2) highlight the importance of using an indicators set to reflect the comprehensiveness of the construction process. Since construction activities span widely, steps for formulating sustainability indicators ought to match the boundary concerned. As shown in Figure 5.5, a few steps should be followed prior to the identification of indicators. Features of the project in terms of location, type and capacity must be considered.

Boundary of the measurement should be defined to explain which level (i.e. macro or micro) and what timeframe the study is based on.

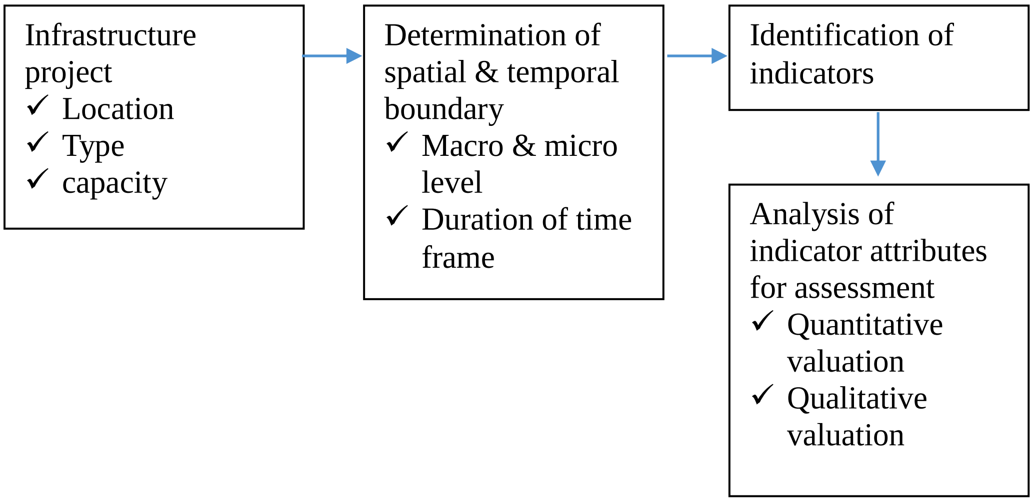


Figure 5.5 Sustainability indicator identification process (amended) (Source: Koo and Ariaratnam 2008)

A well-developed indicators set deserves validation and it is useful for assessment in a way either quantitative or qualitative. In the present study, the identification of SPCP indicators is not confined by specific features of the project, but it is important to elaborate the level and the timeframe that the measure stands for. Therefore, two research methods, namely literature review and Delphi survey are adopted in this step.

5.5 Formulating indicators for SPCP measurement

5.5.1. Literature review

The steps of conducting literature review presented in Section 2.7.1 are repeated again with keywords of "sustainable construction", "performance indicator" and "construction activities". As a consequence, there are totally 8 papers suitable for further analysis in this study, and each one is examined carefully to extract indicators. As shown in Table 5.4, 18 indicators are identified for SPCP measurements.

Table 5.4 Identified SPCP indicators

Indicators	a	b	c	d	e	f	g	h
Air pollution	√	√		√	√	√		√
Biodiversity protection	√							
Comfort disturbance	√							
Conservation of cultural/natural heritage				√				√
Construction quality		√		√				√
Construction cost saving	√	√		√				√
Construction schedule saving		√		√				
Construction waste	√				√	√		√
Dust emission					√	√		
Employment of labour	√							√
Energy utilization efficiency	√	√	√	√	√	√	√	√
Health and safety	√			√			√	√
Infrastructure burden	√							
Land utilization efficiency	√		√	√	√	√	√	√
Lighting pollution					√	√	√	
Materials utilization efficiency	√	√	√		√	√	√	√
Noise pollution		√			√	√	√	√
Water utilization efficiency	√	√	√	√	√	√	√	√

Note: a - (Shen *et al.* 2007); b - (Bakhtiar *et al.* 2008); c - (Kibert 1994); d - (Koo and Ariaratnam 2008); e - (Majdalani *et al.* 2006); f - (Pitt *et al.* 2008); g - (Aktins, 2001); h - (Ugwu and Haupt 2007).

5.5.2. Delphi survey

In order to refine the indicators identified above, a Delphi-type survey of industry and academic experts are carried out. This approach is broadly used in the discipline of construction management to collate opinion consensus of experts on some defined issues. Effectiveness of the approach has been acknowledged by researchers in the area of construction management for concept/framework validation (Okoli and Pawlowski 2004). The validity of findings from a Delphi process depends on the expertise of the constituted panel. Therefore, panel members are carefully selected to mobilise in-depth knowledge and experience in SPCP indicators.

Table 5.5 describes the profile of expert panel by working year, location, organization and expertise. Guidelines provided by Delbecq *et al.* (1975) are followed strictly. The experts attended are academics and professionals with long-standing knowledge of sustainable construction.

Table 5.5 Profiles of participants

Position	Particular			
	Working year	Location	Organization	Expertise
Project manager	10	Shenzhen	Property developer	Construction project planning and schedule management
Project manager	7	Shanghai	Contractor	Construction technologies management
Project manager	13	Shandong	Contractor	Organizational cultural, project management
Department manager of construction	10	Wuhan	Construction enterprise	Construction management, enterprise management
Director	18	Beijing	Construction enterprise	Construction management
Associate director	15	Hangzhou	Contractor	Project management, tendering
Senior engineer	14	Chengdu	Contractor	Construction quality and HSE management
Senior engineer	15	Zhengzhou	Construction enterprise	Construction technologies development and innovation
Human Resources management	6	Haikou	Property developer	Human resources management and utilization
Associate Professor	8	Chongqing	Chongqing University	Green construction
Associate Professor	10	Jiangsu	Southeast University of China	Construction management

Note: Names of the experts are not shown for privacy.

A total of 11 experts are successfully invited to participate in the Delphi survey process. Each participant is sent an email invitation/request with a 3-page attachment describing the identified indicators and its envisaged development.

They are requested to understand the research purpose exactly and then to rate their judgement on indicators to give a 5-point Likert scale. Measures of rating similarity (e.g., the mean ratings of experts) is used before any inference can be drawn from the Delphi survey, and thus interrater reliability (IR) and interrater agreement (IA) are calculated. IR spells out the consistency of the pattern of rations by all experts; IA indicates the degree of similarity in the level or magnitude of rating by all experts. Results of the survey are as follows: mean score (2.85 - 4.30), and standard deviation (0.55-1.1), IR (0.40), IA (0.85). As advised by the participants, the indicator “air pollution” should be removed for its abstractness, lowest mean score (2.85) and difficulty in quantification. Therefore, the results indicate a high consensus among experts on the suitability of the basic framework (seven indicators) for further development.

5.6 Restructuring SPCP indicators

Previous studies have reached an extensive consensus on the contents of measuring sustainability performance for a construction project, namely minimizing environmental impacts, maximizing economic benefit and output, social and cultural conservation, and satisfying basic requirements such as structural soundness and capacity (Koo and Ariaratnam 2008). Whilst this study agrees on these intentions, it is considered that SPCP indicators should be restructured to facilitate the examination on the effects of CSR fulfilment on SPCP. Hence, this section presents a new framework proposed to devise a SPCP indicators set.

5.6.1. An “input-activity-output” model

As presented in Chapter 2, the construction process may be subdivided into five main stages as follows:

(a) Conceptual/inception stage – the client identifies the need for the item of construction and appoints and briefs consultants who examine the client’s requirement, propose an outline of the design, and assess the feasibility of the project.

(b) Design stage – the concept of the project is further developed and production information and contract documentation prepared. Tenders are called at this stage.

(c) Construction stage – production programs are prepared and construction carried out on site.

(d) Operation stage – the completed building or works is delivered for utilization.

(e) Demolition and/or maintenance stage – the completed building or works is maintained, repaired or altered as required over the course of its life.

The application of advanced technologies as well as the expansion of population worldwide have given rise to dramatic depletion of the earth’s natural resources (Bon and Hutchinson 2000, Hill and Bowen 1997). Construction activities are conducted with an aim for the erection of a physical facility. The impacts of construction activities on society and the environment usually go beyond the boundary of a construction site. The impacts scattered along the lifecycle of the built facility. Hence, examining SPCP indicators without connecting one stage to another would infringe the principle of sustainable construction.

The construction process is composed of two key stages, namely pre-construction and construction execution. During the construction execution period, activities are carried out in accordance with design specification, which involves utilization of all types of resources such as labour, construction equipment and materials. The construction process is a combination of technology push and demand pull (Bowden *et al.* 2006), and it is subject to technological complexity and managerial expertise.

In line with the definition of sustainable development given by the World Commission on Environment and Development (WCED), construction activities shall meet the needs of the present without compromising the ability of future generations to meet their own needs. To avoid that such a concept is too general to be applied, previous studies have outlined a pressure-state-response framework that illustrates the linkage between human activities and the environment (Guy and Kibert 1998). This framework presents a connection between pressure brought by human activities on the environment, the environmental states that occur, and the responses of society to those states. According to this framework, minimizing consumption of non-renewable resources, elimination or minimization of the use of toxins, and reduction of energy consumption are the key to the measurement. Therefore, a number of goals with respect to construction time, capital cost of construction, quality, accidents, waste, and productivity specify the outcomes of the construction process.

The construction process is unfolded with a sequence of activities/works that differ from one project to another. In appreciating this, an input-activity-output model is proposed in this section to structure the indicators for the convenient measurement of SPCP. The construction process includes utilizing various types of resources including knowledge, experiences, human resources, equipment, materials, and financial capitals. Many organizations and individuals are involved in this stage, including subcontractors, material suppliers, designers, consultants, and thus the management focus is on coordinating various stakeholders to establish a temporary team.

The new framework is proposed here in light of the input-process-output procedure indicated in Figure 2.1. As presented above, the construction process contains five stages, namely inception, design, construction, operation, and demolition (Shen *et al.* 2007). Behind these five stages are some input-process-output procedures. A typical instance goes to the formulation of an environmental indicators set following an input-process-output model. Specifically, since embedding the tenets of green construction in the inception phase facilitates the attainment of sustainability (Barrett *et al.* 1999), designers and planners should be motivated to use passive energy technologies to equip a green construction project (Lichtenstein *et al.* 2013). A vast majority of resources consumed on construction sites are non-renewable, and their environmental impacts can be triggered from the manufacturing step (Ye *et al.* 2015). Construction materials such as bamboo sticks for scaffold has gained much popularity nationwide in China. Owners/users of a built facility will find it costly to rescue environmental problems if the construction process is placed on scant attention to sustainable construction practices.

5.6.2. Construction inputs indicators

Previous studies have presented a priority for the construction sector to reduce the consumption of resources (Ofori 1998). Reduction, recycling and reusing in the consumption of resources satisfy the principle of resource efficiency (du Plessis 2002). While reduction of building materials necessitates a mixed approach of management, design, cultural and technological practices, it is very important to identify the range of construction resources.

The construction resources refer to those inputs that are manmade or natural (e.g., water, land, wood, stone, sand, energy and soil). The manmade resources include equipment, steel, pipe, grass or some other intangible inputs such as human capital, culture, managerial expertise, and entrepreneur. As stated by du Plessis (2002), land is a costly commodity and the basis of many an economic activity on which survival rests. Reducing consumption of natural resources, the deposition of landfill, energy consumption of material production and all its associated pollution are typical construction activities in the construction process.

In view of the definition of “input-activity-output” framework discussed above, four indicators listed in Table 5.4 are drawn out as construction inputs indicators. These four indicators are elaborated in Table 5.6.

Table 5.6 Construction inputs indicators

Indicator	Definition
Land utilization efficiency (or landing saving)	Measuring how a contractor use land available to conduct construction activities without generating land pollution (e.g., soil erosion, destruction of natural habitats of flora, degradation of waterways).
Water utilization efficiency (or water saving)	Measuring the efficiency of water utilized without generating further pollution.
Energy utilization efficiency (or energy saving)	Reflecting the efficiency of energy (e.g., electricity, fossil fuels) consumption during construction.
Materials utilization efficiency (or materials saving)	Reflecting the efficiency of materials utilization (e.g., wood, stone, sand, concrete, and steel) on construction sites.

5.6.3. Construction activity indicators

A process can be defined as a series of operations in the design, development, and production of something such as an infrastructure project (Wu *et al.* 2004). It is a course or passage of time in which something is created. A process is characterized with a series of actions, changes or operations, and objectives (e.g., cost, schedule and technical performance). Activities during the construction process include preliminaries, demolition, excavation and foundation, concrete and brickwork, finishes, M&E works, and external works. Main contractors and subcontractors transform production factors into a physical facility. Members of the design team supervise construction. Architect/engineer issues payment certificates periodically on the recommendation of quantity surveyors. On completion, architect applies for a temporary occupation license. Therefore, the construction process involves the translation of a client's needs and intentions, and it provides a lens for observing how production and construction activities are able to impact the environment and society.

There are many complex issues which can lead to failure of a project in functional and/or timely manners. The construction process is made up of a number of activities such as hoarding, earthwork, piling, capping, timber formwork, bar bending, reinforcement, paving, grass turfing, screens installation, and painting. It is highly dependent on the application of technology on a construction site including hard technology related to equipment and materials, industrial processes and physical infrastructure solutions, and soft technology such as systems, mental models and those tools that support decision making, monitoring and evaluation, and knowledge and information. In the construction process (i.e., design, construction, production, site activation, testing, delivery), resources are consumed and pollution is created. Since extra cost will be added if some procedures of the construction process have to be reorganized, it is very important to formulate a list of indicators that are flexible enough to measure the impacts of construction activities. By doing so, the practice of sustainable construction can be informed in a regular style.

Bearing in mind the perspective of CSR-C fulfilment, some examples of construction activities indicators can be improving the quality of human life, implementing skills training and capacity enhancement of the disadvantaged, seeking fair or equitable distribution of construction social cost, and seeking intergenerational equity (Lema and Price 1996, Cheng and Tsai 2003, Guo *et al.* 2007). Training and education services may be provided to employees for their professional development. Other common criteria of social sustainability comprise economic contribution, equity, employment opportunities, infrastructure provision, protection of cultural heritage and quality of life (Zuo *et al*. 2012). Keep the public out of work sites through the implementation of adequate fencing (Croker 2013). Proper traffic management is required to ensure safety of road users. This includes reduced speed limits around changed traffic conditions and directional information to direct traffic appropriately to eliminate confusion and accidents. Measures should be adopted to guarantee safety pedestrian including providing alternate walkways when footpaths are blocked off. Control of dust emission and noise pollution, as well as safe disposal of hazardous materials can also be considered for the health and safety of community (du Plessis 2002).

In view of the definition of “input-activity-output” framework proposed in this section, a total of eleven indicators listed in Table 5.4 are refined as construction inputs indicators. However, after consulting the interviewees, ten indicators are interpreted in Table 5.7.

Table 5.7 Construction activities indicators

Indicator	Definition
Lighting control	Lighting generated on a construction site that cause discomfort to workers and local residents.
Noise control	Construction activities such as the idling of equipment, scrubbers and mufflers in equipment, limiting certain activities that cause noise and make workers and local residents feel uncomfortable.
Dust control	Emission of silica, one of the most abundant minerals on earth and found naturally in masonry, stone, sand and aggregates.
Waste management	Wastes of construction materials input for construction activities such as materials, concrete, steel and wood.
Employment opportunities added	Employment opportunities created by the construction project
Health and safety management	Impacts of construction activities on the health and safety of construction workers.
Conservation of cultural/natural heritage	Disturbance to cultural/natural heritage due to the commencement of construction activities.
Overload of infrastructure utilization	Completion against local residents for an increase in use of infrastructure in an unreasonable way.
Comfort disturbance control	Disturbance to local residents in terms of transportation, communication and daily life.
Biodiversity management	The reduction of biodiversity due to construction activities.

5.6.4. Construction outputs indicators

A socially responsible contractor is intended to deliver a project such as transport infrastructure, green building and factories to the client or end users. The extent to which contractors perform the construction process depends on the requirements of the client in describing the potential facility they want. Basically, construction activities build up physical facilities. The built facility continues to consume energy, resources, and materials, and contributes pollutions to the environment. The construction process can result in the completion of a whole project like a building, or part of the project such as a garbagy, a few miles of road, compound wall, and site cleaning. It is thus appreciated important to develop a set of indicators to measure construction outcomes in line with the principle of sustainable construction.

The product of the construction industry is a physical facility that is unique in design and method of production. It is a single "one-off" item stylized in terms of its function, appearance and location. The work program for construction site management elaborates schedule for all major activities in the contract with respect to critical activities, early start time, early completion time, milestones, and sequence of works. Thus, time should be an outcome of construction activity. Outcomes of the construction process refer to those facets that a construction project is delivered to the client in due time, within budget, and with satisfied quality as stipulated in the construction contract. Therefore, it is suggested to propose a set of indicators for measuring SPCP by fixing the line on the outputs of the process. The output of the construction process can embody a comprehensive lens for observers to look at the overall performance of contractors.

In view of the definition of "input-activity-output" framework discussed above, three indicators listed in Table 5.4 are drawn out to be construction inputs indicators. These three indicators are explained in Table 5.8.

Table 5.8 Construction outputs indicators

Indicator	Definition
Cost management	The saving of construction cost in comparison to similar construction project.
Schedule management	The saving of construction schedule in comparison to similar construction project.
Quality management	The improvement of construction quality in comparison to similar construction project.

5.7 Summary

Previous studies have employed three dimensions, namely economic, social and environmental, to measure sustainable construction performance at the project level. Nevertheless, they are not effective enough for detecting the impacts of CSR activities on SPCP indicators. In view of the interdependence between established indicators, the identified indicators are reintegrated into three dimensions, namely construction inputs of resources, construction activities and construction outputs to reflect a cause-and-sequence view on the construction process.

Chapter 6. UNDERSTANDING SYSTEM DYNAMICS IN CONSTRUCTION

6.1 Introduction

As presented in Chapters 4 and 5, 37 CSR activities are identified to present the engagement of Chinese contractors in practice and 18 indicators to measure SPCP. Meanwhile, the effects of CSR-C on SPCP appear to be a causal-sequential relationship. In this chapter, a review on the theory of system dynamics will be presented, and CSR-C activities are discussed in association with SPCP indicators. Specifically, CSR-C activities are linked to SPCP indicators one by one. A system dynamics model can thereby be justified in building a model for simulation in the study.

6.2 Principles of system dynamics (SD)

6.2.1. Concepts of system dynamics

Before presenting the concept of SD, it is vital to discuss the basic meaning of system to lay a theoretical foundation for model development in the study. According to the definition given in Wikipedia, the so-called *system* refers to a set of interacting or interdependent component parts forming a complex/intricate whole. There are many types of systems that can be investigated in both quantitative and qualitative ways. A system can be a very sophisticated form of program logic, or concept mapping is needed to relay the essence of the system.

The size of a system varies remarkably from one field to another, and a system could be structured in a different fashion. In the area of social science, for instance, the attributes of a system could be openness, mechanics, organization, and evolution. Everything that goes in business may be part of one or more systems.

SD is a branch of systems theory. As a method, SD has been applied to explore the dynamic behaviours of complex systems (Shen *et al.* 2005). Nonetheless, giving a precise definition to a social system in a prompt way is not an easy thing to do. One of the main reasons is that the interdependence between a social system's components is covert; different observers may interpret a social system in accordance with their own knowledge, experiences and perceptions. Since the focus of this study is on the construction project level, materials, equipment, technologies and workforce assembled in all steps can be incorporated into the construction process. In appreciating the inherent relationships between project participants and the integration of construction activities, the construction process is defined to be a system or a subsystem to a larger system (e.g., an infrastructure project). By contract, the approach of structural equation modelling might not be useful to present the complicated relationship between CSR and sustainable construction. Viewing the construction process from a system perspective is thus essential to the operation of construction business in the ways towards sustainability. Furthermore, identifying the dynamic relationships between components of a system helps recognize the possible consequences of those relationships or to develop theories about them. With this in mind, researchers have attempted to advance existing approaches and the approach of SD is a typical example in the area (Thompson and Bank 2010).

The method of systems thinking is an effective instrument for exploring how difficult management problems are arising. This tool has been well established for over thirty years (Forrester 1961), and it is widely used in the discipline of construction management and economics. For instance, the transaction and delivery of construction business can be examined using the SD approach for improvement (Thompson and Bank 2010), the sustainability performance for an infrastructure project is revealed in a system way (Shen *et al.* 2005, Zhang *et al.* 2013), and waste management can be appreciated from the perspective of economic, social and environmental sustainability (Yuan 2011). Construction business performance concerning how one set of events causes another has often been examined in the same way (Beheiry *et al.* 2006). In some cases, a problem related to construction management on a project site may be explored to detect how a particular set of construction events is part of a longer term pattern of enterprise behaviours (Shen *et al.* 2005).

SD offers an approach in which the model is developed to resemble reality, and competitive strategies or management policies can be devised correspondingly to image the reality. To this end, the consequences of intervention, timing, delay and feedback between the system's components have the importance of being detected in right ways. The principle of SD presents a requirement for the academic to shift from viewing isolated events and their causes to examining the organization as a system made up of interacting parts.

SD is a mathematical modelling technique to frame, perceive, and explore complex issues and problems. It has attracted much attention in many public or private sectors for policy analysis and simulation. Nevertheless, the difficulty that researchers ought to be confronted with is to address the issue "events cause events" and to derive an effective way to alter the undesirable performance (Zhang *et al.* 2013). The disadvantage of this approach is that researchers may be subject to finding yet another event that caused the one that they thought was the cause. If this is raised to be a problem, determining a comprehensive way to improve organizational performance will become complicated and hard to verify.

6.2.2. A SD-based reconsideration on the construction process

As presented in Section 2.2, the construction process forms an important part of a construction project system, but it configures a system by itself. This system encompasses a number of subsystems that are representative of management, technology, economics, and contract. To ensure the integration of system function, it is unrealistic to single out any element when implementing a construction plan on a consecutive basis. In essence, the project management team ought to undertake construction works by accounting for different claims for interest from different stakeholders. Therefore, the targets of the construction process are multidimensional probably including schedule, cost, quality, environment, and safety. Construction practitioners are often reminded to handle the interdependence between these targets in order to deliver construction works in systematic ways.

The completion of construction works for a specific project is determined by many factors such as the availability of land space to accommodate construction activities, preparedness of construction materials, stock of workforces, and reasonableness of construction plans (Ofori 1990). In the process of construction activities, resources are deployed while the impacts of resource utilization on the environment might not be immediate. Construction contractors are required to remove any negative impacts using a holistic approach. On many occasions, technological renovation or procurement renovation is necessitated to achieve an unexpected problem that they are facing. However, it should be a daunting task to recognize all the potential factors that could lead the construction project teams to make right decisions.

While approaches to the attainment of SPCP and the determinants of these approaches have been documented in the literature (Opoku and Fortune 2011, Brown and Barber 2012), contractors seems to have little knowledge of how to improve SPCP by fulfilling social responsibility. Viewing contractors' performance on construction sites from the perspective of CSR fulfilment can hopefully answer why CSR could be fulfilled on production lines and the extent to which contractors become more productive and responsible. Therefore, the motivation of this study is based on the assumption that the fulfilment of CSR generates substantial effects on the attainment of sustainability along the construction process. Examining this from the perspective of SD is a must for the project management team to complete construction works as expected.

6.2.3. Application of SD models in the field of construction management

SD has been demonstrated to be an effective analytical tool and many corporations including Fortune 500 firms, both in China and worldwide, express much interest in using this approach to enhance enterprise management (Yuan 2011). Likewise, SD is often employed to address the issues of construction management. A couple of reasons can be given below:

The management of construction activities on a construction site belongs to the class of complex dynamic systems. Such kinds of system are complex composed of many interdependent components and have multiple feedback processes and nonlinear relationships (Zhang *et al.* 2013). Furthermore, data about construction activities can be tabulated in both “hard” and “soft” forms. SD models have good efficiency in representing such multiple interdependencies. Indeed, one principal purpose of SD application is to capture interdependency of this kind so that the causal impacts of changes can be traced from the outset of the construction process. Interdependencies between the elements of construction management complicate analysis beyond the capabilities of mental models because a change in one part of the construction process may have implications in others.

Out of all the formal modelling techniques, many guidelines of SD have been posed for proper representation and elaboration of the dynamics of complex technical and managerial entities (Tang and Ogunlana 2003, Cruz 2008). Management of a construction project is intrinsically dynamic. Time delays in carrying out programs can be found frequently (Braimah and Ndekugri 2009). Discovering and correcting construction rework errors require contractors not to stop reviewing their behaviours. In responding to unexpected changes in project scope or specifications, contractors must spend extra resources and time accumulating experiences and identifying the potential risks they might have in the next step. The team for construction management has to take a proactive attitude towards the happening they might have and the impacts they generate on the surrounding environment. An event can drive other events to happen and a series of events can lower the probability of achieving project success. Therefore, SD models have the potential of being an effective tool to deal with such dynamics exactly.

6.3 Modelling process of applying SD approach

As discussed above, when a construction management problem is surfacing along the construction process, it is supposed to be that some external events drive it. However, according to the principle of SD, the internal structure of the system deserves more attention than external events in generating the problem (Yuan 2011). In this study, the fulfilment of CSR-C is deemed to be an external event, but the event changes SPCP in its own ways. By applying the principle of the SD approach, the pattern of the changes in behaviours can be simulated.

6.3.1. Purpose of the model

Basically, elaborating the purpose of SD application exactly is a basic step of the modelling process. In this study, three purposes are raised to develop SD models. The first one is to allow decision-makers involved in the construction process to understand the dynamics of construction activities, particularly to comprehend the input and output of construction activities from a dynamic point of view. The model functions as an experimental platform for examining the effects of implementing CSR activities on SPCP.

The second purpose of the model is to provide a useful foundation for identifying those determinants affecting SPCP from a specific perspective. The model's underlying theory explicitly defines the variables that are related to the implementation of CSR and could have impacts on SPCP. It is envisaged that subsequent discussion on the topic will encourage decision-makers to embark on an efficient paradigm in pursuing sustainable construction.

The third purpose is to provide a utilitarian tool for illustrating the advantages and disadvantages of specific management policies to be implemented with respect to CSR engagement. This purpose is to clarify that the impacts of CSR activities are deeply rooted in the construction process, and a construction plan should be addressed to encompass the details of CSR in different construction procedures.

6.3.2. Boundary of the model

In line with the principle of SD, elaborating a boundary for the model from the outset of its development is vital (Sterman, 2000). By doing so, the variables that can be embraced or excluded from the model can be recognized. Since this study is aimed to investigate the impacts of CSR-C activities on SPCP, ranging from construction site preparedness, onsite construction activities, and construction project delivery, is therefore the focus of the model.

Having a closer look at a typical construction process, three nodes can be derived, namely inputs of production elements (e.g., land, materials, water and energy), execution of construction activities, and the completion of construction works. These nodes exist somehow like a chain and work as a flow from the beginning to the end. The construction chain is not a collection of independent construction procedures but a system of interdependent activities, which is a principal reason for the choices of SD as the approach for model development in this study. However, managing the serviceability of a building during its lifetime and eventual deconstruction and recycling of resources to reduce the waste stream is not included in this study.

Based on the above discussion, a conceptual model elaborating the boundary of the model and the construction process can be developed as shown in Figure 6.1. The six rounded rectangles indicating six key areas of CSR-C and three ellipses indicating construction inputs performance, construction activities performance, and construction outputs performance form the boundary of the model. In other words, the model will be concentrated on examining interrelationships of variables affecting input, activities, and output performance of construction activities throughout the construction process chain, which is composed of five phases.

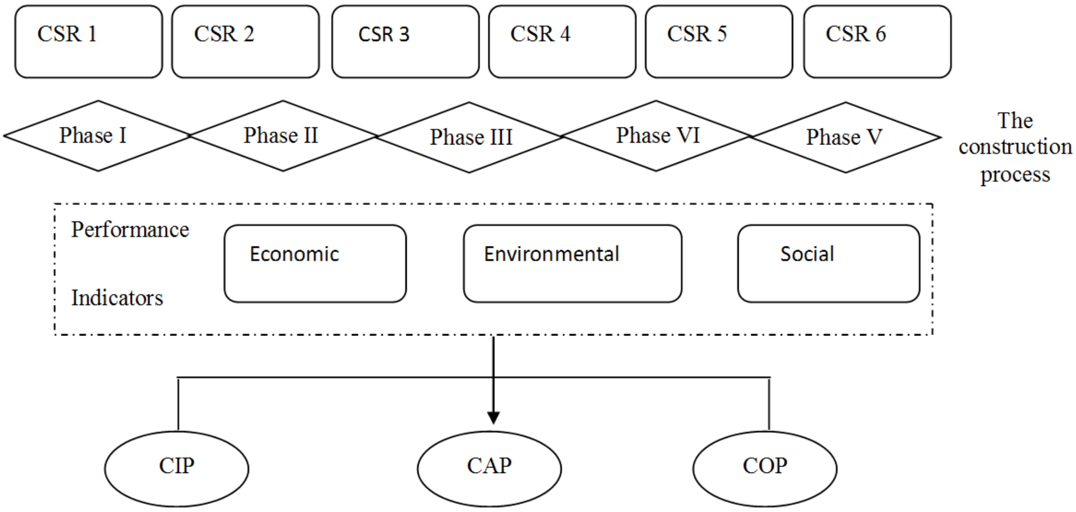


Figure 6.1 Boundary of the model

6.3.3. Multiple feedbacks in the construction process

A complex system such as a large-scale construction project is characterized with multiple interacting feedback processes. For example, when a construction project falls behind a predefined schedule, one possible managerial response is to increase the use of overtime. More resources will be invested to speed up relevant construction procedures. Managerial contribution on site is needed to motivate frontline workers' efficiency. However, a significant saving of time can result in some other problems with quality, cost, environment and safety. Meanwhile, environmental issues might be outstanding. Consequently, feedback processes on the schedule provide useful information for the improvement of managerial, technical, and other systems along the construction process.

Feedback means the transmission and return of information. Feedbacks in the construction process can be triggered from a couple of sources such as stakeholders. For instance, feedbacks about the client's satisfaction over the performance of the project team signify how the construction process has been organized. A strong complain from the surrounding community urges contractors to lower the negative impacts of the construction process as far as possible. In reverse, a positive response from local government inspires the project team to pay extra efforts to increase the condition of local transport infrastructure. Diverse sources of feedbacks coincide the challenge of construction activities management, and enhance the difficulty in the attainment of sustainability.

SD is an effective approach to modelling choices whenever there are significant feedback processes. Previous studies have demonstrated that SD models have the efficiency in portraying the rich range of nonlinear relationships in the construction context (Thompson and Bank 2010, Zhang *et al.* 2013). Similar to other modelling techniques, the capability of SD has the strength of outlining nonlinearity in model formulation. By using SD approach, feedbacks distributing along the construction process can be utilized better.

In the field of business management, the majority of all data are descriptive and qualitative and have not been written down fully. Yet they are crucial for understanding and modelling complex systems. SD practitioners and theorists recognize the importance of such so-called soft data. System dynamicists are taught to use multiple sources of information, including numerical data, interviews, direct observation, and other techniques to elicit the decision rules, organizational structures, goals, and other important managerial dimensions of the system.

6.3.4. Steps for SD modelling

A construction project, whatever size it is, is not merely a matter of engineering - of drawings, steel, pipes, and wiring. It is essentially made up considerable factors that have found their roles but they are hard to be understood exactly in terms of technical relations as well as social relationships. Some of the important data favouring the perception of a construction project in terms of evolution and dynamics are concerned with managerial decision and other so-called "soft" variables. To reach an effective model for detecting the influence of CSR fulfilment on SPCP, six steps of SD modelling are taken as described below.

(i) Identify a problem. In this study, the problem goes to the influence of CSR implementation on the performance of construction process, or to the extent to which SPCP can be improved.

(ii) Develop a dynamic hypothesis explaining the cause of the problem. To start to consider system structure, generalizing from some specific events associated with CSR activities to considering patterns of behaviour along the construction process is required. Usually this requires to examine that how one or more variables of interest change over time. The hypothesis is about the components of

CSR activities, the way in which SPCP is restructured, and the influence of CSR activities on SPCP.

(iii) Build a model of the system at the root of the problem. The SD approach gains much of its power as a problem solving method from the fact that similar patterns of activities show up in a variety of different situations, and the underlying system structures that cause these characteristic patterns are known. Once a pattern of behaviour is identified to be a problem, the system structure should be considered to find out how the pattern of behaviours is caused. In considering that the concepts of both CSR and SPCP are abstract and covert to seize, SD model to be developed in the study is placed on the problem and hypotheses described above. The inherent relationships between these two dimensions are the core of the SD model.

(iv) Ensure that the model properly reflects CSR activities in the real world. Since CSR has a variety of definitions that different persons may have their choices in line with their perceptions, the SD model to be developed in the study has the importance of mirroring the options of contractors in a specific context (e.g., in China). CSR activities span widely in terms of intensity, types and stakeholders involved, but it is true that not all of the CSR activities have the relationships with SPCP. Thus, the question about whether a SD model reflects CSR activities is determined by linking it sustainable construction on a construction site.

(v) Detect the model to see what insights it gives over the aforementioned problem. By letting all inputs of CSR to go in different dimensions, the effects of CSR activities on SPCP will be detected. Sensitivity analysis is conducted by offering three or more sceneries and thus, those aspects of CSR that have more significant roles in determination of SPCP are uncovered.

(6) Draw conclusions from these insights. The insights from the above steps are hopeful to map out strategies for contractors to implement accordingly. In reverse, the implementation of this helps contractors to put efforts to the implementation of CSR programs.

6.4 Causal loop diagrams

6.4.1. Understanding CLDs in the modelling process

Causal loop diagrams (CLDs) have long been used in the exercises of standard system dynamics for purposes associated with simulation modelling. They are nowadays used prior to simulation analysis, to depict the basic mechanisms hypothesized to underlie the reference mode of behaviours over a period of time. CLDs have been used to describe relevant factors and the causal relationships between them (Kim and Reinschmidt 2006). Components of a CLD are factors and links used to connect the factors. Any link has annotations about its polarity and delay. The polarity spells out whether a dependency has positive polarity or negative polarity. Since CLDs are a good start for system modelling (Haraldsson and Sverdrup, 2003), emphasis in the study goes directly to the development of CLDs in the model development as described below:

(i) Use nouns or noun phrases to represent the elements instead of verbs.
(ii) Be sure that the definition of an element clarifies which direction is “up” for the variable.
(iii) Causal links should imply a direction of causation rather than a time sequence.

CLDs are a way of graphically representing feedback structures in a business process. As constructing links in a diagram, possible unexpected side effects which might occur in addition to the influences that are drawing are well considered. To understand the system structures which cause the patterns of behaviour, a notation is introduced to represent system structures. In this diagram, the short descriptive phrases represent the elements which make up the sector, and the arrows represent the causal influences between these elements. This diagram presents those relationships that are difficult to verbally describe, because normal language presents interrelations in linear cause-and-effect chains, while the diagram shows that in the actual system there are circular cause-and-effect chains. When an element of a system indirectly influences itself in the way, the portion of the system involved is called a feedback loop or a causal loop.

6.4.2. Types of feedback loops

The essence of changing business management is in changing the way that information is circulated within an organization. However, the information links in a business process is usually difficult to model because of the abstract nature of these links. More formally, a feedback loop is a closed sequence of causes and effects, or, a closed path of action and information.

Positive feedback loops

Sometimes positive feedback loops are also called vicious or virtuous cycles, depending on the nature of the change that is occurring. As shown in Figure 6.2, a positive (or reinforcing) feedback loop reinforces change with even more change. This can lead to rapid growth at an every-increasing rate. This type of growth pattern is referred to as exponential growth. The growth seems to be slow in the early stages, but it speeds up later on. Hence, the nature of the growth in a management system that has a positive feedback loop can be deceptive.

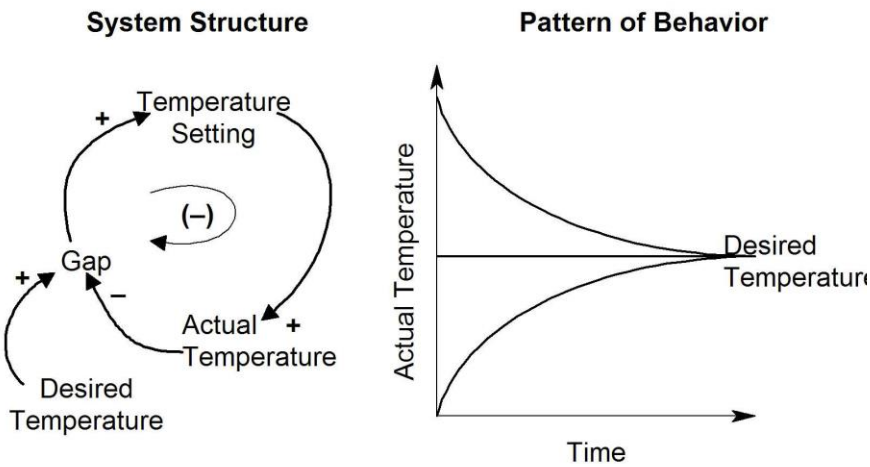


Figure 6.2 An example of system structure and pattern of behaviours in SD

Negative feedback loops

A negative (or balancing) feedback loop seeks a goal. If the current level of the variable of interest is above the goal, the loop structure will drive down its value. Meanwhile, if the current level is below the goal, the loop structure will push up its value. Many management processes contain negative feedback loops which provide useful stability, but they can also resist needed changes. These types of feedback loops are powerful in some organizations that the organizations will go out of business rather than change.

Combination of positive and negative loops

A variety of patterns can be established by combining a number of positive and negative loops. For instance, a positive feedback loop leads to early exponential growth, but then, after a delay, a negative feedback loop comes to change the system's behaviour. This combination can result in an s-shaped pattern because the positive feedback loop leads to initial exponential growth, while the negative feedback loop results in a goal seeking behaviour.

6.5 Stock and flow diagrams

The other common notations for SD and systems thinking are stock-and-flow diagrams (SFDs). Proponents of CLDs laud their accessibility to non-experts, and claim that SFDs are subject to ambiguity and lack of detail in CLDs which prevents simulation of the modelled systems and prefer at least to start with stocks first (Ford, 1999). Haraldsson (2004) propose to use CLDs for brainstorming and then to switch to an SFD which models the system exactly. This raises the question how CLDs can be used as a base for an SFD.

By virtue of different types of elements (i.e., stocks, flows, and information), a SLD describes relationships between variables which are assumed to change over time. The variables shown in rectangles are called a stock, level, or accumulation. The variable usually shown next to a “bow tie” or “butterfly valve” symbol is called a flow, or rate. Factors whose type is exactly one of stock, flow, auxiliary, or system boundary are often contained in a SLD. The system boundary constitutes a stock which represents an anonymous source or sink.

There are two types of links: material flows and information dependencies. The former one may only connect stocks, while the latter one must not point to stocks. However, transiting a CLD to SFDs is not straightforward. The information on SFDs is hidden in CLDs. Extracting stocks, flows and auxiliaries from CLDs requires further investigation of links and what they represent. This process may increase the number of factors in the system. Therefore, in-depth knowledge about the system is necessary.

6.5.1. Understanding SFDs in the modelling process

To draw a CLD, it is important to determine which events can determine the understanding of system structure and the pattern of behaviour over time. Once the pattern of behaviour is determined, the concepts of positive and negative feedback loops can be used to simulate behaviour patterns. However, turning an SFD into a model is also called a quantification process as described below:

(i) Start and end time for the simulation run,

(ii) Formulas for all flow and auxiliary factors including the specification of the delay values or functions for all links,

(iii) Values or time-dependent functions (defined between start and end time from (i) for all input factors (i.e., factors without incoming dependencies),

(iv) Initial values for all stocks, and

(v) Initial values or time-dependent functions for all factors which have outgoing dependencies with delays.

6.5.2. Transforming CLDs into SFDs

In a SD model, small "clouds" usually shown at the right and left ends of the production and distribution processes represent either a source or a sink of flow. A CLD describes the interrelation of variables in a system. It consists of a set of nodes that represent variables and edges that mirror a connection or a relation between two variables. CLDs in the study are proposed in line with the principle of sustainable construction.

A SFD indicates more the process structure than a CLD, but it does not tell some important questions for the performance of the processes. When deciding how to quantitatively model a business process, it is necessary to consider a variety of issues. The data in (iv) and (v) in the above section are often simply assumed to be zero. Another technique to avoid having to specify (v) is to simulate the model until it may reach a steady state, in which case one simply discards the initial time segment of the simulation. To produce a labelled CLD, the modeller must identify the stocks and flows among the factors and the types of links.

The main task of this step is to label initial CLDs properly. This means deciding which factors are stocks, and which are flows or auxiliaries, and specifying links represent flow dependencies and which information dependencies. To identify whether a given factor is a stock or a flow, the following questions are considered in the present study:

(i) Does it accumulate?
(ii) If time stops, can it be measured?
(iii) Can it be stocked somewhere and used t later?
(iv) Is there a level?

In effect, all non-stocks are deemed to be either flows or auxiliaries. It seems that the identification depends on the nature of outgoing dependencies. Once a stock is chosen, all the incoming links can decide whether or not they can be labelled as flow dependency. The resulting labelled CLDs can reveal inconsistencies in the initial CLD, such as missing factors or illicit links.

(i) Using manually controlled steps to incrementally transform all labelled CLDs. These steps are guided by a handful of constraints which characterize syntactic inconsistencies of the model. The results of this phase, a labelled CLD which fulfils the constraints mentioned above, are called a structured CLD.

(ii) Transforming the structured CLD automatically into an SFD.

(iii) Quantifying the structured SFD, i.e., provides parameters, initial values and formulas for information dependencies. This yields a quantified system dynamics model, which can be simulated.

6.6 Summary

The theory of system dynamics (SD) has been widely applied within the discipline of construction management and economics. In this chapter, the application of SD modelling is justified in examining the causal relationships between CSR-C activities and SPCP indicators. The main tasks of SD application in the study is to build causal-and-loop diagrams and the corresponding stock-and-flow diagrams, in which feedbacks on the implementation of CSR-C on a construction site are expected to reveal in due ways. Therefore, SD modelling steps should be followed strictly to model the causal relationships and the boundary of the model should be stated clearly.

Chapter 7. MODEL DEVELOPMENT

7.1 Introduction

With reference to the principle of system dynamics, this chapter presents the development of models proposed to detect the effects of CSR fulfilment on SPCP. As addressed in previous chapters (see Figure 7.1), six key activity areas of CSR-C are derived, and SPCP indicators are categorized into three groups (i.e., construction inputs, construction activities, and construction outputs). These two dimensions are included in the model with the intention of elaborating the inherent causal relationships. In this chapter, the causal relationships will be discussed with an emphasis on all potential links between a CSR-C activity and a SPCP indicator. While variables for the proposed model are situated in the Chinese construction context, it is assumed that the model can apply to other construction industries.

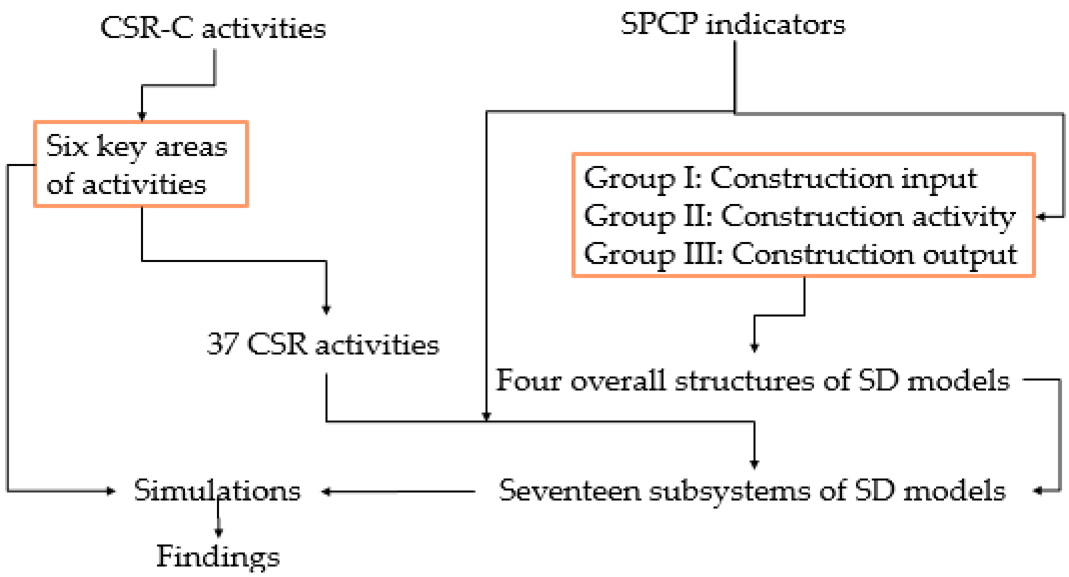


Figure 7.1 Overall research design

7.2 Overall structure of the model

A stock-and-flow chart is the key to all SD models as shown in Figure 7.2. The flow comprises three subsystems, namely construction inputs performance (CIP), construction activities performance (CAP), and construction outputs performance (COP). The inclusion of these three dimensions of flow is triggered from a contractor's attempt per day, while the stock SPCP mirrors all cumulative efforts that the contractor puts to complete construction works.

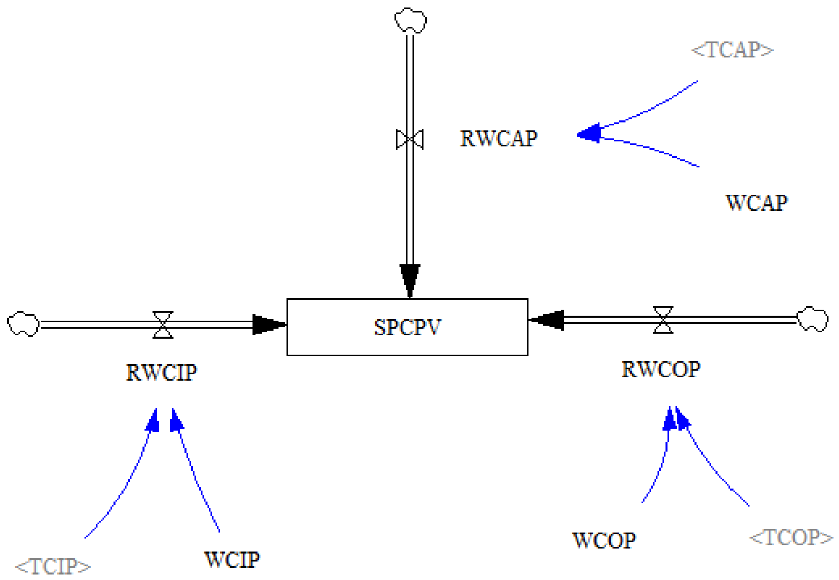


Figure 7.2 Structure of the model

Note: definitions of variables of all models in this chapter can be found in the enclosure.

As imaged in Figure 7.2, the value of SPCP (or SPCPV) is a stock that measures the aggregative performance of a contractor in implementing sustainable construction practices over the period of construction time. Three flows or auxiliaries (i.e., RWCIP, RWCAP, and RWCOP) are included. These three auxiliary variables are proxies for the daily performance of three subsystems (i.e., CIP, CAP, and COP). Each subsystem contains a number of variables, of which stocks and flows are recognized to develop other SD models. Details about mother model structures are presented in the following sections.

7.2.1. Model structure for the subsystem of construction inputs performance (CIP)

The construction inputs performance (CIP) delineates the way in which a contractor attempts to reduce the consumption of construction elements. The main question to the boundary of CIP is determined by the project's complexity that a contractor has to deal with and the scope of tasks that the contractor has to complete within a period of time. For instance, a two-story apartment is simpler than a cross-strait bridge in building structure and the need of either construction equipment or materials. Construction initiatives for a downtown high-rise should be more complicated than those for a factory at the outskirt of city.

Many evidences have shown that contractors are much interested in putting efforts to actualize the saving of these four types of resources (CSCEC 2013, Hochtief 2015). One of the main reasons is that they have to exert a lowest price contract which inspires them to cut off any extra cost. The saving of the four construction inputs mirrors the efforts of contractors in controlling construction cost. Different projects are characterized by dissimilar requirements posed by the client and the availability of resources for the construction process. Therefore, establishing a CLD for CIP subsystem must give a weighting to reflect the significance of indicators as shown in Figure 7.3.

Construction inputs range significantly from one project to another. For simplicity, it is considered that construction elements for an infrastructure project mainly include land, water, materials, and energy (Table 5.6). This matches *the Code of Green Construction* circulated by the Ministry of Urban-rural Housing and Construction China. The code stresses that the duty of a contractor in pursuit of green construction is to attain sustainability through saving four types of resources, namely land (LRIP), water (WRIP), materials (MIP), and energy (EIP). An auxiliary variable (TCIP) is employed to totalize values of all the four sub-variables.

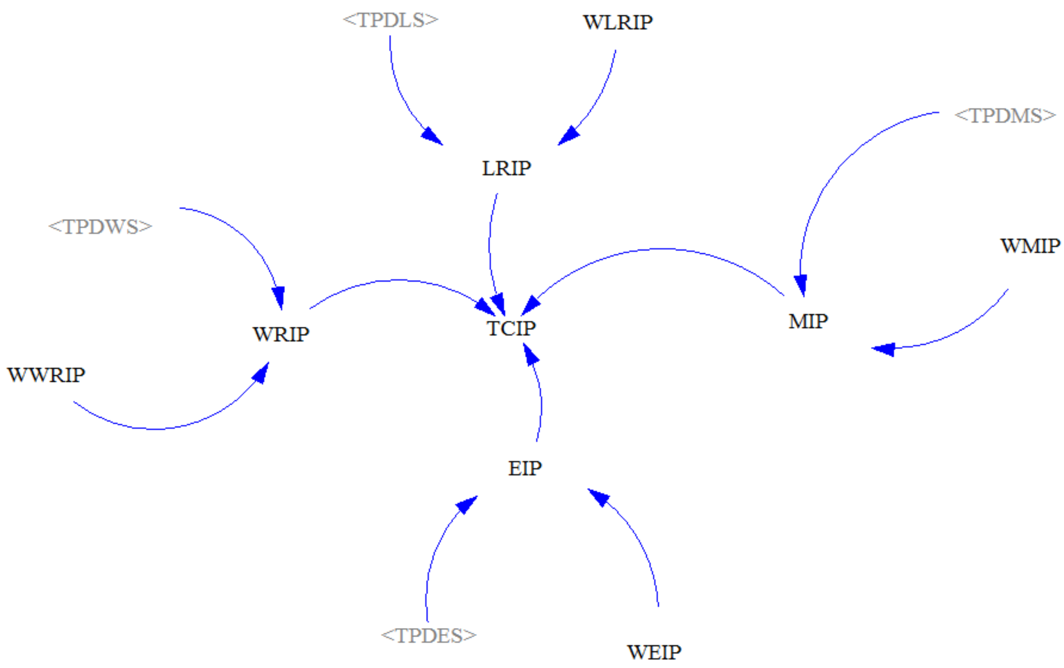


Figure 7.3 Model structure for the CIP subsystem

7.2.2. Model structure for the subsystem of construction activities performance (CAP)

In line with the potential relationships between SPCP indicators, a CLD model is proposed as given in Figure 7.4 to delineate the subsystem of construction activities performance. The construction process yields considerable negative impacts on the construction site as well as the surrounding communities (CDP). One of the key issues is about how to develop a thorough approach to identify all aspects of the negative impacts. The first mind jumping into an observer's mind could be that that a construction site is a noise pollutant, which is indicated by the NPP variable (Figure 7.4). Dust emission (DEP) will be serious if the contractor fails to take an effective measure immediately. Dust emission can be outspread by transportation tools, which often attracts much attention of local people. Some construction activities release considerable light (LPP) that can cause health problems if a person watches it for a long time.

While such kind of activity is highly criticized for its negative impacts on frontline workers or local residents, increased demand for local infrastructure (referred to the variable IBP) as a result of construction activities, lower diversity of biology (referred to the variable BPP) due to construction activities, diminishing culture and heritage (CCHP) triggered from the construction process, an increase in construction wastes (CWP), and significant impacts to health and safety (HSP) are often alerted by stakeholders. Since these negative impacts of the construction process are surfacing, the contractor has many opportunities of recruiting local people whatever they are professionals or providing labours (ELP). A higher recruitment in this connection can be deemed to contribute more to the development of society.

A weighting scheme is additionally included to offer a flexibility when the CLD is applied to different projects, and it is changeable depending on project attributes and the scope of construction task.

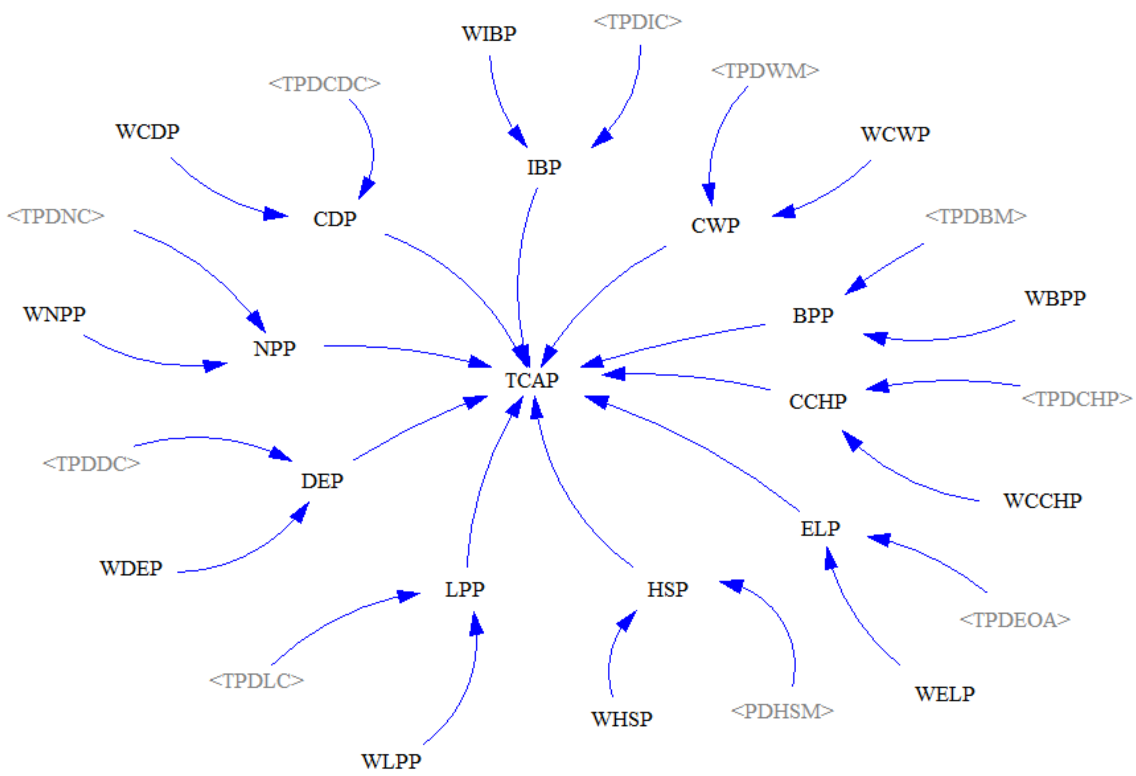


Figure 7.4 Model structure for the CAP subsystem

7.2.3. Model structure for the subsystem of construction outputs performance (COP)

Construction activities are carried out for building, alternation, or repair (e.g., dredging and excavation) of buildings, structures, or other properties. Any betterment or change to an existing facility to allow its continued or more efficient use within its designed purpose is deemed as one kind of construction activities. The results of construction activities include, without limitation to, the erection of roads, power plants, buildings, bridges, water treatment facilities, and vertical structures.

A CLD model is proposed as given in Figure 7.5 to present the outcomes of contractors in the attainment of sustainability. Construction activities are implemented as stipulated in contracts. Cost is estimated (as indicated by the variable CCP), and quality (CQP) and schedule (CQP) are stated clearly. As defined previously, construction outputs image the consequence of a contractor in implementing work contracts to achieve conventional project goals (i.e., quality, cost, and schedule). Despite the existence of other project goals (e.g., safety and environment), it is considered that the aforementioned three goals are typical and the remainder can be incorporated into the former two subsystems (i.e., CIP and COP). Weighting to the three goals changes with the uniqueness of the client and the scope of construction works.

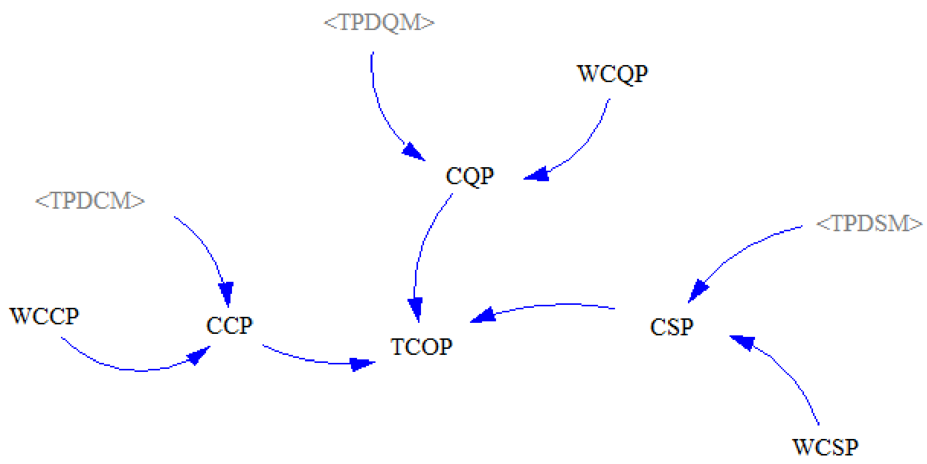


Figure 7.5 Model structure for the COP subsystem

7.3 CIP subsystems

As presented in Chapter 2, the fulfilment of CSR-C at the project level has impacts on SPCP levels. Therefore, CSR-C activities are well discussed in this section with an intention to build SD models for the CIP subsystem. The relationships are shown in Table 7.1, which are based on results of extensive literature review as well as interview with experts. The derivation of these relationships paves the way for model development as given in Figures 7.5 – 7.8.

Table 7.1 Impacts of CSR-C activities on CIP indicators

SPCP indicators / CSR-C activities		Land saving LS	Water saving WS	Energy saving ES	Materials saving MS
B10	Applying/optimizing a training and education system for occupational skills	√	√	√	√
B12	Applying environmental technology and green energy to promote energy saving and emission reduction			√	
B13	Applying evaluation mechanism for collaborators to implement CSR	√	√	√	√
B19	Applying a saving and recycling system for resources and energy utilization	√	√	√	√
B20	Applying a selection, management and supervision system for sub-contractors	√	√	√	√
B23	Conducting green office		√	√	√
B40	Formulating/implementing CSR crisis precautionary and response mechanisms	√	√	√	√
B41	Formulating/implementing a CSR training scheme	√	√	√	√
B42	Giving priority to the procurement of local products and services	√			
B63	Setting up special division(s) for CSR management	√	√	√	√
B64	Setting up special units or/and positions to conduct daily environmental management	√	√	√	√
B66	Strengthening communication with collaborators and improving collaboration space and efficiency		√	√	√

7.3.1. Land utilization

Land is a costly commodity and fundamental factors for all economic activities on which survival rests (du Plessis 2002). The construction industry has huge impacts on agricultural lands such as soil erosion and land degradation(Irurah 2001). Inefficient land use happens on construction sites and it increases construction cost and aggregates seriousness of environmental problems to the end. An approach called resource saving and recycling is necessitated for contractors to improve the efficiency of land use. A higher awareness of land use efficiency can be secured by means of training and education. Purchasing construction materials from local market seems to be effective to the efficient use of land as it is convenient to reduce the occupation of construction sites. Therefore, the effects of CSR-C fulfilment on the performance of contractors in land utilization are shown in Figure 7.6.

While contractors are apt to using those lands outside the construction site without being fine, it is very important that contractors are not required to do so. In effect, the engagement of social responsibility such as a specialized department, CSR training, CSR manipulation and crisis management in CSR fulfilment contributes to the use of urban land.

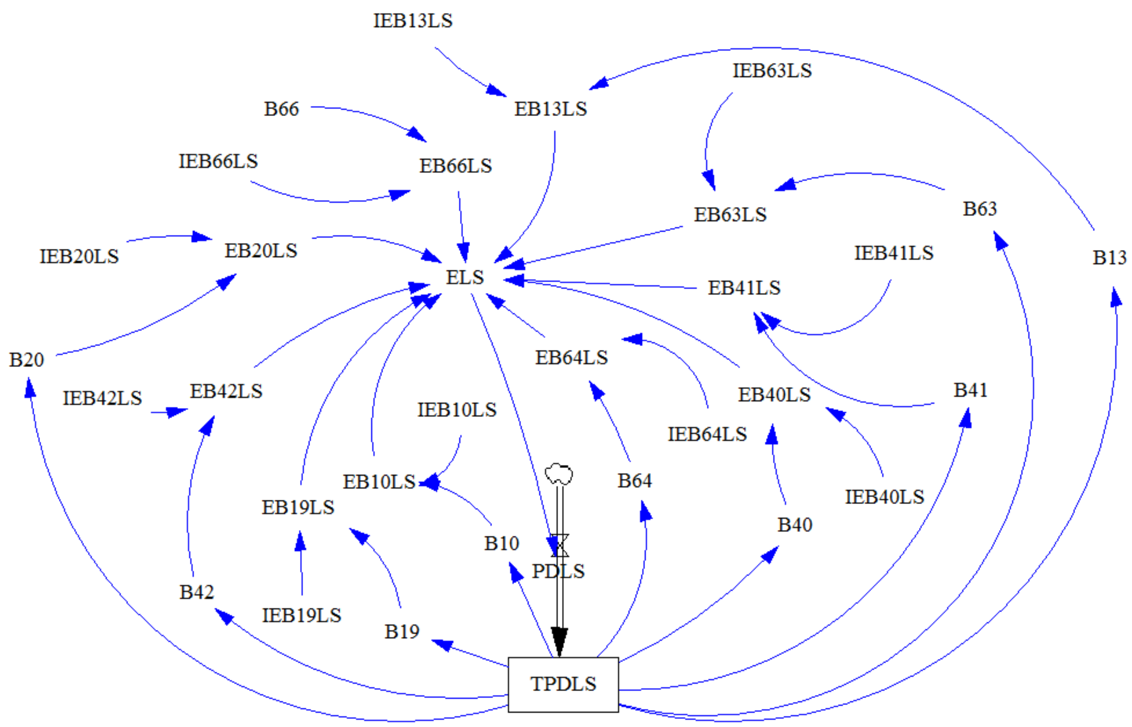


Figure 7.6 Land utilization

7.3.2. Water utilization

Water is one of the most important elements in construction. For instance, the consumption of cement, steel, and iron on a construction site is water-intensive. However, water pollution has not yet been manipulated effectively on construction sites (Deb 1998, du Plessis 2002). Sediment is a very common pollutant washed from construction sites, which can harm aquatic life and disturb the food chain. It goes without doubts that water pollution prevention can reduce potential environmental and human health impacts, and comply with national and provincial laws. Therefore, minimizing the potential impacts that construction activities may have on water utilization and protecting their beneficial uses for future generations is vital to sustainable construction. In this study, it is called saving of water.

Contractors have the importance of executing water pollution control compliance, carrying out the contract per construction plan, specifications and permits, and implementing water pollution control measures (Dasgupta and Tam 2005). Sedimentation ponds, oil/water separators, spill containment facilities, concrete drainage systems are control practices that should be in place to reduce water pollution. Therefore, the practice of water saving is incorporated into the CIP subsystem as shown in Figure 7.7.

Figure 7.7 suggests that a scope of CSR activities is helpful to improve water efficiency. For instance, environmental protection initiatives ought to highlight the details of water utilization on the construction site; saving and recycling of resources should be put into place; and the implementation of green working condition can reduce the use of water for non-construction activities. The framework of social responsibility at the project level may take into account the requirements of water saving and conduct training and education on this practice as expected.

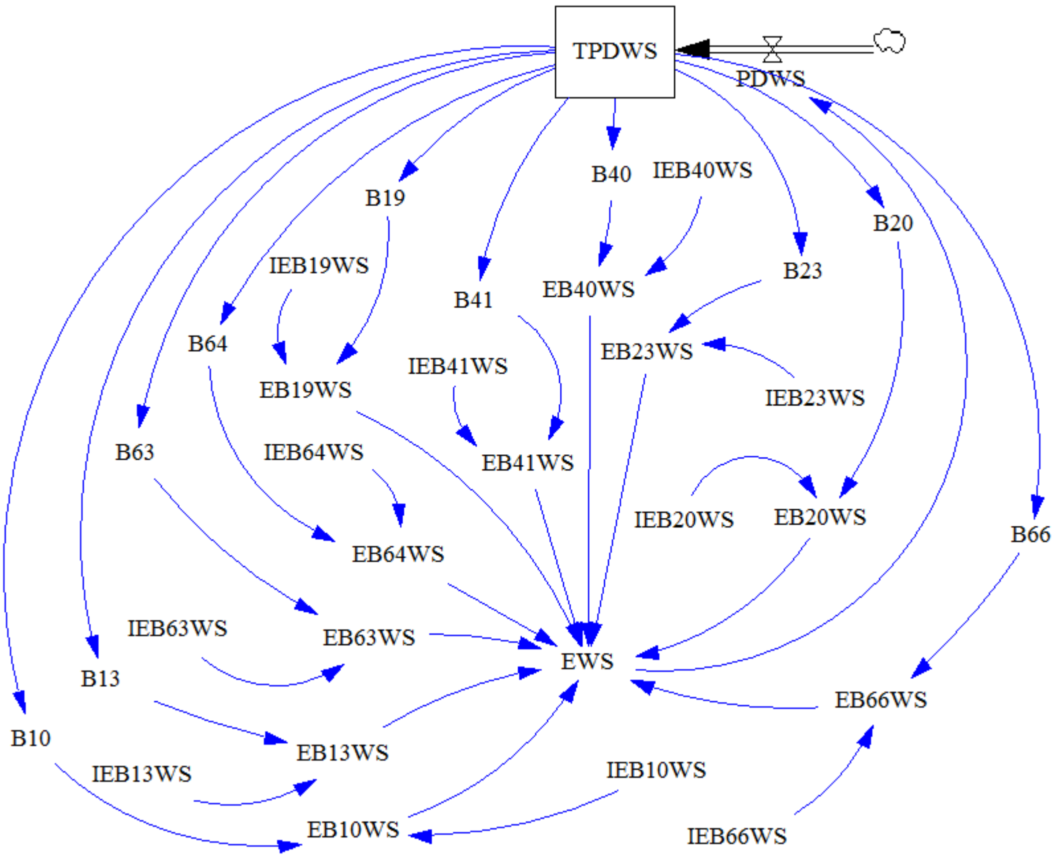


Figure 7.7 Water utilization

7.3.3. Energy utilization

Construction activities consume a great deal of energy. For instance, constructing a 1 km length of typical two-lane road with flexible pavement consumes 7 TJ of energy (Horvath and Hendrickson 1998). Contractors have to know the way to integrate all of the building components and how they interact to produce a high performance physical facility. As prescribed in a green construction, environmentally friendly building techniques usually contain energy efficient construction means. Utilizing energy efficient lighting sources such as compact fluorescent lamps can save money by using less electricity while reducing harmful emission from power plant generation. Natural light may be used in appropriate ways to minimize the need for turning on electric lights. Taking advantage of "nature's heating and cooling system" through the effective use of landscaping is a significant way.

Energy tips and recommendations in practice also go to quality materials and workmanship as well as a whole house or house as a system approach, and the utilization of renewable energy opportunities in constructing an energy efficient home such as water heaters, passive solar applications and photovoltaic panels to produce clean electricity. In view of energy utilization on construction sites, the effects of CSR activities on energy saving are imaged in Figure 7.8.

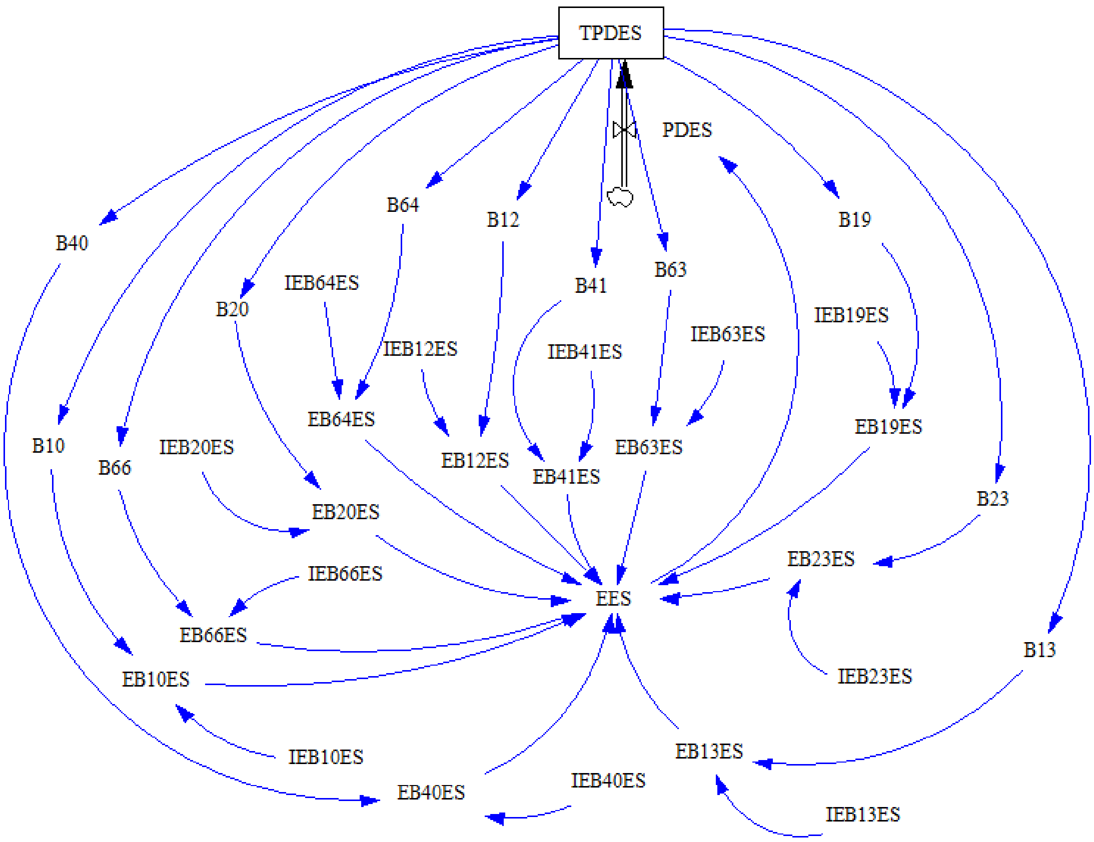


Figure 7.8 Energy utilization

Figure 7.8 suggests that contractors' partners are requested to improve the practice of energy saving. Management of subcontractors are hopeful to arouse more energy saving awareness along the production chain. The implementation of environmental protection and green energy utilization can be a straight approach to saving energy. The establishment of special department in charge of social responsibility may pose energy saving to be strictly monitored on construction sites. Training and education on energy saving facilities the operation of this practice as it increases the awareness and provides a mechanism for reviewing the performance of energy saving on a daily basis.

7.3.4. Materials utilization

Basically, construction means a mechanism for the realization of settlements and the provision of infrastructures that supports human development. The extraction of raw materials, manufacturing of construction materials and components, processing and distribution of components, and assembly of components on sites are one of the main types of construction activities. Concrete and steel are the basis of modern construction and have been extensively used across the world. As revealed in *Agenda 21 for Sustainable Construction in Developing Countries*, the built environment accounts for half of all the new materials taken out of the earth's crust by weight, and consumes between 40% and 50% of a country's energy. The manufacturing and production of building materials are responsible for the pollution of watercourse and filling up of landfill sites, degradation of land and ecosystems, air and dust pollution and they consume a great deal of energy. With this in mind, Figure 7.9 is given to present the impacts of CSR activities on the efficiency of materials utilization.

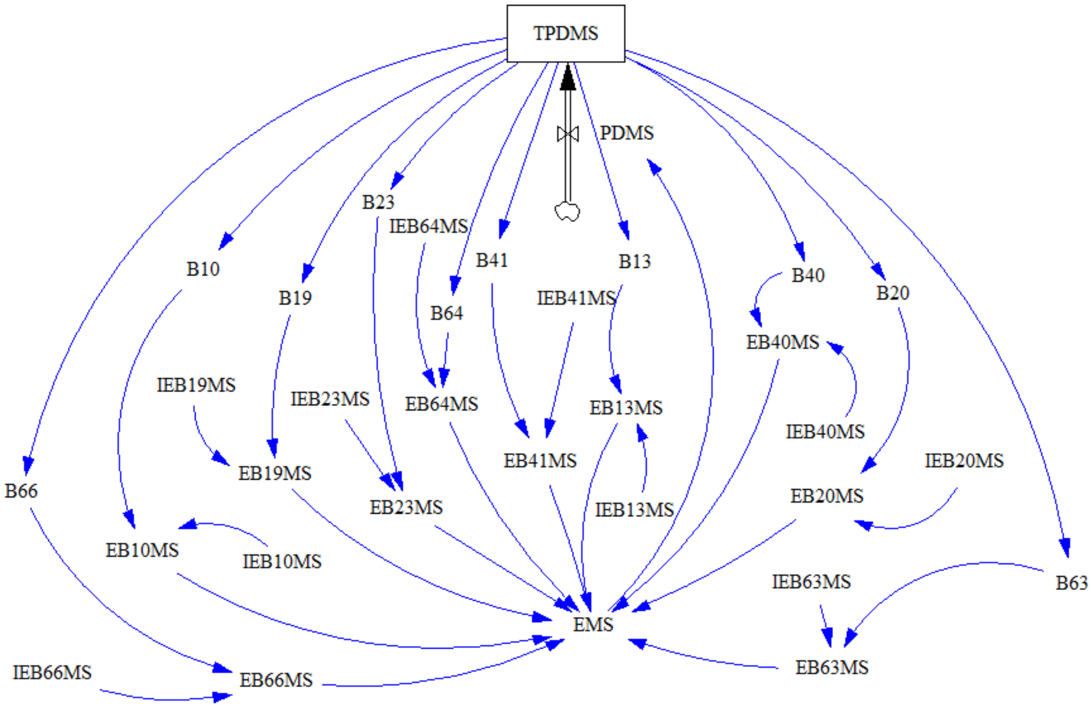


Figure 7.9 Materials utilization

As shown in Figure 7.9, the saving of materials can be handled in the domain of socially responsible activities. Approaches to saving resources and recycling ought to address the complexity of reducing the use of materials. The saving of materials depends on closer collaboration between business partners. The efficiency of sub-contractors management helps guarantee a thorough saving of construction materials along the production chain. It is also reported on media that substandard materials are often used in the building process, leading to in whole or in part the poor quality of built facilities. To this end, highlighting the saving of materials in the package of social responsibility deserves much attention. CSR education and training, the establishment of a CSR management department, and requirements on business partners' CSR fulfilment are expected to exert impacts on materials saving.

7.4 CAP subsystems

Based on results of critical literature review as well as interview with experts, the relationships between CSR-C activities and the CAP subsystem are discussed in detail in this section with an aim to support SD model development. As shown Table 7.2, the relationships are more complicated for those causal relationship shown in Section 7.3.

Table 7.2 Impacts of CSR-C activities on CAP indicators

CSR-C activities \ SPCP indicators		1	2	3	4	5	6	7	8	9	10
		NC	LC	DC	CDC	IC	WM	BM	CHP	EOA	HSM
B04	Applying/optimizing an environmental impact assessment and precaution system prior to construction	√	√	√	√		√	√	√		√
B06	Applying/optimizing precaution mechanism for safety management										√
B10	Applying/optimizing a training and education system for occupational skills									√	√
B12	Applying environmental technology and green energy to promote energy saving and emission reduction	√	√	√	√		√				
B13	Applying evaluation mechanism for collaborators to implement CSR	√	√	√	√	√	√	√	√	√	√

B16	Applying pollution emission control systems (e.g. gas, dust, noise, sewage and waste)	√	√	√	√		√				
B19	Applying a saving and recycling system for resources and energy utilization				√	√					
B20	Applying a selection, management and supervision system for sub-contractors	√	√	√	√		√	√	√	√	√
B23	Conducting green office										√
B25	Conducting research development and technological innovation to improve quality and safety management level										√
B36	Establishing effective communication channels with local community				√	√					
B40	Formulating/implementing CSR crisis precautionary and response mechanisms	√	√	√	√	√	√		√	√	√
B41	Formulating/implementing a CSR training scheme	√	√	√	√	√	√	√	√	√	√
B42	Giving priority to the procurement of local products and services					√					
B45	Implementing/optimizing environmental training scheme to improve employees' environmental awareness and skills	√	√	√	√		√	√	√		
B46	Implementing/optimizing a quality management system to strictly prevent quality accidents	√									
B48	Implementing/optimizing a safety management system to prevent safety accidents										√
B51	Implementing emergency mechanism and scheme for environmental pollution accidents	√	√	√	√		√				√
B61	Protecting biological diversity and ecological systems							√			

B64	Setting up special units or/and positions to conduct daily environmental management	√	√	√	√		√	√	√		√
B62	Respecting and protecting cultural tradition and heritage of the community								√		
B63	Setting up special division(s) for CSR management	√	√	√	√	√	√	√	√	√	√
B66	Strengthening communication with collaborators and improving collaboration space and efficiency				√	√				√	
B67	Supporting the development of infrastructure and public services of local community				√					√	
B69	Taking care of low-income groups (e.g. Build-transferring low-income housing without charge)									√	

Note: 1 - Noise control; 2 - Lighting control; 3 - Dust control; 4 - Comfort disturbance control; 5 - Infrstructure overload; 6 - Waste management; 7 - Biodiversity management; 8 - Cultural/natural heritage protection; 9 - Employment opportunities added; 10 - Health and safety management.

7.4.1. Noise control

In reality, contractors are required to comply with noise ordinance, otherwise they would get an issuance of a written warning, a possible citation, and a potential stop work order. They ought to notify neighbours prior to starting a job that can create noise. Communication with neighbours can reduce complaints from arising, and resolve concerns before there is a problem. Subcontractors are expected to collaborate with the contractor closely to mitigate noise from power equipment or other noise producing activities with sound barriers, muffling devices, lower settings on power equipment, and shortened work periods. Contractors need to evaluate noise pollution before the commencement of construction plan. Therefore, the effects of CSR fulfilment on noise control are described in Figure 7.10.

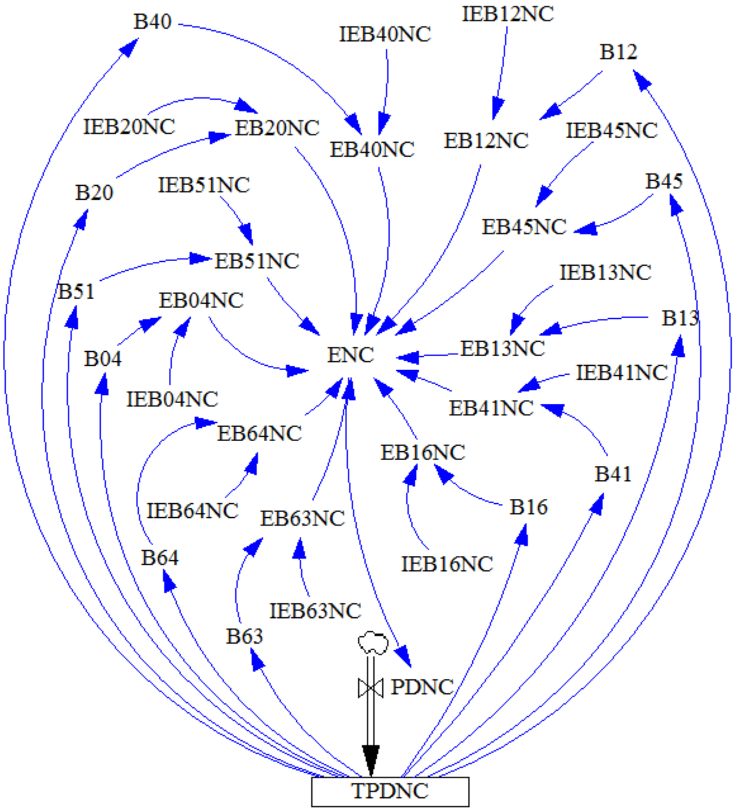


Figure 7.10 Noise control performance

7.4.2. Light pollution management

Light pollution causes uncomforted feelings to surrounding residents. Contractors might often receive complains if they cause considerable light interruption to local people. However, it seems difficult for a contractor to completely avoid light pollution in the construction process. A closer cooperation with subcontractor could be helpful to make sure that every kind of construction activities cannot yield too much lighting, though it is quite hard to require them to do so. Therefore, the impacts of CSR activities on light pollution are reflected in Figure 7.11.

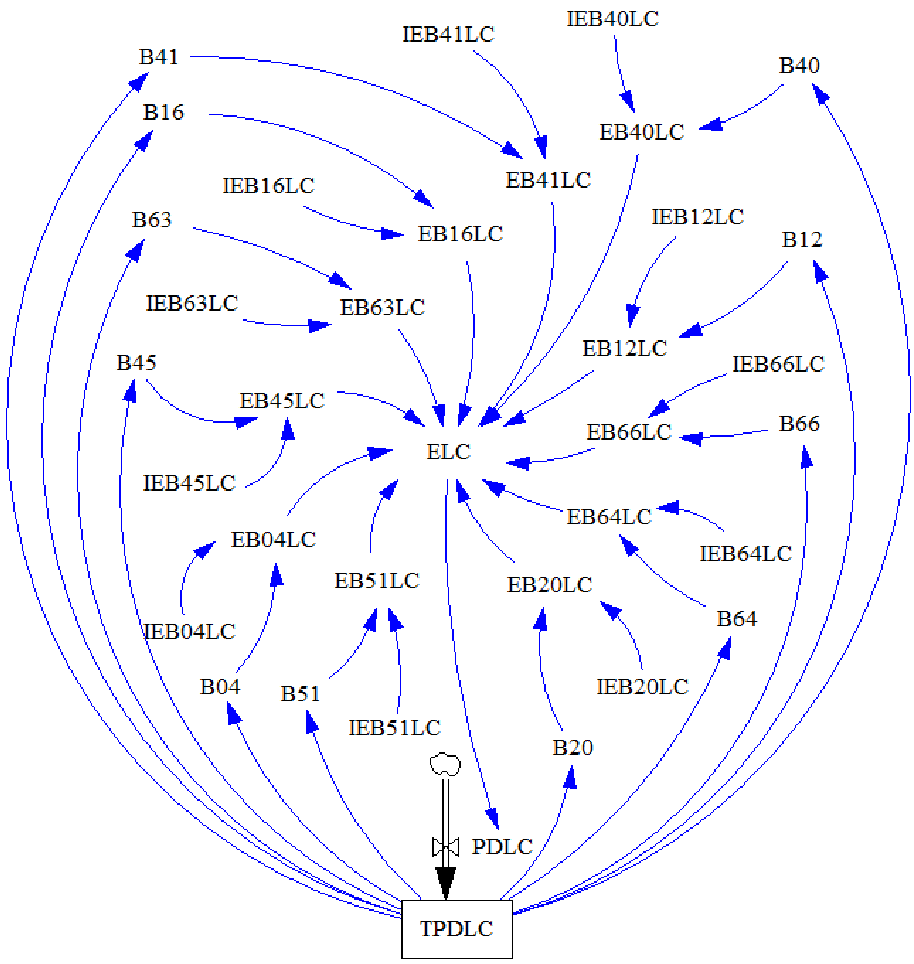


Figure 7.11 Performance of light pollution management

7.4.3. Dust control

Figure 7.12 describes the effects of CSR-C on the performance of dust control. In effect, suspended particles from fugitive dust sources (e.g., paved and unpaved roads, construction and demolition sites, storage piles, wind erosion) contribute much PM10 in many urban areas. Many kinds of construction works create a large amount of dust, presenting significant risks to the health of construction workers. In Great Britain, it was estimated that about 10 people a week is believed to die from lung cancer caused by silica dust alone. The contribution of fugitive dust from construction to air pollution can no longer be ignored in China.

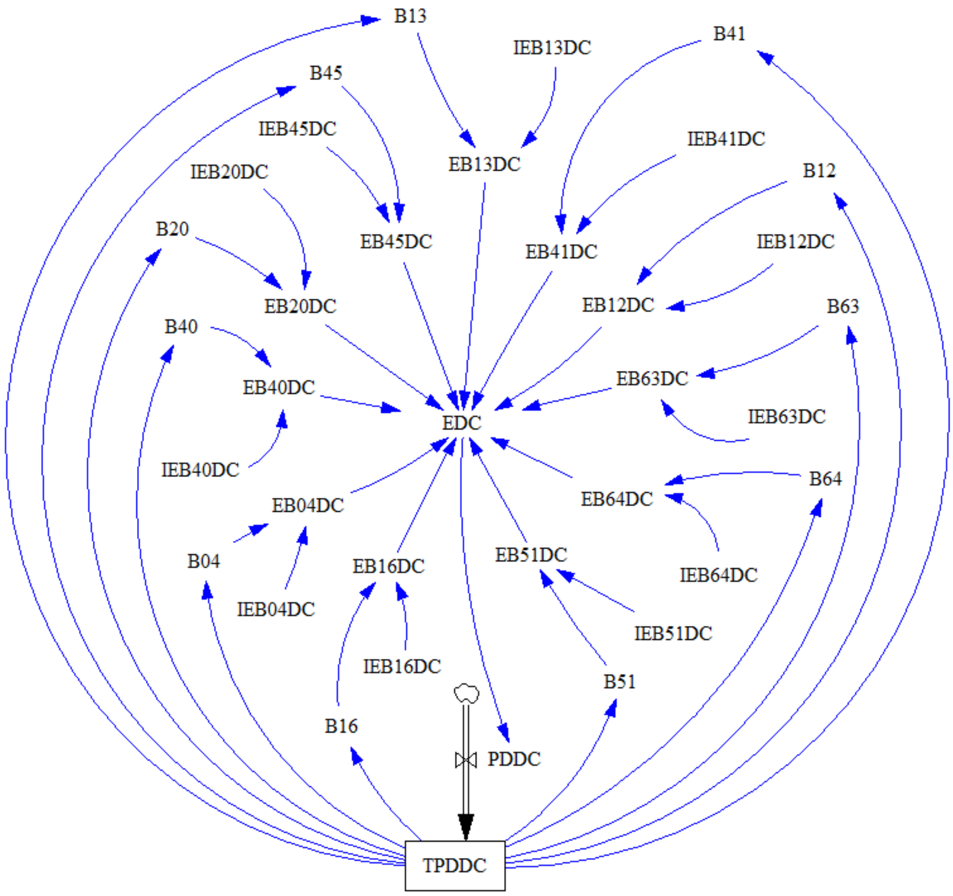


Figure 7.12 Dust control performance

As shown in Figure 7.12, a lack of priority given to this issue by contractors, poor awareness of risks among workers, little attempt to design out dust risks, a poor understanding and use of on-tool extraction, inadequate management arrangements to control dust, poor worker compliance with the arrangements that are in place are the main reasons.

7.4.4. Interruption of locals

Interruption of locals means the negative impacts of construction activities on the surrounding communities. Although dust control, an all-pervading phoneme that generates many impacts of construction on the physical environment, could be categorized into this type, it is considered that other pollutants can be treated as major sources to present the impacts of construction activities. The interruption of locals is thus presented here to describe those construction activities other than noise, light, dust pollutants impacting on the physical environment. Consequently, the fulfilment of CSR can be useful to alleviate the frequency of interruption of locals as shown in Figure 7.13.

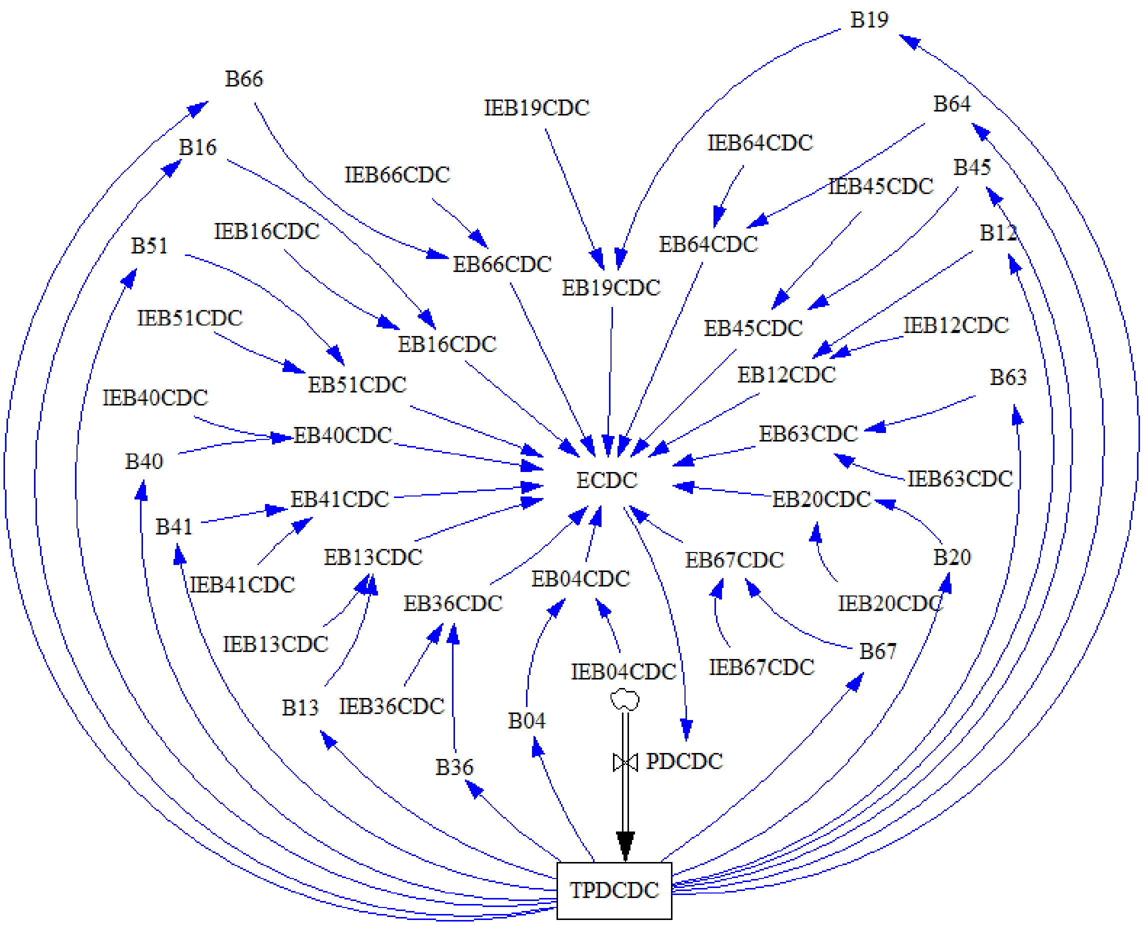


Figure 7.13 Interruption of locals

The interruption of locals includes any uncomforting caused by construction activities such as unsafe topographic condition, poor air condition, inconvenience of daily life, and so on. The generation of these impacts can be manipulated by enhancing the awareness of social responsibility among contractors, a close cooperation between subcontractors and contractors, a high measurement of construction pollutants, an efficient construction method, and the implementation of green construction. It goes without doubts that less interruption of locals will be rewarded with more supports from local people.

7.4.5. Overloading with local infrastructures

Infrastructure is not only one engineering facility to provide public services for social production and living materials, but also a public service system to support social and economic activities (Faturechi & Miller-Hooks 2014). In addition, it refers to a range of services including public service facilities (e.g., sanitation, water supply, telecommunication, sewerage and environmental protection) and municipal public works facilities (e.g., roads, water transport, railways, airports, bridges and transport) (the World Bank 1994). Since construction projects should be delivered within a period of time and by doing so contractors would secure the success of the construction process. For instance, electricity facilities for a construction project might be prioritized while locals will be impacted due to a smaller amount of energy supply. The overloading with local infrastructures is also embodied with road transportation to convey materials and equipment from factories. In appreciating the connection between CSR fulfilment and infrastructure burdening, Figure 7.14 is proposed to describe the impacts of CSR on SPCP.

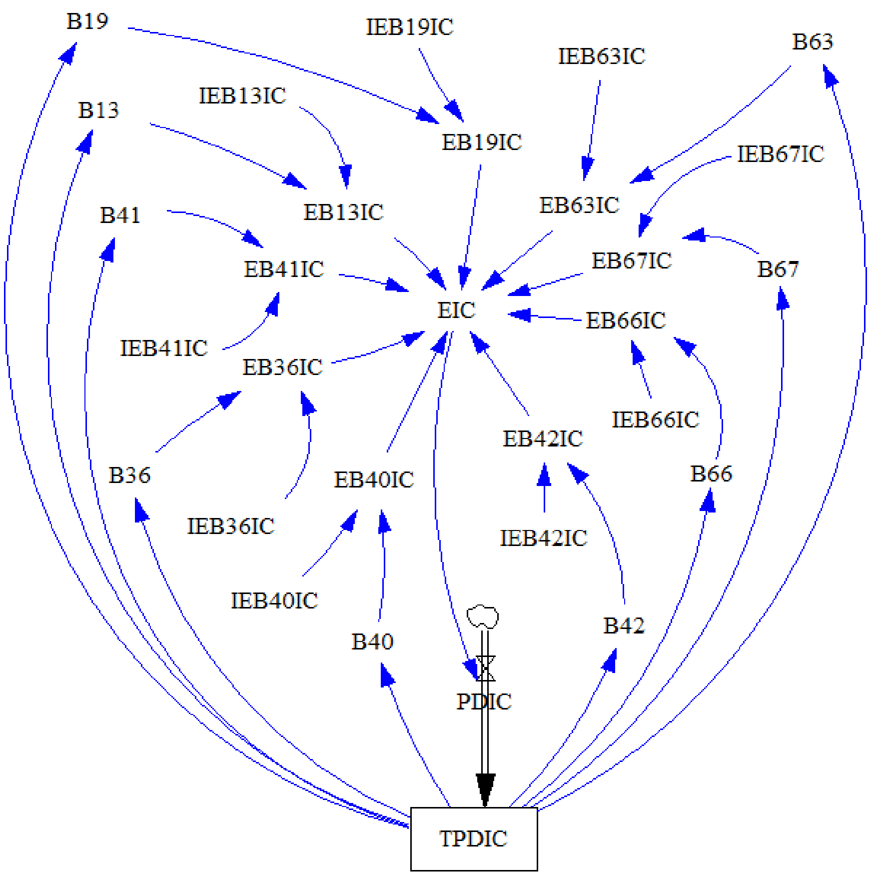


Figure 7.14 Overloading with local infrastructures

As shown in Figure 7.14, communication between the team and local residents should be well contacted to avoid the conflicts of utilizing infrastructures. Using more local materials is a means of lowering the impacts of overloading of infrastructure. Meanwhile, stakeholders are encouraged to work together to reduce the overloading. It also suggests that involvement in local community development is useful to gain much recognition of locals to support the operation of a nearby construction project.

7.4.6. Waste management

Construction waste refers to by-products generated and removed from construction, renovation and demolition work from building and civil engineering projects (Yuan 2011). The form of construction waste include building debris, rubble, earth, concrete, steel, timber, and mixed site clearance materials (Bossink and Brouwers 1996). Construction waste is usually a main waste generator in a region. With the decrease in new landfills for construction waste, a growing awareness of this matter has been surfacing and has become an urgent need. It has been reported that 40% of total natural resources were consumed by China's construction industry and the construction waste occupy about 40% of all municipal solid waste (Wang *et al.,* 2004). Many methods for disposing construction and demolition waste have been identified, including recycling to incineration and land filling. Waste avoidance, waste minimization, waste recovery, waste bulk reduction and waste disposal are five waste management actions (Yuan 2011). In this study, the fulfilment of CSR is supposed to improve the management of construction waste as given in Figure 7.15.

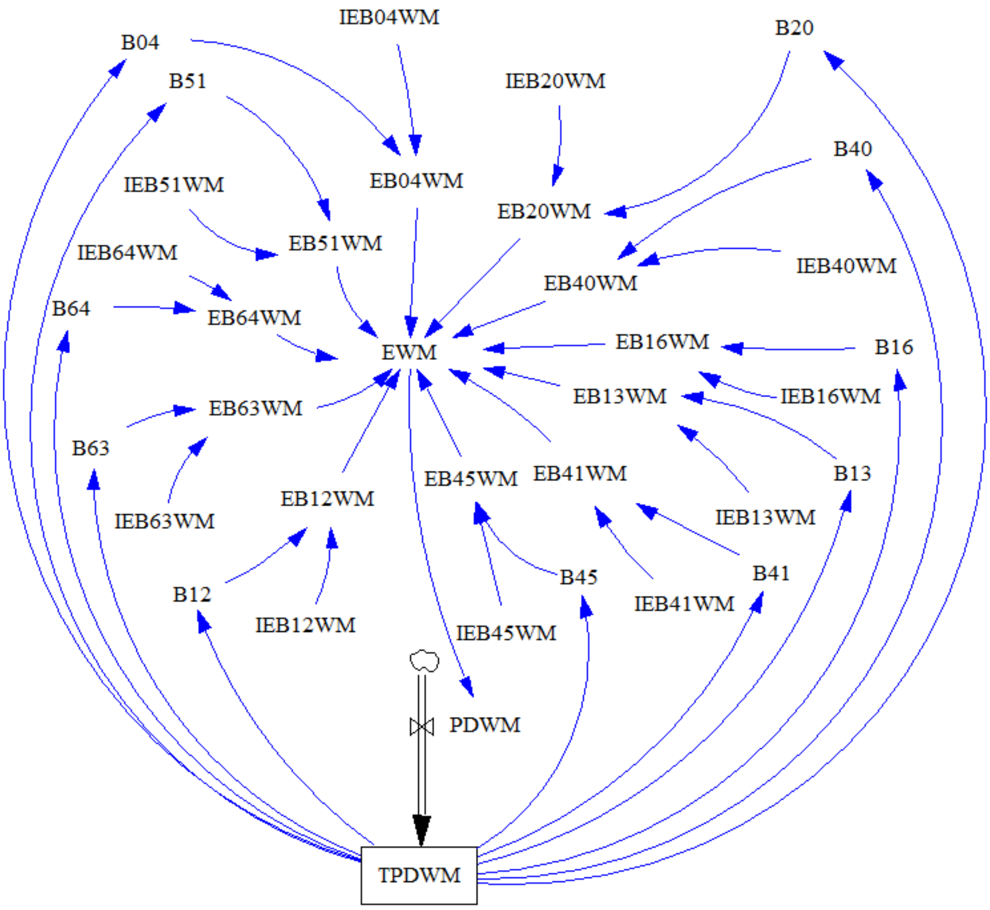


Figure 7.15 Waste management

7.4.7. Biodiversity conservation

The rationale for sustainable construction is to keep planetary conditions favourable for human life both globally and locally (Irurah 2001). Basically, the construction process may give rise to the loss of biology on construction sites. A mega road infrastructure project is usually built across regions. Its impacts on the natural environment is distinctive as a diversity of valuable trees may be moved. On many occasions, damages to biology would be straight and considerable, and the natural cycle will be broken as such (du Plessis 2002). It is vital that biologic situation is well appraised to inhibit the happening of this as much as possible from the perspective of CSR fulfilment (see Figure 7.16).

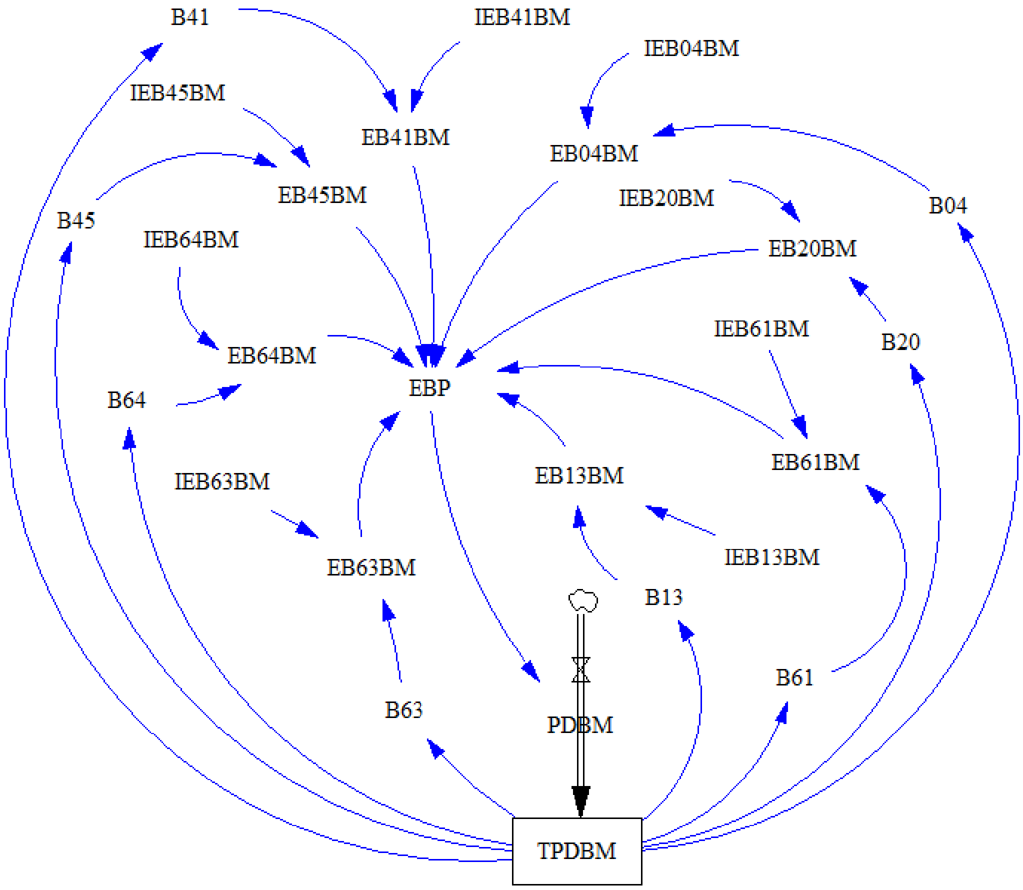


Figure 7.16 Biodiversity conservation

To improve biodiversity conservation, it is very useful to conduct environmental performance measurement prior to the commencement of construction activities. A detailed biodiversity conservation scheme is expected to put in place, in which the roles and responsibility of various construction bodies should be assigned. Since a vast majority of construction works are completed by subcontractors, their contribution to biodiversity protection should not be overlooked. The complexity of biodiversity conservation ought to be simplified if a special department in charge of this is established.

7.4.8. Cultural heritage protection

The impacts of CSR fulfilment on a construction site are assumed to improve the protection of cultural heritage as shown in Figure 7.17. As one of social dimension of sustainable construction, cultural heritage may be encountered in the construction process. The so-called cultural heritage means permanent values which yield the unity, stability and cohesion of ancient societies from civilizations and cultures from all over the world (Murray and Dainty 2009). Previous studies have called for providing low-income communities with opportunity to construction their own shelter, create liveable settlements and maintain their cultural heritage (Irurah 2001). In the sphere of construction activities, cultural heritage ought to be revaluated in terms of the contribution it can make to sustainability by providing technological, institutional and value enablers.

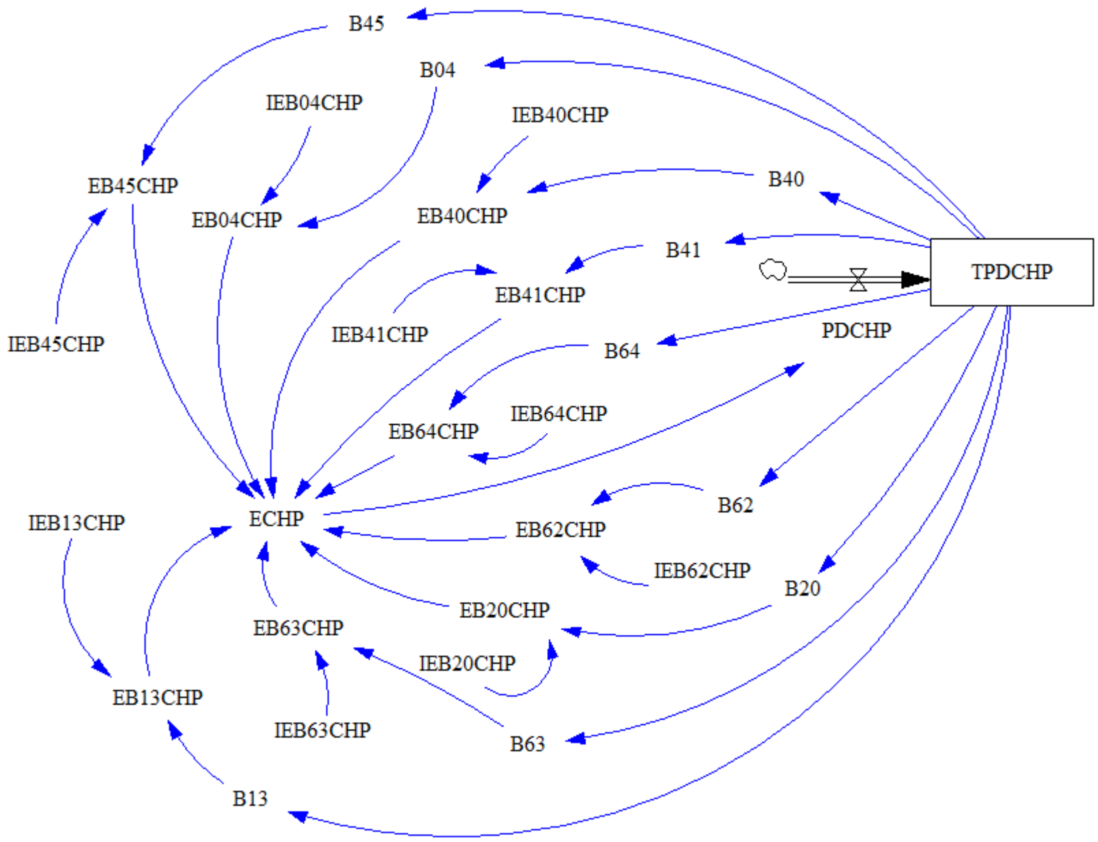


Figure 7.17 Cultural heritage protection

7.4.9. Employment opportunities

As stated in *Agenda 21 for Sustainable Construction in Developing Countries*, the construction industry has been the largest industrial employer in the world, and 74% of the employment opportunities are provided in the low-income countries. In the industrialized countries, the construction sector employs between 6% and 10% of the workforce. Due to the attributes of “employment intensity” of production, the construction industry has been given much expectation to provide more employment opportunities to local communities. By doing so, its employment conditions can contribute to the attainment of sustainable development and improving the quality of life for the whole society.

While a larger number of employment opportunities created by the industry are widely recognized, there is a high rate of gender discrimination and sexual harassment, and the existence of this phenomena continue to limit the equal participation of women in the construction sector. Meanwhile, contractors are requested to provide better employment conditions and training programs. It seems therefore to be that a holistic approach is in need to improve the employment performance on a construction site. As shown in Figure 7.18, closer collaboration between contractors and subcontractors facilitates the choice of technologies and can avoid the reduction in local employment opportunities. Caring low-income workers is crucial to advocacy, awareness raising and education.

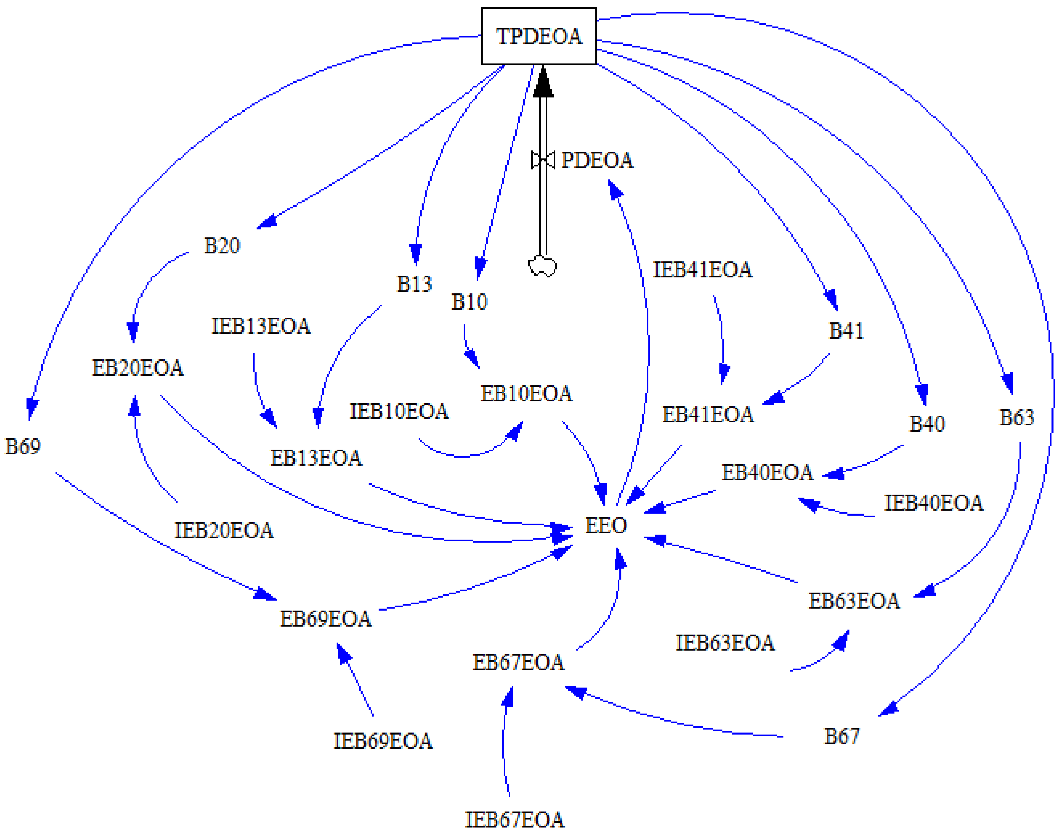


Figure 7.18 Employment opportunities created

7.4.10. Health and safety management

Many types of construction activities such as installation and maintenance of utility and pavement works rely heavily on the input of workforce. The expectation that workers are able to be productive without suffering harm is penetrating the construction industry. According to the International labour Organization (ILO), over 60 000 fatal accidents occur each year on construction sites around the world, and construction shares one in every six fatal accidents recorded at work annually (International labour Organization, 2005). In view of these shocking statistics, policy makers, industry employers, union groups and researchers are spoken to the need for a determined and coordinated effort to improve the health and safety management on construction sites (Croker 2013).

The construction process is technologically and organizationally complex. This means that various stakeholders are involved in the sphere of construction activities, and addressing occupational health and safety on construction sites within a single enterprise of contractors is no longer sufficient to ascertain improvement in OHS in the construction sector. Instead, there is an urgent need to manage the interests and influences of multiple construction stakeholders by virtue of coordinating and interactions. As shown in Figure 7.19, training and education is prerequisite to the performance of health and safety management. In addition, innovation and advancement of construction technologies are deemed useful in the area. The fulfilment of green working condition, appraisal of construction environmental performance are essential to the operation of OHS on construction sites.

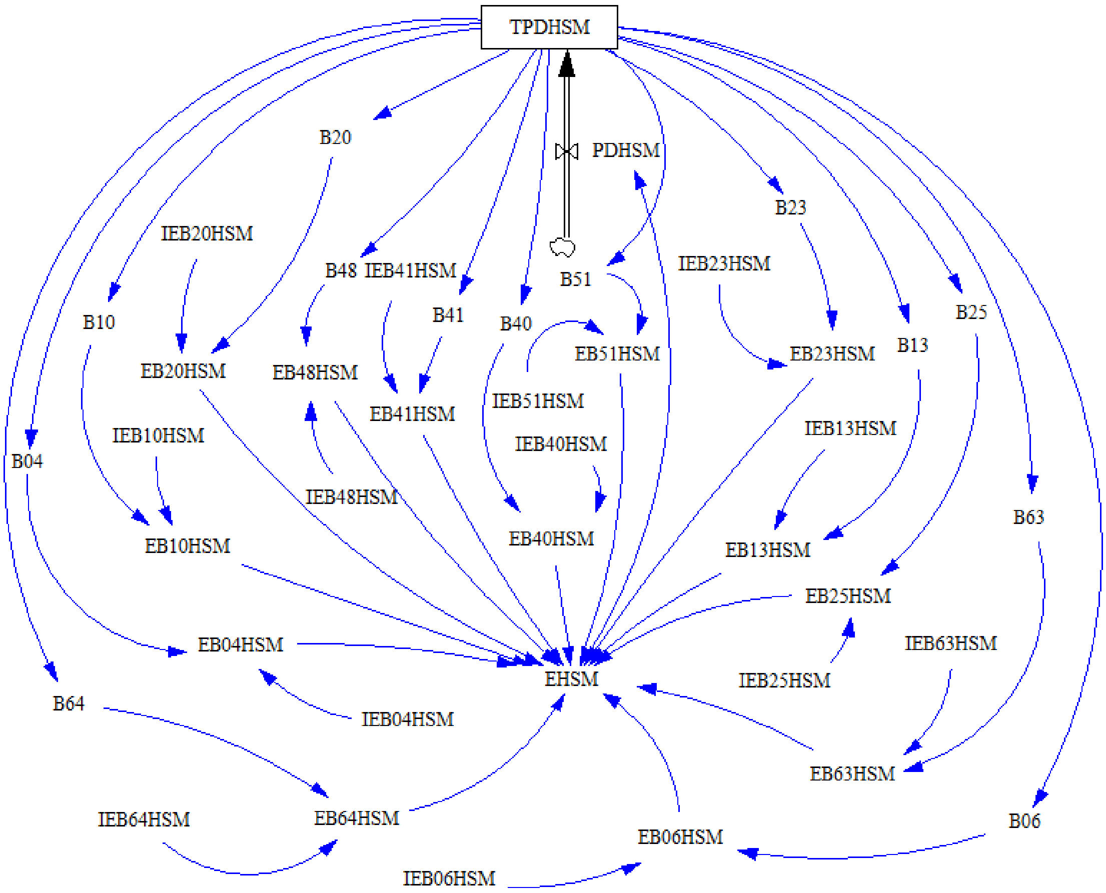


Figure 7.19 Healthy and safety management

7.5 COP subsystems

Based on an extensive literature review and interviews with experts, it is found that three COP indicators are subject to the impacts of CSR-C activities. In particular, all CSR-C implements can result in the increase in construction cost as shown in Table 7.3.

Table 7.3 Impacts of CSR-C activities on COP indicators

CSR-C activities \ SPCP indicators		Quality management	Cost management	Schedule management
		QM	CM	SM
B02	Applying/optimizing a confidentiality system for customers' information	√	√	
B03	Applying/optimizing a customer satisfaction management system in responding to customers' claims	√	√	√
B04	Applying/optimizing an environmental impact assessment and precaution system prior to construction		√	√
B06	Applying/optimizing precaution mechanism for safety management		√	√
B10	Applying/optimizing a training and education system for occupational skills	√	√	
B12	Applying environmental technology and green energy to promote energy saving and emission reduction		√	
B13	Applying evaluation mechanism for collaborators to implement CSR		√	
B16	Applying pollution emission control systems (e.g. gas, dust, noise, sewage and waste)		√	
B17	Applying a post-construction service system and providing customers with proper post-construction services	√	√	
B18	Applying quality management certification	√	√	
B19	Applying a saving and recycling system for resources and energy utilization		√	
B20	Applying a selection, management and supervision system for sub-contractors	√	√	√
B21	Applying a strict quality inspection system for material and equipment procurement	√	√	
B23	Conducting green office		√	
B25	Conducting research development and technological innovation to improve quality and safety management level	√	√	√
B35	Establishing/improving employer-employee communication and negation mechanism (e.g. Labor union)		√	√
B36	Establishing effective communication channels with local community		√	√
B37	Establishing regular and effective communication mechanism with customers	√	√	

B40	Formulating/implementing CSR crisis precautionary and response mechanisms	√	√	√
B41	Formulating/implementing a CSR training scheme	√	√	√
B42	Giving priority to the procurement of local products and services		√	
B44	Guiding employees in career development and establishing employee promotion mechanism		√	√
B45	Implementing/optimizing environmental training scheme to improve employees' environmental awareness and skills		√	
B46	Implementing/optimizing a quality management system to strictly prevent quality accidents	√	√	
B47	Implementing/optimizing quality training to improve employees' quality awareness and skills	√	√	
B48	Implementing/optimizing a safety management system to prevent safety accidents		√	√
B50	Implementing disaster prevention/ relief activities for the society and local community		√	√
B51	Implementing emergency mechanism and scheme for environmental pollution accidents		√	
B58	Organizing/supporting occupational skills training programs for local community		√	√
B61	Protecting biological diversity and ecological systems		√	
B62	Respecting and protecting cultural tradition and heritage of the community		√	
B63	Setting up special division(s) for CSR management	√	√	√
B64	Setting up special units or/and positions to conduct daily environmental management		√	√
B66	Strengthening communication with collaborators and improving collaboration space and efficiency	√	√	√
B67	Supporting the development of infrastructure and public services of local community		√	
B68	Taking care of employees and their families and help employees to achieve work-life balance		√	√
B69	Taking care of low-income groups (e.g. Build-transferring low-income housing without charge)		√	

7.5.1. Quality management

If a construction project results in a low quality facility, then the price paid, money will waste. Nevertheless, poor quality is often surfacing on many construction projects nationwide in China (Shen and Song 1998, Zou *et al.* 2007). Poor quality means that the client does not get what they have reason to expect. A number of reasons can be derived to explain such a construction output performance. First, the client might not be careful enough in choosing contractors and drawing up the contract for the project. Second, contractors ought to be equipped with much experience and knowledge, and lack of much incentive can prevent them from responding actively to whatever changes on construction sites. Last but not least, contractors need to keep communication with the client and other stakeholders to improve the efficiency in project delivery.

Since most of the above issues are beyond the contract that the client signs with contractors, contractors ought to motivate themselves to achieve the goals of quality. Apparently, failing to achieve the quality goal might result in considerable contract conflicts and construction works payment. In this study, the accomplishment of construction quality management is highly associated with the fulfilment of social responsibility as shown in Figure 7.20.

Since construction quality is determined in part by the cooperation between construction undertakers, it is very important they can work as a team. The regular check on materials' quality and equipment, construction quality assurance, technical innovation for safety and quality, and subcontractor management are considered to be the main details that contractors should attach much importance. Meanwhile, constant communication with customers and staff within the contractor organization helps to reach more consensus on construction quality. Satisfaction management enables contractors to understand the clients' needs, requirements and expectation.

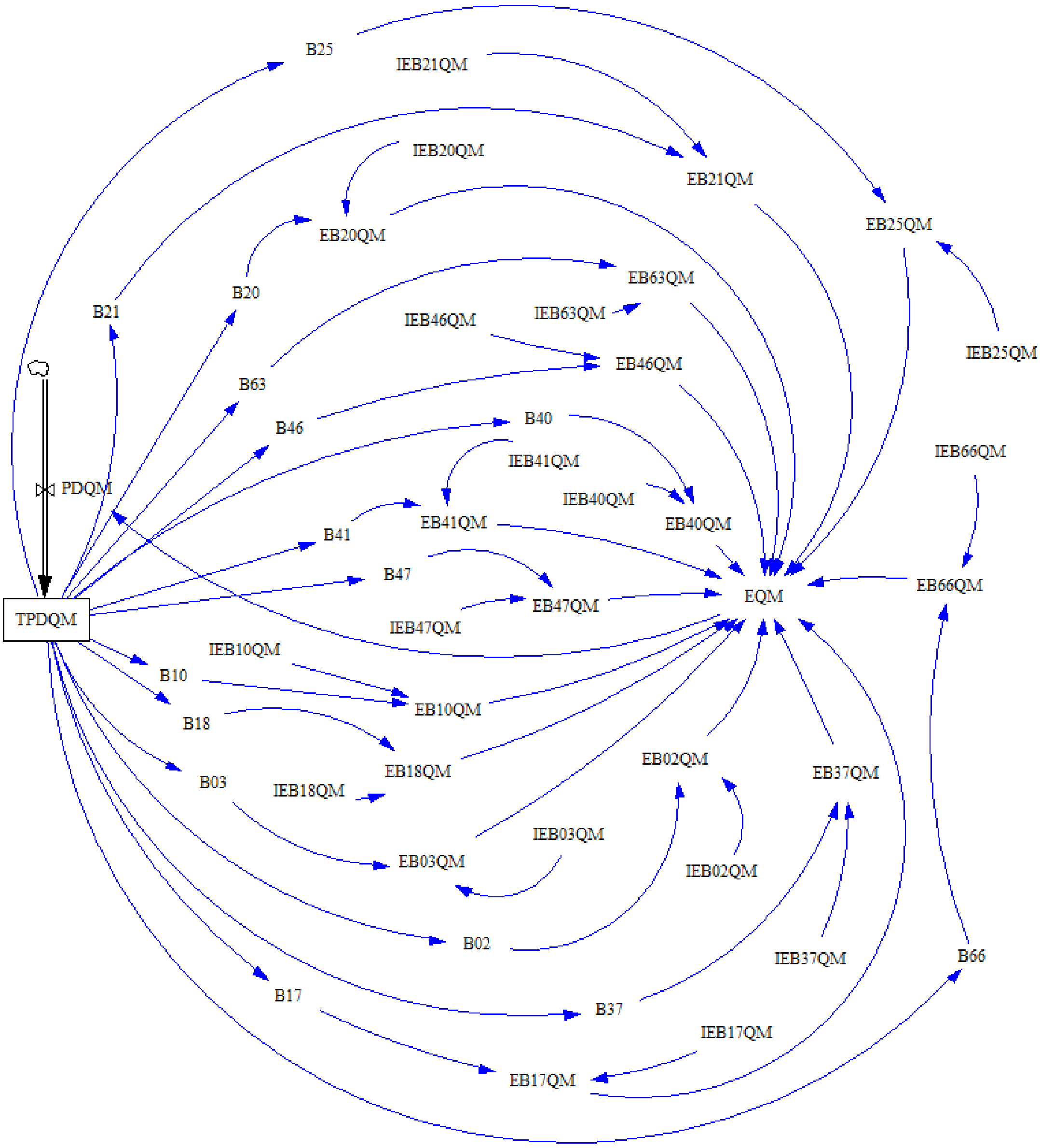


Figure 7.20 Quality management performance

It is also highlighted that training and education seem in parallel important to contractors to improve the capacity of construction management. Probably for the reasons that construction quality could be improved significantly if the contractors can be motivated effectively. One of the means is to establish a special department of CSR management, to conduct CSR training and education, to protect customers' privacy in terms of project description and instructions for construction, and to improve the ability of responding to CSR crisis.

7.5.2. Schedule management

Scheduling is a core activity that a project team has to take good care. The robustness of construction project schedule is a key indicator for measuring success performance of the construction management team. The schedule performance by the project team is usually assessed based on the deviation error between a baseline or estimated outcome and the actual outcome at completion. To achieve this, a number of approaches to scheduling include bar charts, basic networks, critical path method, precedence networks, resource allocation and levelling, schedule compression and time-cost trade-off have been widely applied in practice**.** However, construction projects are characterized by complexity and uniqueness, and they are subject to various constraints including resource availability, inefficient cooperation between players on a construction sites, and the change of construction works. It is assumed that the fulfilment of CSR can generate impacts of schedule management as shown in Figure 7.21.

The achievement of project schedule relies on specific characteristics of the project and challenge of work contracts. It is considered in the study, however, that construction schedule is somewhat determined by construction workers on the construction site. They are required to work as a team and have more willingness to rethink project outcome and keep innovation to improve the performance. Therefore, caring frontline workers, enhancing the technologies for construction quality, ensuring closer collaboration between subcontractors, and improving the satisfaction of the client can favour the delivery of construction projects in due time. Embarking on timely communication with local communities, embedding schedule management in association with the fulfilment of social responsibility, and fortifying education and training on CSR are deemed to be an important means in the ways towards sustainability.

7.5.3. Construction cost management

The subject of cost performance has been extensively published in the mainstream construction management literature (Anastasopoulos *et al.* 2014, Pellicer 2005, Lahdenperä 2010). The underlying responsibilities of main stakeholders such as the client, contractors, consultants, and suppliers in managing cost problems have attracted much attention. Previous studies have found that those factors influencing construction cost should be well investigated and obtain much consideration from contractors. According to Hicks (1992), improving cost estimation accuracy at an early stage is indispensable to avoid cost overrun in projects. Meanwhile, a larger number of researchers have highlighted the effects of project complexity, technology requirements, vagueness in scope, and the project team's capability in the area of cost management (Mansfield 1988, Akintoye 2000).

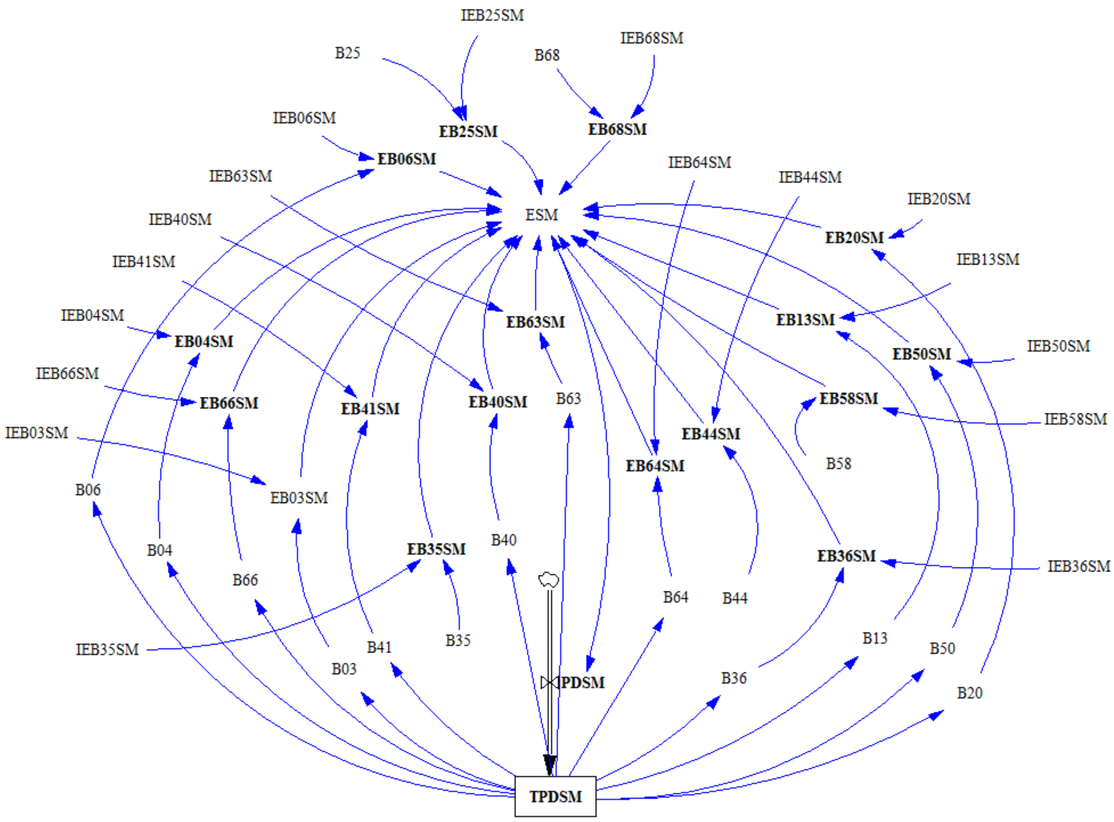


Figure 7.21 Schedule management performance

Inefficient site management and supervision, low speed of decision-making, and client-initiated variations have been appreciated to be most significant causes of poor cost performance (Trost and Oberlender 2003; Iyer and Jha 2005). Precise understanding of the factors and protocols of responsibility sharing between stakeholders is very important the success of construction project. In this study, it is noted that the effectiveness of construction cost management is in part dependent upon whether it is incorporated into the fulfilment of corporate social responsibility. One of the specific reasons is that those cost-related risks, underlying drivers, and impediments for effective cost management are not only technical, economic and managerial, but also measurable from a social and environmental perspective.

The main thought imaged in Figure 7.22 is to improve the effectiveness of cost management by virtue of the fulfilment of CSR on a construction site. Carefulness to frontline workers, satisfaction management for customers, and communication with the client can inspire the main players to pay much attention to the saving of construction cost. The establishment of a CSR department, training and education on CSR implementation, and CSR crisis management are useful to stir the enthusiasm of constructors to manage those activities not stipulated in the contract. An active interaction with local community, caring local residents, and provision of professional training for local workers can be rewarded with more supports from the surrounding community. By doing so the project can be delivered effectively, and cost will be saved.

Meanwhile, the performance of construction quality by means of quality assurance, daily quality management approach, quality management training and education, and subcontractor management can be enhanced significantly. It is double-edged that the engagement of these activities increase construction cost while the construction team might not receive benefits from them immediately. On one hand, the contractor possibly has much interest in conducting CSR activities. On the other hand, they have to bear cost overruns. A rule of thumb might be there that main contractors decide to the sphere of social responsibility behaviours on construction sites.

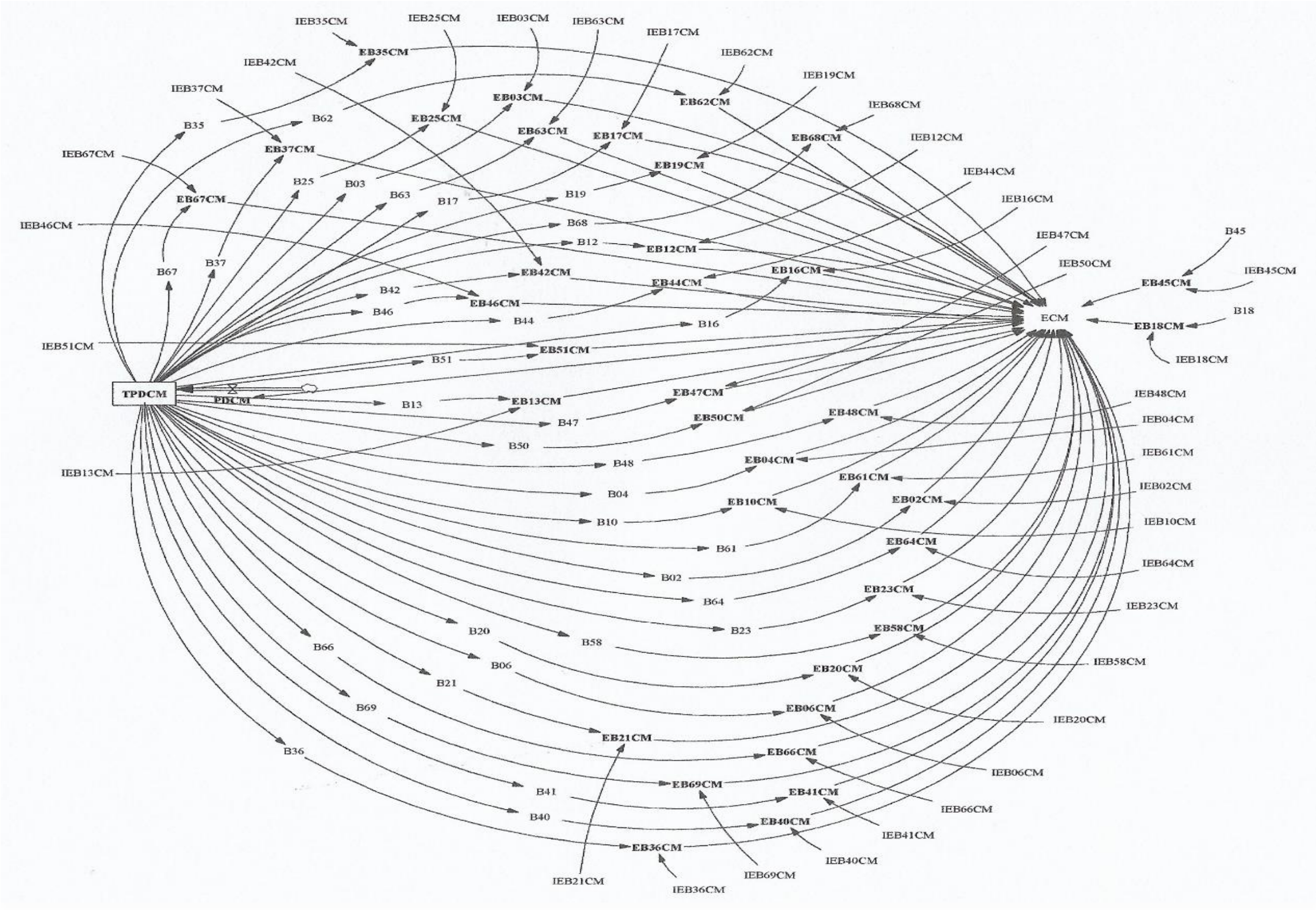


Figure 7.22 Construction cost management performance

7.6 Summary

In this chapter, a set of SD models is proposed to model the effects of CSR activities on SPCP by detailing the feedbacks between CSR fulfilment and sustainable construction process. The proposed model is composed of three subsystems, namely CIP, CAP and COP with seventeen paradigms. These models are developed based on a thought that the fulfilment of CSR on a construction site can bring many impacts on SPCP. Case study is to be adopted to quantify the variables included in the SD model and data are to be collected in due ways.

Chapter 8. APPLICATION OF THE SYSTEM DYNAMICS MODEL – A CASE STUDY

8.1 Introduction

As presented in Chapter 7, a system dynamics model for measuring the effects of CSR-C activities on SPCP is proposed using causal loop diagrams and stock-flow diagrams. In this chapter, the proposed model will be illustrated using a major transportation infrastructure project from western China. The aim of this step is to apply the proposed model to a real project. Thereby, the confidence in the model could be consolidated and the model used as an experimental platform for further application.

The chapter starts with an introduction to the case project. It moves on to interpreting variables and methods for data collection. A couple of research methods such as interview with the contractor, professionals and subcontractors and field study are conducted to collect data. Different types of variables in the model are quantified. The applicability of the models is validated by conducting different tests as required by the SD approach. The base run of the model is simulated and the resultant outcomes are detected as a consequence.

8.2 Background of the project

8.2.1. Reasons for the case selection

This project is a superhighway located in Guizhou province China. The length of this project is 249.637 kilometres, and three phases of this project are determined: Phase I (73.81 kilometres), Phase II (76.321 kilometres), and Phase III (96.135 kilometres). About 40% of the project measured by length is bridges and tunnels. The project distributes widely over an altitude of 600~1,070 meter in mountainous areas. The designed speed for the completed superhighway is 80 kilometre per hour.

The project was kicked off in August 2014 and is projected to be completed in July 2018. The client is the Construction Commission of Guizhou Province. The main contractor is a major state-own engineering enterprise called CCC in abbreviation. The contractor CCC has a good track record of CSR fulfilment and its CSR reports are released annually for five recent years in their website. It seems that CCC has been actively involved in disaster area rebuilding projects, and has accumulated much experience in localization strategies.

In spite of a large magnitude of infrastructure projects similar to this project, the reasons for investigation on this case are given below:

(a) It is a large project with many interfaces with local environments. Thus, the contractor has many opportunities of implementing CSR activities.
(b) The project has been started for a period of time, and the contractor has specific understandings on how it has been and what kind of CSR activities have been conducted. In addition, they have the knowledge about CSR fulfilment and sustainable construction.

(c) It is usually imaged that state-owned enterprises are on behalf of the Central Governments and they have more willingness than private firms to carry out CSR activities. The contractor has input considerable resources into non-construction matters.

8.2.2. Construction plan of the project

The contractor is motivated to fulfil some kinds of corporate responsibility, but this is not a must for the contractor to fulfil as said in the contract. This superhighway goes through ten little towns and considerable rural areas. There distributes thousands of rural people and they might participate in the construction project, and the contractor has the responsibility of considering the expectation and demand of local residents.

Construction technologies for this project is challenging due to extensive distribution of rock and ground foundations. The contractor ought to set priority to construction technology innovation to handle heavy construction tasks of bridges and roads including two main bridges, twenty-eight tunnels, and considerable structural forms. A spot survey on high rock slop is required and excavation for dock is suggested to use. Wet sprayed concrete are highly expected to use for high bank slope and tunnel excavation. The contractor has to deal with a little bit challenge of geological situations, suggesting the necessity of innovation on construction technologies.

The impacts of construction activities on the surrounding environment shall be very cautious to ensure that the fragility of ecology is well protected. Construction dust must be kept lowly and any temporary construction facilities cannot be left after the completion. Plentiful underground and surface reservoirs are hopeful to reduce the pressure of searching for water utilization for construction activities, but the contractor is reminded to protect the natural water system without generating pollution. Special attention may also be paid to underground drainage system, which is subject to the impacts of construction activities.

The stakeholders involved are multiple and the main task of construction management on the site is to conduct coordination effectively. The contractor must strictly adhere to both *Quality Evaluation Grade for Road Infrastructure Project* and *Approach for Delivery of a Road Infrastructure Project*. Construction quality should be good and no major quality accidents happen. *Green Construction Initiative* should be executed and no complain on ecology breach is reported. Dynamite construction works have to be used. Furthermore, no major fire emergency is reported and a negligible rate of incidents would be adopted as a key performance indicator for the contractor. Construction safety is highly regulated and heath of frontline workers is monitored in a regular fashion.

The construction project consumes a great amount of materials including steels, concrete, cement, and stocks and procurement of these resources is an overwhelming task. Fortunately, the contractor can purchase most of construction materials from local markets. Large demand for construction materials means that the project team has to predict the fluctuation of materials prices and take proactive response to manage them. The principal contract is based on a lump sum mode and the contractor has to pay for any extra cost if it happens unexpectedly. Transportation is convenient as construction materials and equipment may be carried to the construction site through county road, rural roads, highways, and expressways. Considerable vehicles should be put into use. Nearly 400 transportation vehicles are running on a day. Therefore, the contractor is strongly expected to care very much about the interrupt of transportation into local communities and the ecological environment.

8.3 Methods for quantification of variables and data collection

As presented in Chapter 7, there are three types of variables: quantitative, qualitative and dependent, and data sources per variable are presented in this section. The first type of parameters is quantitative variables which refer to constant parameters. Their values remain unchanged over the period of simulation. Basically, variables of this kind influence other variables but they bear little influence exerted by other variables. Their values could be derived with reference to information and records of the cited project, relevant research papers, reports and governmental regulations. The second type of parameters is dependent variables, of which values are determined by other variables in the model. In essence, a dependent variable has interrelationships with other variables. The last one of parameters is qualitative variables, whose values are obtainable through survey including questionnaire, interview, and onsite visit. As addressed in the proposed model, a large number of variables involved in the proposed model are qualitative, and quantification of these variables should be done prior to the model simulation.

8.3.1. Quantification of CSR activities

Variables for CSR fulfilment span widely over a diversity of items as shown in Table 4.3 (Contractors' CSR activities in the Chinese construction industry). Those qualitative variables have limited values and they are usually presented in construction management plans for implementation. Procedures for quantifying variables of this kind are called *Method I*. Since not all CSR activities can be quantified and resource consumption differs from one CSR activity to another, it is considered that all necessary inputs for a CSR activity (e.g., time, manpower, and fee) can be converted into an amount of money. The contractor is simply to determine budget for CSR activities in whole and individually. To allocate budget among CSR activities, three mid-level managers of the contractor CCC are invited to give a weighting per CSR activity.

Different types of CSR activities consume different inputs. Some kinds of CSR activities are resource-intensive such as B25 (Conducting research development and technological innovation to improve quality and safety management level) and B50 (Implementing disaster prevention/ relief activities for the society and local community). However, some other activities consume less resources such as B35 (Establishing/improving employer-employee communication and negation mechanism (e.g. labour union). Furthermore, CSR activities including B42 (Giving priority to the procurement of local products and services) and B19 might be helpful to save cost. To apply the weightings given in Table 4.3, all CSR activities can computed with monetary inputs.

Contractors are often advocated to use more resources for the fulfilment of CSR along the construction process. However, their willingness to embark on the matter depends on resources availability that a contractor can have. In this project, resources used to engage in a CSR activity are fixed and the total input for CSR activity is reliant on the availability of resources that the contractor owns at the moment as well as the extent to which they would like to be flexible in resource allocation. In this sense, quantifying the initial value of resources input into a CSR activity is necessary. Step of this kind is called *Method II*.

In this transportation project, a totality of one million Yuan per month is settled down in a package and the project manager asked their general office to allocate budget across all of the CSR activities. The project management team finds that 40% of the package should be secured and the remainder depends on SPCP.

In similarity to those qualitative variables quantified above, there are some of variables describing SPCP indicators and they are pursuing the largest values. The real situation is that their values change with the construction process, but they are subject to uncertainty and uncontrollable factors. Those qualitative variables aim for higher performance value and have the bottom limits required by the decision rules of a variable itself. Two reference points are defined in the same dimension, corresponding to the best and worst performance, and assigned values of 0 and 100 respectively. Steps for quantifying variables of this kind are named *Method III*.

In the proposed model, variables also go to the weightings between SPCP indicators. A score ranging from 0 to 1 are assigned to each qualitative variable by those expert knowledge in the area wherever appropriate. This quantification is called *Method IV*.

The impacts of a CSR activity on SPCP indicators are changeable. Values of this kind are required to be equal or greater than 0 when a decision is made. The value of the impacts is expected to maximize but let it change at intervals. Thus, the largest coefficient of the variable and thus interval for simulation should be derived. The step for this approach is called *Method V*. A CSR activity can have impacts on a number SPCP indicators at the same time. It is thus considered that this approach should be devised to measure the extent to which a SPCP indicator is subject to one CSR activity. One unit of input for a CSR behaviour is shaped and its impacts on an indicator is gauged by virtue of interview. However, the total of the impacts should equal to one.

8.3.2. Equations

In line with the aforementioned approaches, equations are categorized into three parts. One is for quantifying SPCP indicators, one for quantifying the inputs of CSR resources, and one for measuring the outcomes of subsystem and the total SPCP as listed in the attachment.

(1) Equations for the quantification of impacts coefficients of CSR activities on SPCP indicators

RANDOM UNIFORM (Minimum, Maximum, Interval)

This equation means that the impacts are determined using random data from a normal distribution.

(2) Equations for the quantification of inputs of CSR activities.

Initial input + RANDOM UNIFORM (0, IF THEN ELSE(X, Maximum-Initial input, 0), 0)

This equation means that input per CSR activity is decomposed of two parts, namely initial input plus a random input subject to the measurement of SPCP.

(3) Equations for the quantification of impacts of CSR fulfilment on SPCP

$CSR\text{-}SPCP_i$ = RANDOM UNIFORM (Minimum, Maximum, Interval) * (Initial input + RANDOM UNIFORM (0, IF THEN ELSE(X, Maximum-Initial input, 0), 0))

This means that the impacts can be quantified by multiplying the coefficients with input.

(4) Equations for the measurement of SPCP

$TSPCP = CSR\text{-}SPCP_i * Wi$

This means the total SPCP is based on aggregation of all components.

Detailed equations for all calculations are enclosed in the attachment of this thesis.

8.3.3. Data collection

Interview with three senior mid-level managers (see Table 8.1) was executed to collect data. The data collection is for three purposes, namely to quantify the impacts of a CSR activity on a SPCP indicator, the proportion of resources among all CSR activities, and the initial input of resources for a given CSR activity.

Table 8.1 Profiles of interviewees

Professional	Position	Working year	Expertise	Degree
I	Manager	8	Construction management	PhD
II	Cost engineer	12	Cost planning and financial management	Bachelor
III	Senior manager	9	Project management and construction technology	Bachelor

Note: name was hidden due to the interest of privacy.

(a) The coefficient for measuring the impacts of a CSR activity on a SPCP indicator.

Interviewees were invited to give a score on each CSR activity based on their experience and understanding. They were reminded to take into account the situation with which the project is faced. The results are listed below.

Table 8.2 Weightings for CSR activities

Activity	Respondent			Weighting*	Activity	Respondent			Weighting*
	1	2	3			1	2	3	
B64	2	1	3	0.0241	B58	3	2	1	0.0241
B45	1	2	1	0.0161	B42	4	3	4	0.0442
B04	2	2	2	0.0241	B62	1	1	1	0.0121
B19	1	4	2	0.0281	B50	3	3	3	0.0361
B16	3	4	3	0.0402	B67	1	3	2	0.0241
B12	2	3	3	0.0321	B69	2	2	1	0.0201
B51	2	2	3	0.0281	B10	3	2	1	0.0241
B61	1	1	1	0.0121	B44	2	1	2	0.0201
B23	2	1	1	0.0161	B35	1	2	1	0.0161
B18	2	1	3	0.0241	B68	2	1	2	0.0201
B46	3	5	4	0.0482	B03	2	2	2	0.0241
B47	2	1	3	0.0241	B02	2	1	3	0.0241
B21	3	2	4	0.0361	B37	3	2	4	0.0361
B20	4	3	2	0.0361	B17	3	1	1	0.0201
B48	4	5	3	0.0482	B66	2	2	3	0.0281
B06	4	3	4	0.0442	B63	3	3	4	0.0402
B25	3	2	2	0.0281	B41	3	2	1	0.0241
B13	2	1	2	0.0201	B40	1	1	2	0.0161
B36	2	1	1	0.0161					

* Note: weighting was calculated in line with the above equation.

(b) To quantify the inputs of resources among all CSR activities.

As described above, the contractor determines to use one million Yuan monthly for CSR fulfilment during the period of construction. As listed in Table 8.3, each activity should have a number of inputs. After detailed discussion with the three professionals, 40% of the total input is considered suitable to be initial input. Thus, resources input for all CSR activities are listed below.

Table 8.3 Inputs for CSR activities

Activity	Weighting	Input			Activity	Weighting	Input		
		Total	Initial	Remainder			Total	Initial	Remainder
B64	0.0241	2.4096	0.9639	1.4458	B58	0.0241	2.4096	0.9639	1.4458
B45	0.0161	1.6064	0.6426	0.9639	B42	0.0442	4.4177	1.7671	2.6506
B04	0.0241	2.4096	0.9639	1.4458	B62	0.0121	1.2048	0.4819	0.7229
B19	0.0281	2.8112	1.1245	1.6867	B50	0.0361	3.6145	1.4458	2.1687
B16	0.0402	4.0161	1.6064	2.4096	B67	0.0241	2.4096	0.9639	1.4458
B12	0.0321	3.2129	1.2851	1.9277	B69	0.0201	2.0080	0.8032	1.2048
B51	0.0281	2.8112	1.1245	1.6867	B10	0.0241	2.4096	0.9639	1.4458
B61	0.0121	1.2048	0.4819	0.7229	B44	0.0201	2.0080	0.8032	1.2048
B23	0.0161	1.6064	0.6426	0.9639	B35	0.0161	1.6064	0.6426	0.9639
B18	0.0241	2.4096	0.9639	1.4458	B68	0.0201	2.0080	0.8032	1.2048
B46	0.0482	4.8193	1.9277	2.8916	B03	0.0241	2.4096	0.9639	1.4458
B47	0.0241	2.4096	0.9639	1.4458	B02	0.0241	2.4096	0.9639	1.4458
B21	0.0361	3.6145	1.4458	2.1687	B37	0.0361	3.6145	1.4458	2.1687
B20	0.0361	3.6145	1.4458	2.1687	B17	0.0201	2.0080	0.8032	1.2048
B48	0.0482	4.8193	1.9277	2.8916	B66	0.0281	2.8112	1.1245	1.6867
B06	0.0442	4.4177	1.7671	2.6506	B63	0.0402	4.0161	1.6064	2.4096
B25	0.0281	2.8112	1.1245	1.6867	B41	0.0241	2.4096	0.9639	1.4458
B13	0.0201	2.0080	0.8032	1.2048	B40	0.0161	1.6064	0.6426	0.9639
B36	0.0161	1.6064	0.6426	0.9639	In total	1	100	40	60

(c) To determine the sensitivity simulation.

Discussion was held among the interviewees to determine the scenes for simulation in the study. A consensus was reached on that the simulation should satisfy the situations that the project team might encounter and the preference that the team is considering. Furthermore, the simulation should be able to detect the significant impacts of CSR activities on SPCP values. Therefore, five simulation scenes were agreed after two rounds of negotiation among the three interviewees. The simulations are described in Table 8.4.

Table 8.4 Simulations for the study

No	Indicator	Weighting	S1	S2	S3	S4	S5
1	SPCP	SPCP-W_A	0.33	0.6 *	0.2	0.2	0.33
2		SPCP-W_O	0.33	0.2	0.6 *	0.2	0.33
3		SPCP-W_I	0.33	0.2	0.2	0.6 *	0.33
4	CIP	CIP-W_L	0.25	0.7 *	0.1	0.1	0.1
5		CIP-W_W	0.25	0.1	0.7 *	0.1	0.1
6		CIP-W_E	0.25	0.1	0.1	0.7 *	0.1
7		CIP-W_M	0.25	0.1	0.1	0.1	0.7 *
8	CAP	CAP-W_I	0.1	0.05	0.05	0.05	0.05
9		CAP-W_D	0.1	0.05	0.05	0.05	0.05
10		CAP-W_N	0.1	0.55 *	0.05	0.05	0.05
11		CAP-W_{DU}	0.1	0.05	0.05	0.05	0.05
12		CAP-W_G	0.1	0.05	0.05	0.05	0.05
13		CAP-W_s	0.1	0.05	0.55 *	0.05	0.05
14		CAP-W_E	0.1	0.05	0.05	0.05	0.05
15		CAP-W_C	0.1	0.05	0.05	0.05	0.05
16		CAP-W_B	0.1	0.05	0.05	0.55 *	0.05
17		CAP-W_W	0.1	0.05	0.05	0.05	0.55 *
18	COP	COP-W_Q	0.33	0.6 *	0.2	0.2	0.33
19		COP-W_C	0.33	0.2	0.6 *	0.2	0.33
20		COP-W_T	0.33	0.2	0.2	0.6 *	0.33

Note: * represents the highest weighting in the subsystem.

8.4 Model validation

According to Sterman (2000), a SD model can be ready for test as soon as all of the variables are quantified and their functions are determined. The key to the model test is to demonstrate whether the accuracy of the model could be acknowledged to properly reflect the real world. As pointed out by Yuan (2011), the confidence in a SD model accumulates in a gradual fashion with the model passing more tests and new points of correspondence between the model and empirical reality are recognized.

A SD model is usually tested with three intentions, namely verification, validation and legitimation. Verification aims to ensure the structure and parameters of the real system that should be correctly transcribed into the model. Validation spells out the demonstration that the SD model should yield same type of behaviours as expected from the real system. Legitimation serves to determine whether the proposed model adhere to the laws of system structure or any generally accepted rules.

In line with the suggestions by Coyle (1996), the following steps and guidelines are adopted to test the proposed SD model:

(i) The statement of the problem must be addressed by the causal loop diagram;
(ii) The causal loop diagram particularly including the '+' and '-' signs should be well explained by equations.
(iii) The model must be valid in dimensions.
(iv) The behaviour of the model should be plausible as expected.
(v) The model functions well even in some extreme conditions.

In this study, the proposed SD model for appraising the effects of CSR fulfilment on SPCP is adopted herein to illustrate the validation process as presented above. By doing so, the confidence in the model can be built for contractors to behave accordingly on construction sites. The following tests are performed for validation:

Test 1: The CLD must satisfy the statement of the problem.

The CLDs described in Chapter 7 (Figure 7.3~Figure 7.22) are composed of four subsystems, namely CSR activities, CIP, CAP, and COP; or CSR fulfilment, economic performance, environmental performance, and social performance. These parts of CLDs correspond to the statement of the research problem, which aims to measure the effects of CSR fulfilment on SPCP. Therefore, these diagrams are considered effective.

Test 2: The equations must correspond to the CLDs; in particular, the '+' and '-' signs in the equations must match the signs in the CLDs.

A closer examination of the equations in the SD model suggests that all the relationships described in the proposed model equations match well the corresponding directions in the CLDs described in Chapter 7. Model equations are listed in Appendix B.

Test 3: The model must be dimensionally valid.

The dimensions of the variables on the right-hand side of the equation should be able to be converted to the dimension of the variables on the left-hand side of the equation. This test serves to check and ensure the consistency. It seems that the variables dimension on the left-hand side is consistent with the variables dimension on the right-hand side of the equation. All equations in the model have been checked in the similar way to ensure dimension consistency.

Test 4: The behaviour of the model must be plausible.

Sensitivity analysis is employed to detect this validation. As an important part of the validation, the detection is to identify how the proposed model will behave if the variable values vary over a reasonable range. The test is to identify how robust the proposed model will have. An example is given in Figure 8.1 to show how the variable SPCP changes with the alteration in the variable. Two main conclusions can be drawn from the sensitivity analysis exhibits a similar shape, suggesting that the fulfilment of CSR at the project level makes positive contributions to the performance of sustainable construction. Therefore, it is concluded that the model can correctly predict the outcome of changes in variables.

Test 5: The model must behave properly when subjected to extreme conditions.

The proposed model in Figure 7.2 elaborates the effects of the variable CIP, CAP and COP on the variable SPCP. All of them are qualitative variables and thus quantified based on a scale ranging from -100 to 100, with -100 having totally negative impacts. These results from the extreme condition tests are in accordance with the general understanding of how CSR fulfilment would affect the occurrence frequency of sustainable construction. In this way, extreme condition tests on other variables in the model are conducted and analysed. Results of the above tests have confirmed that the proposed model can reasonably reflect the impacts of CSR behaviours on SPCP.

8.5 Results of the case study

By virtue of the quantification methods presented above, all variables as inputs into the model are quantified carefully. After importing all data into the model and defining the interrelationships of all independent variables, the model is used for simulation with the aid of Vensim software. In the case study, the model is simulated in a total period of 48 months, which corresponds to the construction duration of the project as indicated in this chapter.

8.5.1. Results of the SPCP system

Simulation results of the SPCP subsystem reflect values of variables examining the impacts of CSR fulfilment on SPCP, which include CAP (weighted impacts of construction activities due to CSR activities), CIP (weighted impacts of construction resource input due to CSR activities), and COP (weighted impacts of construction output due to CSR activities).

Figure 8.1 shows the value of SPCP throughout the project duration. As given in the figure, SPCP is used to investigate the overall effects of CSR activities, which can range from -100 to 100, with -100 having the lowest effectiveness and 100 having the highest effectiveness. It is computed based on the following formula:

$$SPCP = CIP^{*} W_{CIP} + CAP^{*} W_{CAP} + COP^{*} W_{COP}$$

Where,

CIP – Effects of CSR activities on construction inputs

CAP – Effects of CSR activities on construction activities

COP – Effects of CSR activities on construction outputs

W_{CIP} – Weights of CIP

W_{CAP} – Weights of CAP

W_{COP} – Weights of COP

In the current simulation, each variable is equally assigned with a value of 1/3. The results show that the value of SPCP in the first month is 0, and then it increases to positive values in the second month. After that, it presents a general increase in positive effects.

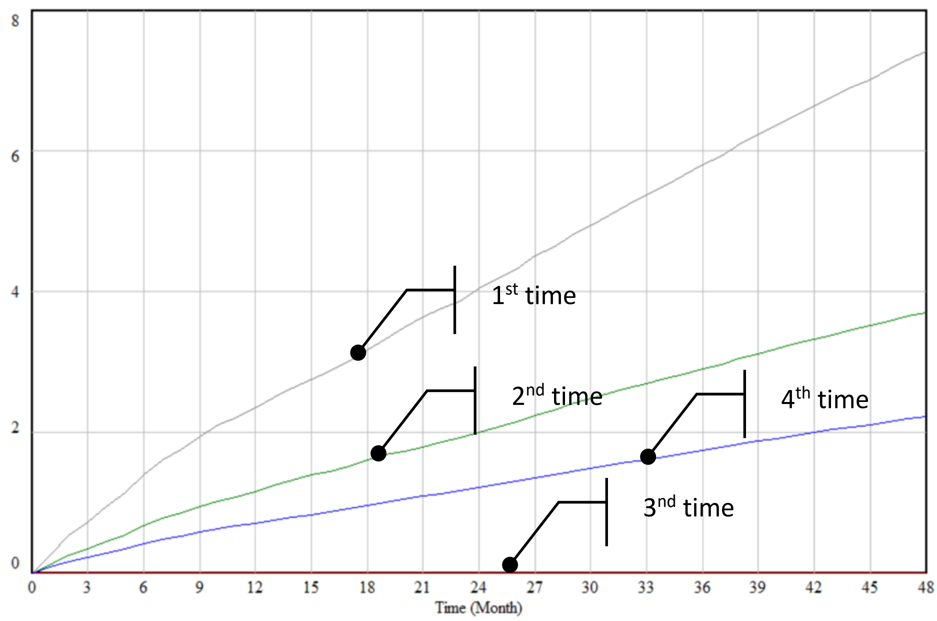


Figure 8.1 Simulation results of SPCP system

(Note: four scenarios are simulated to detect whether CSR can change SPCP)

8.5.2. Results of the CIP subsystems

Simulation results of the CIP subsystems are exhibited in Figure 8.2, which reflects values of variables examining the effects that CSR fulfilment would have on all construction inputs throughout the project duration.

In viewing that each of the five variables is hypothesized to have an equal weight of 1/4 in the CIP model, each of them can range from -25 to 25. Variation of CIP throughout the project duration is also illustrated in Figure 8.2.

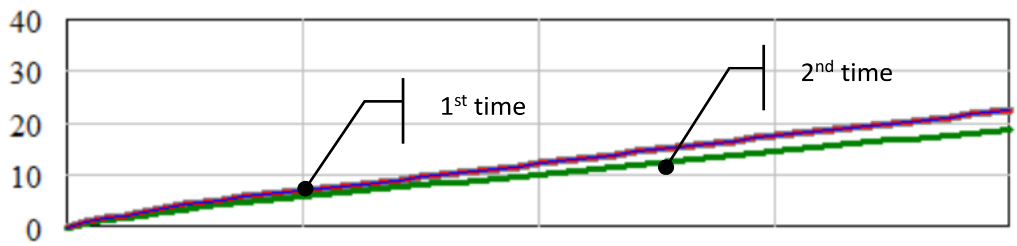
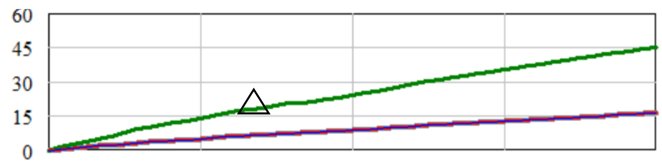
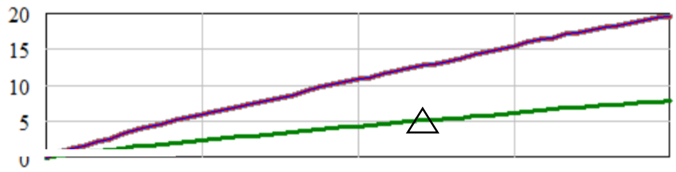


Figure 8.2 Simulation values of CIP in whole

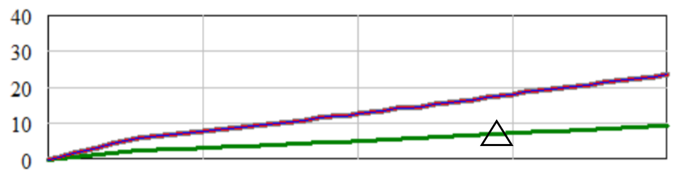
It can be observed from the simulation results of all CIP subsystems (Figure 8.3) that throughout the whole construction process, all of the five performances are positively contributed by the engagement of CSR; land resource input is most significantly impacted by CSR fulfilment, while material saving is subject to less impacts by CSR fulfilment. The longer interval between lines suggest a sensitivity of the performance impacted by weight setting.



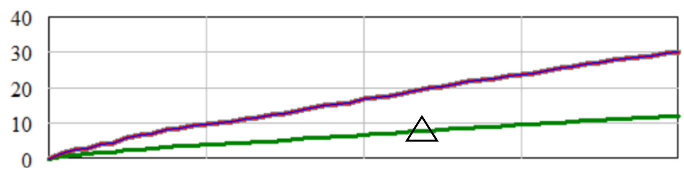
(a) Land utilization



(b) Materials utilization



(c) Water utilization



(d) Energy utilization

Figure 8.3 Simulation results of CIP subsystem in part

8.5.3. Results of the CAP subsystems

Simulation results of the CIP system are exhibited in Table 8.7, which tabulates values of variables examining the impacts that CSR fulfilment would have on the construction activities. Figure 8.4 shows the values of CIP throughout the project duration.

In view that each of the eleven variables is hypothesized to have an equal weight of 1/10 in the model, each of them can range from -10 to 10. Variation of CIP throughout the project duration is also illustrated in Figure 8.4. It can be found that the sustainability performance of construction activities receives positive contribution by CSR fulfilment. It also indicates that the sustainability performance of construction activities change little with the variation in weights.

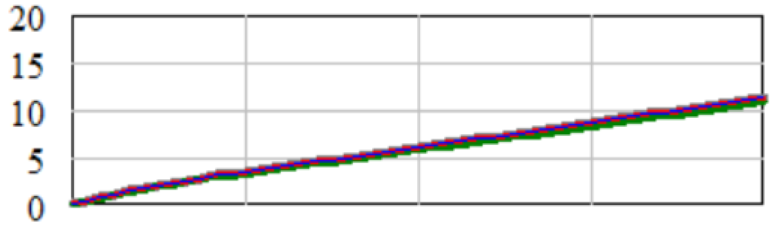
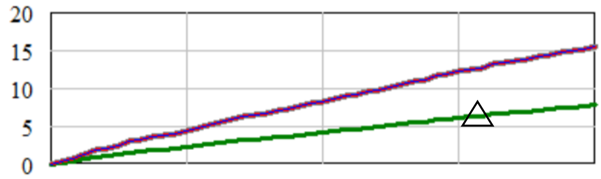
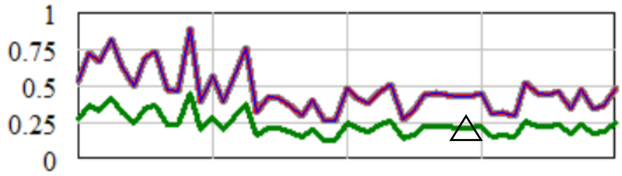


Figure 8.4 Simulations results of the CAP subsystems in whole

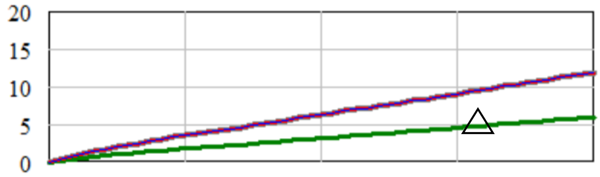
It is observed from the simulation results that throughout the whole construction process, the noise management performance is most impacted by CSR fulfilment, while health and safety performance changes little with CSR inputs.



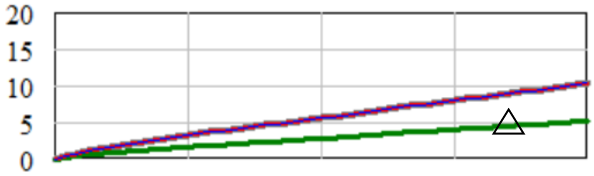
(a) Infrastructure burdening



(b) Health and safety management



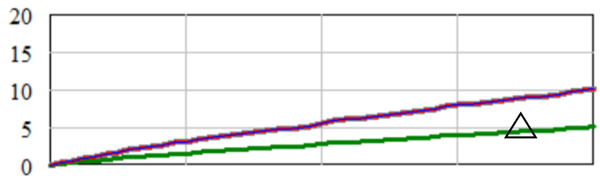
(c) Interrupts to local community



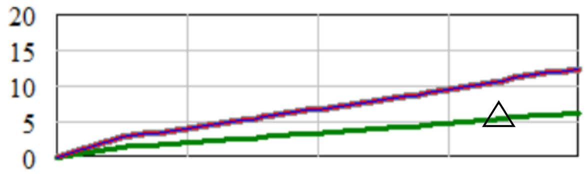
(d) Lighting pollution

8.5.4. Results of the COP subsystems

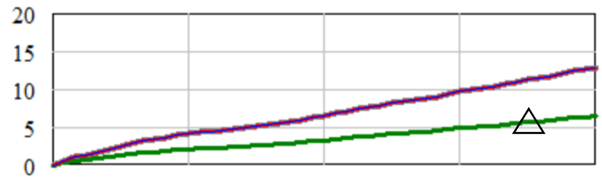
COP indicators are conventional objectives that project management teams have to achieve in line with construction work contracts. In this study, the simulation results of the CIP system are exhibited in Figure 8.6, which reflect values of variables examining the impacts that CSR fulfilment would have on the construction inputs, which comprise of three parts namely quality, schedule and cost. Figure 8.6 shows the values of CIP throughout the project duration.



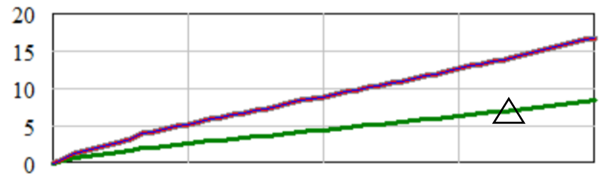
(e) Cultural and natural resources protection



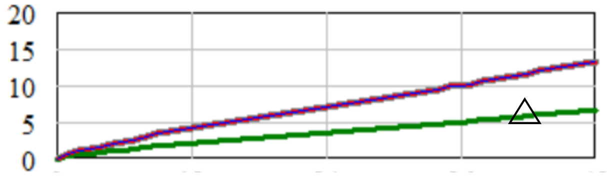
(f) Employment opportunities



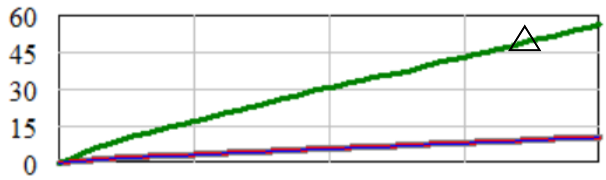
(g) Biodiversity protection



(h) Noise management



(i) Dust control



(j) Waste reduction

Figure 8.5 Simulations results of the CAP subsystems in part

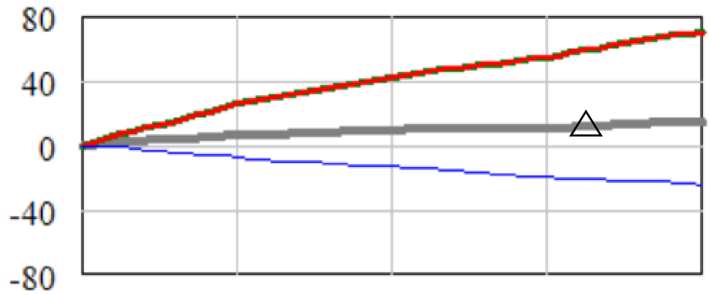
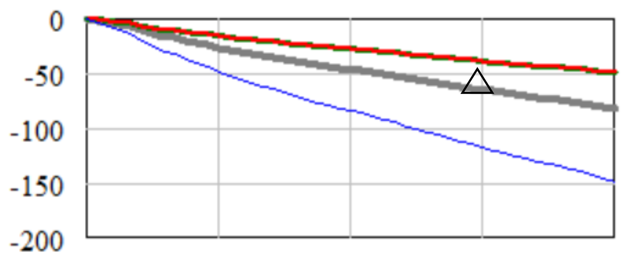
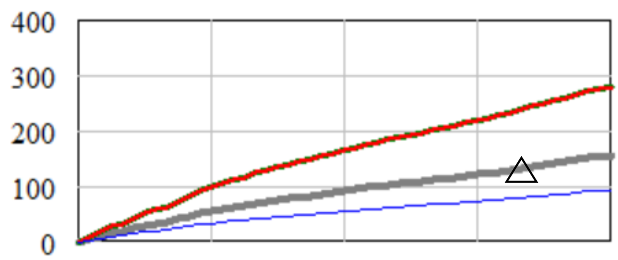


Figure 8.6 Simulation results of the COP subsystem in whole

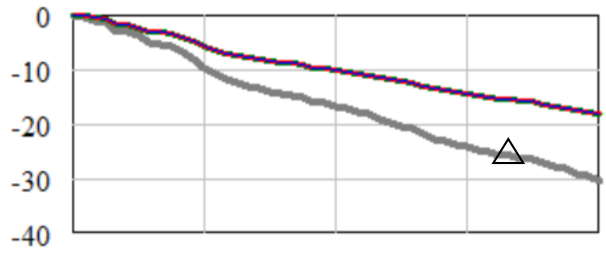
In view that each of the three variables is hypothesized to have an equal weight of 1/3 in the model, each of them can range from -33.3 to 33.3. Variation of CIP throughout the project duration is also illustrated in Figure 8.7. It is found that CSR fulfilment cannot always contribute the promotion of SPCP. In detail, the engagement of CSR will lower the performance of construction cost as well as schedule management. The contribution to quality management is positive.



(a) Construction cost



(b) Construction quality



(e) Construction schedule

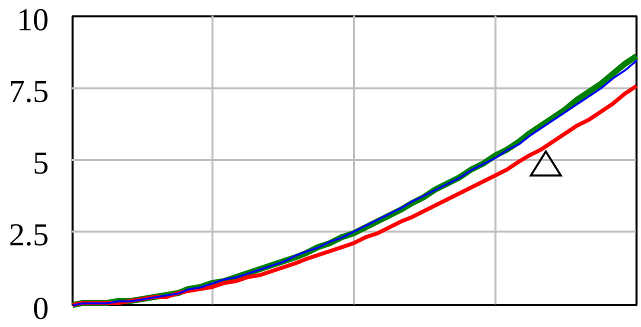
Figure 8.7 Simulation results of the COP subsystem in part

8.6 Improving SPCP through CSR fulfilment

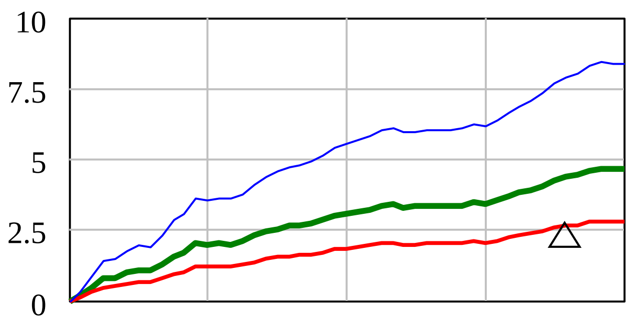
As presented in Section 8.5, the values of SPCP can be changed significantly by the fulfilment of CSR-C at the project level. It is now considered what kind of strategies that a contractor can adopt in order to improve the level of SPCP. Therefore, the most important outcomes from the SD models are presented in this subsection.

8.6.1. Impacts of weights between CIP, CAP and COP

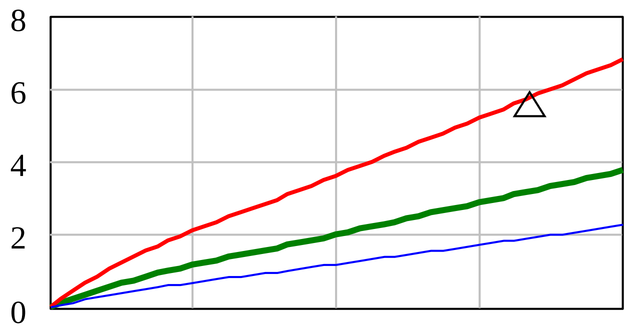
Four scenarios are adopted to simulate the impacts of CSR fulfilment on the SPCP as indicated below. It is found that whatever the change of weights, the curve of SPCP sustains changes along the construction process. The output-based SPCP has a significant fluctuating over the construction process, which means that the construction project management team has to handle the change of conventional management objectives as they do not follow a regularly changing track. The higher the weights given to construction outputs, the higher the output-based SPCP level. However, it cannot promote the SPCP distinctively. Instead, more efforts of contractors have to put to treat the lower level of performance of construction activities as indicated in Figure 8.8.



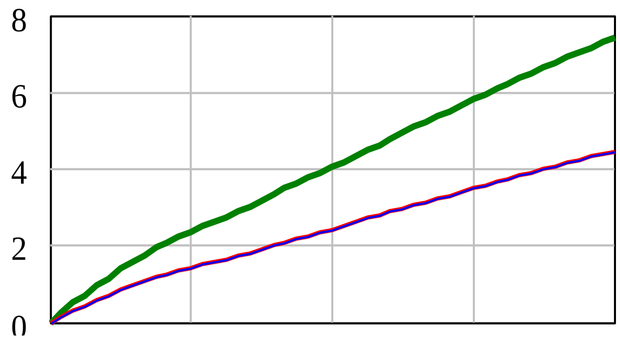
(a) SPCP



(b) CIP



(c) CAP



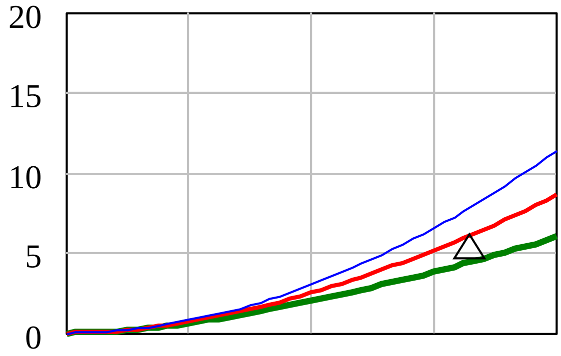
(d) COP

Figure 8.8 Simulation results of SPCP based on a change of weights between CIP, CAP and COP

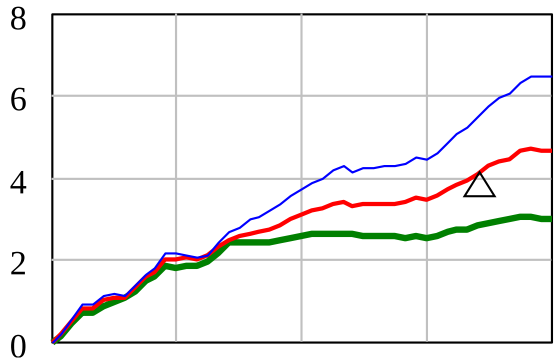
Very interestingly, the gradual increase in all curves suggests that the fulfilment of CSR is constructive to the promotion of construction process.

8.6.2. Analysis on initial inputs for CSR fulfilment

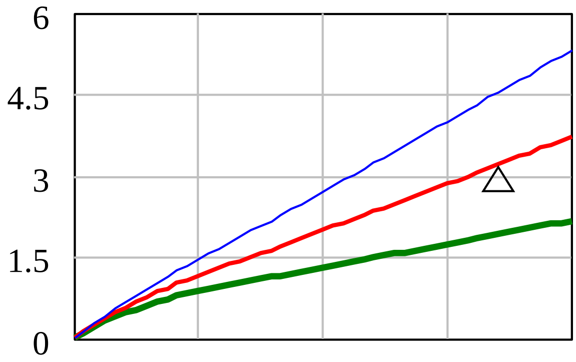
It is considered that the contractor may let it go on initial inputs for CSR fulfilment. Thereby the impacts of CSR fulfilment on SPCP can be observed. In line with this consideration, three scenarios are adopted to simulate the impacts, namely, 20%, 40%, and 60%. The results are given below. As shown in Figure 8.9 (a), it can be found the three scenarios can contribute positively to the promotion of SPCP along the construction process; an increase in initial inputs for CSR fulfilment means a higher possibility of achieving SPCP or a higher level of SPCP; an change in initial inputs poses less change of SPCP in the first quarter of the construction process.



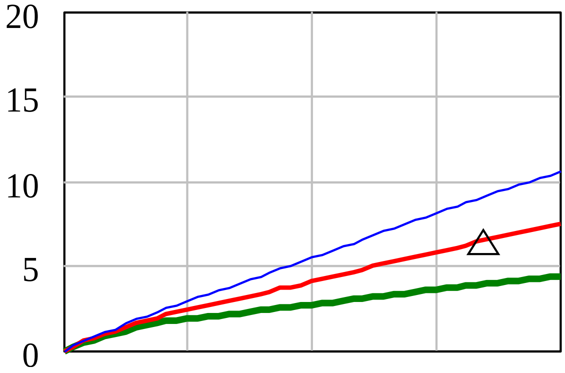
(a) SPCP



(b) CIP



(c) CAP



(d) COP

Figure 8.9 Simulation results of SPCP based on a change of initial inputs for CSR activities

In addition, the impacts of initial input for CSR fulfilment on the three dimensions are occurring in the same way. The larger the amount of the initial input, the higher the level of SPCP. Specially, the impacts on CAP change more significantly than the other two, and the impacts are not minor in the first year of the construction process. The impacts on CIP appear to be least significant although the impacts sustain gradual increase. It is found that the initial inputs on COP fulfilment is unfolded in a more straight way.

Although an increase in the initial input for CSR fulfilment can improve the results of SPCP, it will confront the contractor with some difficulty in striking the trade-off between those objectives required in the contract and those objectives expected by society. The main reason for this is that CSR fulfilment may occupy the consumption of resources and this might inhibit the contractor from arranging sufficient resources to achieve project management goals. This implies that the contractor has to determine a certain amount of inputs for CSR fulfilment and accounts for it in the package of construction plan.

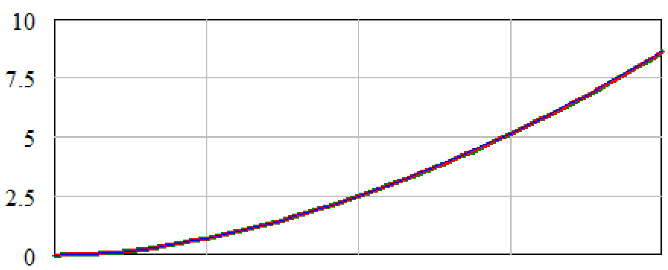
8.6.3. Analysis on key CSR activities

The simulation of CSR fulfilment is also expected to specify in what ways that SPCP is changed by some individual CSR activities. As presented in Chapter 4, 37 key CSR activities are identified in the Chinese construction context. It is too lengthy to address the impacts of all CSR activities in this chapter. However, it is considered acceptable to delineate those factors have more distinctive impacts. The 37 CSR activities are classified into six groups. Thus, one CSR activity per group is adopted to conduct the simulation. The simulation is built on the assumption that if the contractor increases the initial input for this kind of CSR activity, what results of SPCP will occur?

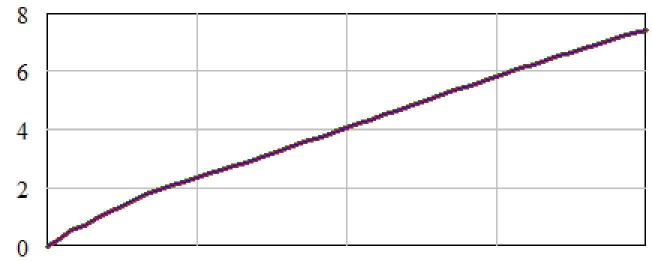
(a) An increase in *applying pollution emission control systems (e.g. gas, dust, noise, sewage and waste)* (B10)

This social responsible behaviour is concerned with construction activities, in which the contractor is required not to generate much negative impacts on the environment. As shown in Figure 8.10 (a), an increase in the change of B10 fails to bring significant improvement on SPCP. However, CAP could be enhanced while COP is decreased and CIP has negligible variation. Therefore, the relatively unchanging SPCP might be because that the increase in CAP is compensated by a decrease by COP.

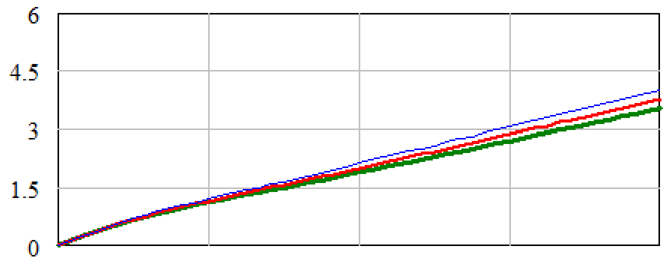
The research findings mentioned above suggest that resources put to improve construction activities can aggregate the difficulty in achieving the project's conventional goals (e.g., quality, schedule and cost). If a contractor fails to deliver the project's goals as stated in its contract, punishment might be unavoidable. This agrees with the practice and explains why contractors have lower enthusiasm of embarking on CSR activities. It is implied that contractors who place more emphasis on CSR matters on construction sites have to make due response to its impacts on main tasks that they are required to complete. Meanwhile, the saving of inputs with respect to land, water, materials and energy may not be changed with the increase in the intensity of B10.



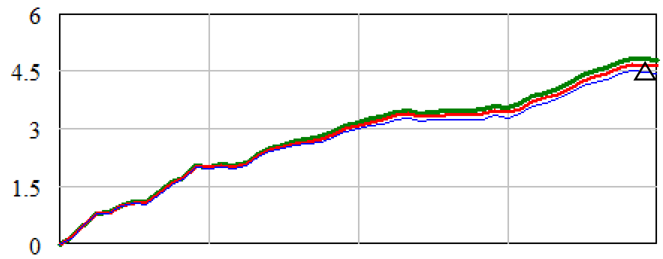
(a) SPCP



(b) CIP



(c) CAP



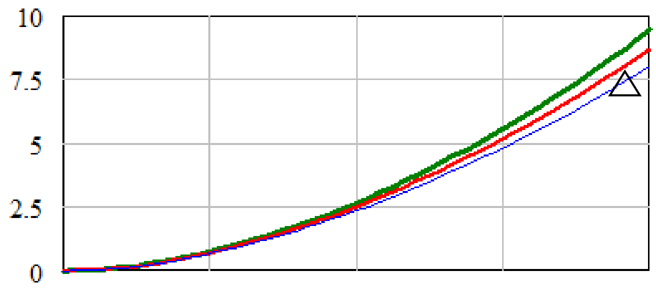
(d) COP

Figure 8.10 Simulation results of SPCP based on an increase in B10

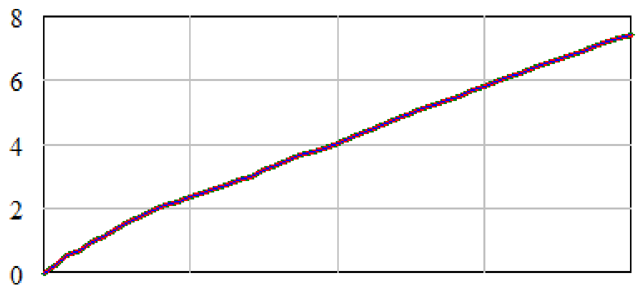
(b) An increase in *implementing quality/optimizing quality management systems to prevent quality accidents* (B46)

Construction quality is vital to the performance of a contractor. A high performance of quality management is a key success factor of contractors in undertaking construction work business. It is highly required that contractors have to endeavour to ensure an acceptable level of quality when the project is delivered to the client. Otherwise, the contractor's credit will be plagued.

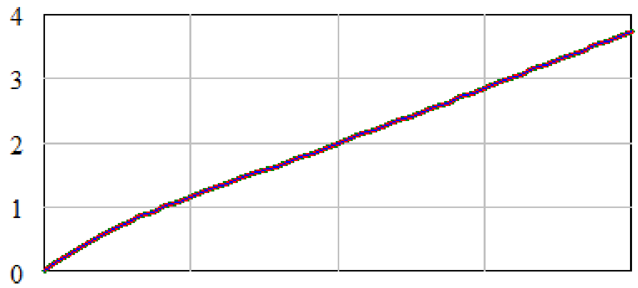
In differing from an increase in B10, the item B46 appears to have higher potential of enhancing the level of SPCP as shown in Figure 8.11. In effect, an increase in B46 can improve SPCP along the construction process whilst the improvement is not transparent at the beginning of the construction process. As suggested in Figure 8.11 (b) and (d), an enhancement on B46 cannot bring much negative impacts on construction activities and construction resources input. The significant improvement of construction outputs is directly associated with the performance of construction quality. This means that efforts of the contractor are devoted to quality management can be rewarded properly.



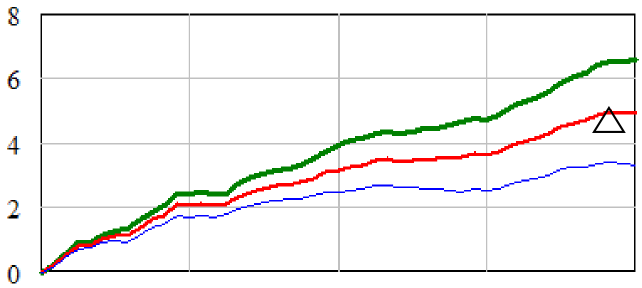
(a) SPCP



(b) CIP



(c) CAP



(d) COP

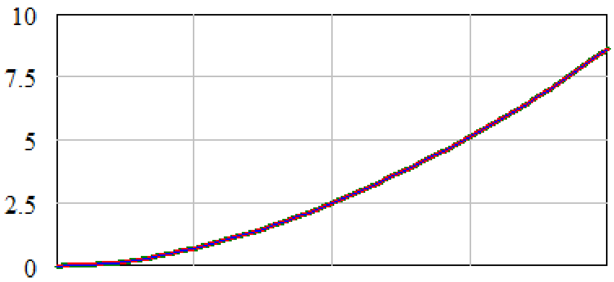
Figure 8.11 Simulation results of SPCP based on an increase in B10

As presented above, the contractor can develop a well-developed quality assurance system to conduct daily quality management duties, such as a self-adjustment mechanism to deal with quality problems that various contractors might be confronted. Quality assurance could be performed via this system and contractors have their own rights and obligations. Most importantly, contractors can be motivated in due ways to ascertain the quality of construction project.

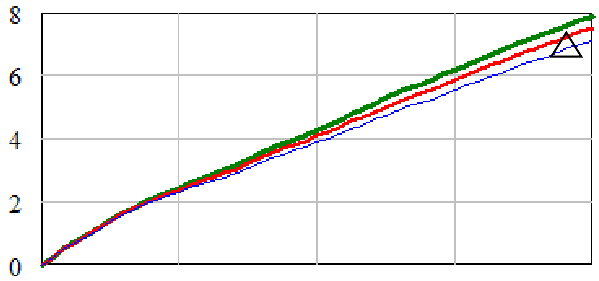
(c) An increase in *giving the priority to the procurement of local products and services* (B42)

This factor spells out the importance of procuring local products and services in the ways towards sustainable construction. A procurement of local production factors hopefully reduces the burdening of transporting considerable materials from downtown areas and it could be an economic means for the project to improve sustainability. It is also expected that the larger the amount of local procurement, the better the contribution to the attainment of sustainable construction. Nevertheless, this may not be the case as imaged in Figure 8.12. As shown in the figure, no significant variation between the three scenarios suggests that an increases in local procurement seems unfavourable to the improvement of SPCP.

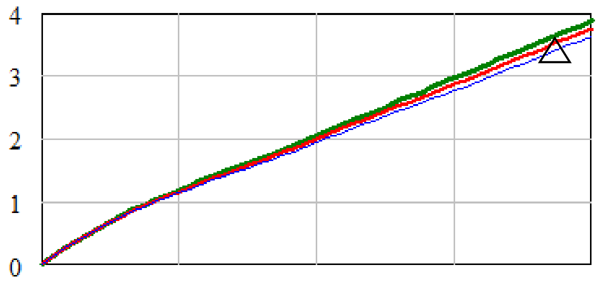
The negligible change of SPCP, however, does not deny the role of this kind of CSR behaviours in the attainment of sustainable construction. Figure 8.12 (b) indicates an increase of CAP as a result of an increase in the larger amount of input local construction factors. Such contribution occurs in parallel with the decrease in construction production factors. One of the primary reasons maybe that longer time necessitates from searching, transporting and assembling local construction materials on the construction sites. In reverse, construction quality and schedule may be ascertained if prefabrication is adopted as a construction means.



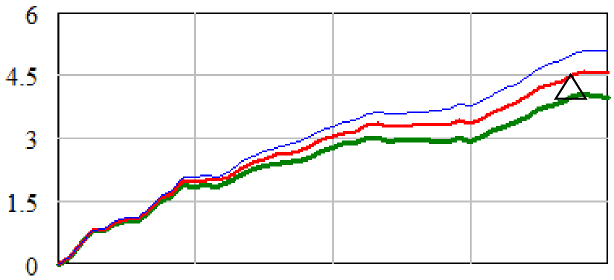
(a) SPCP



(b) CIP



(c) CAP



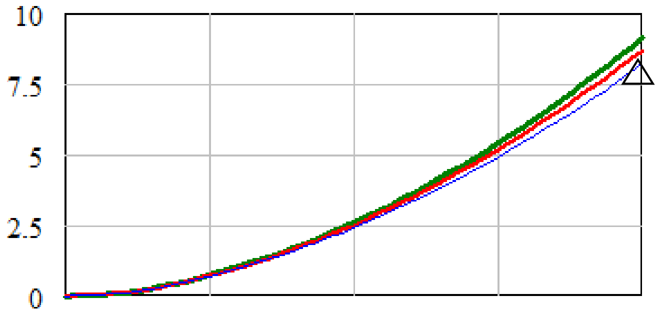
(d) COP

Figure 8.12 Simulation results of SPCP based on an increase in B42

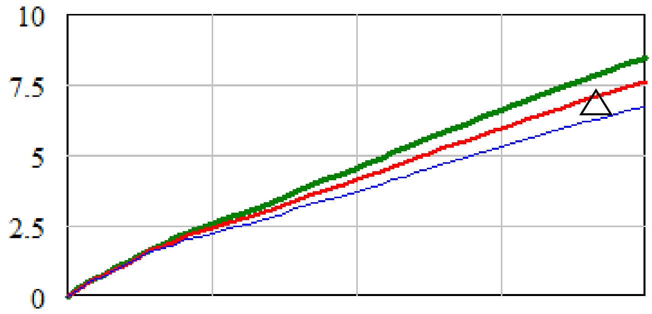
The contribution of this factor outlines a paradox that the contractor might have in the choice of local construction materials. On one hand, it is expected to embed local construction materials in the infrastructure project. On the other hand, the contractor has to adopt response strategies to avoid the impacts on the achievement of construction goals. A well-intentioned schedule of local procurement is thus a prerequisite to this kind of CSR activity.

(d) An increase in *applying/optimizing training and education system for occupational skills* (B58)

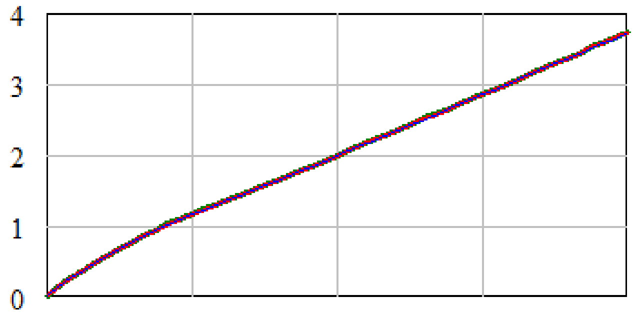
In the practice, contractors are usually faced with a hard-to-make decision on whether to conduct training and education for employees to improve their occupational skills. Such activity might not be helpful to construction assignment they are facing, but it can aggregate the burdening of construction cost. In this study, this type of activities conducted by the contractor is deemed to belong to the domain of CSR. The effects of CSR fulfilment in this sense are detected in connecting to the attainment of sustainable construction. It can be found from Figure 8.13 that this kind of CSR activity can improve the results of SPCP to the end. This might be beyond the expectation of many practitioners that using resources to execute training and education appears not constructive to the attainment of sustainability.



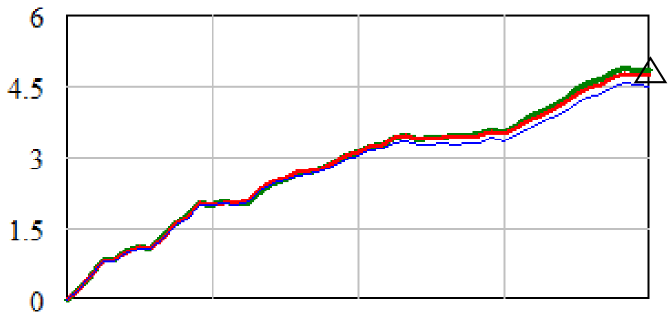
(a) SPCP



(b) CIP



(c) CAP



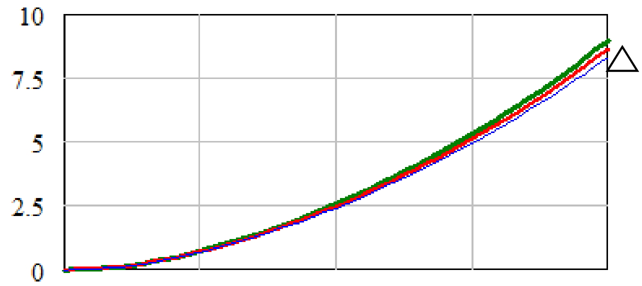
(d) COP

Figure 8.13 Simulation results of SPCP based on an increase in B58

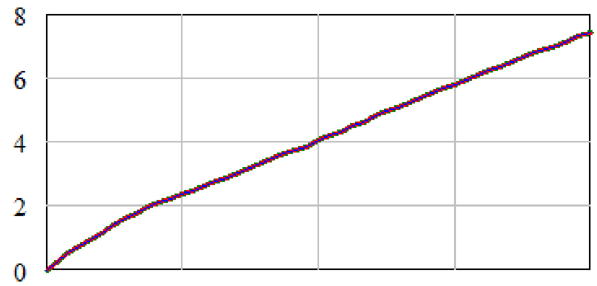
The effects of this kind of CSR activities are mainly contributed by its impacts on both COP and CIP, although the impacts on the later one seems to be more distinctive. The higher the amount of resource being placed on B58, the higher the level of both COP and CIP. The positive contribution is unveiled more significantly when the case project comes to the third or fourth year. This is largely because that a high motivation of construction workers assist them in understanding how to have higher proficiency in construction works. Thus, they might be willing to adopt the means of recycling and reusing of construction materials and complete construction works as stipulated in contracts.

(e) An increase in *establishing regular and effective communication mechanism with customer* (B45)

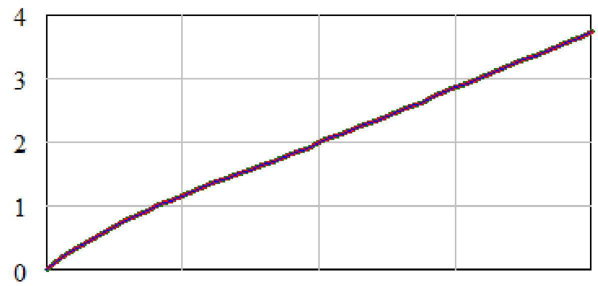
This factor highlights the importance of comprehending the client's requirements and expectation properly along the construction process. The establishment of effective communication channel with customer can helps the contractor to chase and appreciate the client's attitudes and concerns over the progress of the construction project and take due action subsequently. In China, contractors have to spend considerable time fortifying effective communication with the client to follow up any change posed by the client, which is quite often seen nationwide. For a number of unexpected reasons, the contractor must know exactly what the client have changed their mind and what their new expectations are.



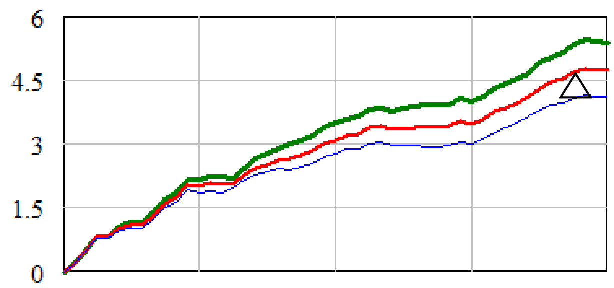
(a) SPCP



(b) CIP



(c) CAP



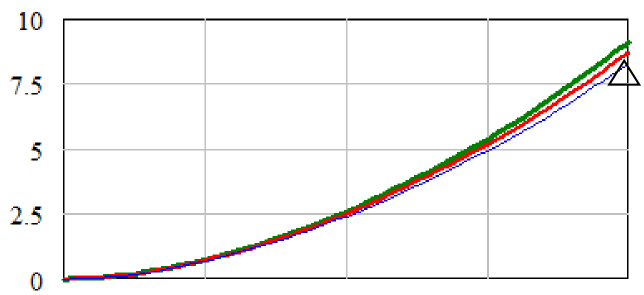
(d) COP

Figure 8.14 Simulation results of SPCP based on an increase in B45

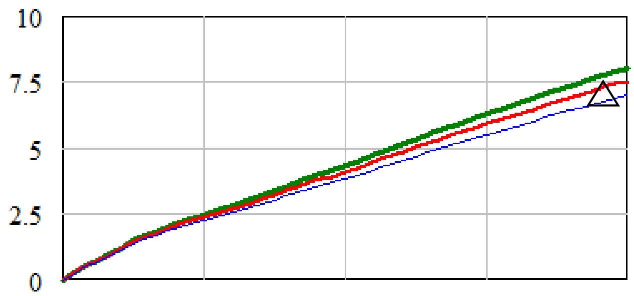
The effects of this CSR activity are confined to COP indicators and its effects on CIP and CAP are very minor (Figure 8.14). The reason could be that contractors have to handle those considerable issues related to the accomplishment of project goals in terms of quality, progress, and construction cost, while the client's requirement on sustainable construction activities and saving of construction resources are simple that the contractor may find it easier to follow up.

(f) An increase in *setting up special division(s) for CSR management* (B63)

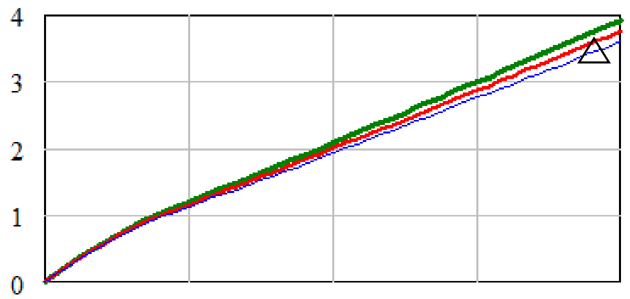
Establishing special division for CSR matters within the project organization is useful for the construction team to get involved in those social responsibility activities under or beyond the stipulation in the contract. The simulation results shown in Figure 8.15 (a) suggest that the establishment is helpful to the contractor in achieving a better result of SPCP. The positive impacts are comprehensive as given in the other three figures. The earlier the establishment of this division, the better the performance of SPCP, CAP, COP and CIP.



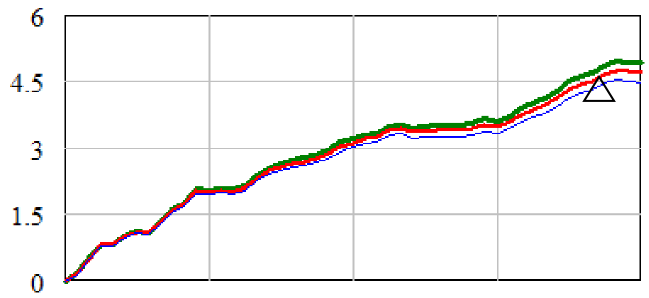
(a) SPCP



(b) CIP



(c) CAP



(d) COP

Figure 8.15 Simulation results of SPCP based on an increase in B63

In practice, the contractor might be reluctant to develop such a division in charge of social responsibility within a construction organization as it is not useful to yield profits for the company. However, this might not be true as that the establishment can ascend the level of all-around sustainability performance. The rationale behind this kind of CSR activity could be that CSR fulfilment can be conducted in an efficient way if there is a special department managing this issue.

In fact, contractors have little knowledge of how to complement CSR activity and what the scope of social responsibility they have to focus on. Some contractors might be active involved in CSR but they have little knowledge of the contribution they have put to society. Therefore, contractors are recommended to single out CSR activities from the general management department within the project organization team and assign this new department with well-defined duty in terms of CSR fulfilment.

8.7 Summary

The primary content of this chapter is to describe the application of case study within an intention of testing the applicability of the proposed model. Using a major infrastructure transport project in western China, the proposed model is demonstrated suitable and effective to mirror the impacts of CSR activity on the achievement of SPCP along the construction process. The results show that contractors have the importance of embedding CSR activities in the contract and consider it seriously. It can be highlighted that a contractor can reap a higher level of SPCP by changing the weights between CIP, CAP and COP. In addition, initial inputs into CSR-C activities should be secured to enable a certain level of SPCP. Furthermore, the values of SPCP are vulnerable to contractors' choices on CSR-C activities from the six key areas.

Chapter 9. CONCLUSIONS

9.1 Introduction

This chapter presents the conclusion of this research. The research objectives are reviewed, followed by a summary of key conclusions achieved through undertaking this study. The contributions, significance and limitations of the study are also indicated, and areas for future research are suggested eventually.

9.2 Major conclusions

This study develops a dynamic model for assessing the impacts of CSR fulfilment on the achievement of sustainability performance of the construction process. The research objectives have been completed, namely (a) to identify the attributes of both CSR-C and SPCP; (b) to examine the key areas of CSR-C activities; (c) to formulate the indicators of SPCP; (d) to model the effects of CSR-C on SPCP; and (e) to validate the proposed model. Through accomplishing the research objectives, conclusions that are presented in previous chapters have been described and they can be further summarized below.

9.2.1. Attributes of CSR-C activities and sustainability performance of the construction process

Basically, CSR delineates the contribution of an enterprise in the attainment of sustainability, which might be beyond the scope of profitability. Academic debates on the attributes of CSR in whichever industry has pointed to the fact that this concept is easy to comprehend but difficult to practice. A better understanding of the characteristics of CSR activities paves the ways towards the fulfilment of social responsibility. In this study, it is stressed that CSR in construction bridges the connection between construction industry and local community. It can be a management tool for contractors to gain confidence in fortifying competitiveness. The attributes of CSR in construction are embodied with a broad range of activities that contractors could be able to do as needed. Furthermore, CSR in construction points to stakeholders at the enterprise level as well as at the project level. These attributes are discussed in Chapter two, but they are validated as presented in the thesis.

The importance of identifying the attributes of SPCP should coincide with the fulfilment of social responsibility in the construction context. As far as SPCP is concerned, contractors have to know precisely the essence of sustainable construction process.

9.2.2. Socially responsible activities in the construction context

Contractors might adopt activities to fulfil social responsibility in accordance with their understandings. As a consequence, different kinds of CSR activities can be found in some annual reports of construction firms. As presented in Chapter 2, it is better to combine the general concept of CSR with the uniqueness of construction business as well as the contextual background of the construction industry. In this study, 37 social responsible activities are identified to outline the major areas that contractors can do. The derived set of CSR activities provide a useful framework for Chinese contractors to conduct socially responsible activities. Given the availability of CSR activities, contractors can develop their own ways in contributing to the well-being of local communities while the construction process can be unfolded effectively.

In this study, the 37 socially responsible activities belong to six groups, which are also called six key factors, namely environmental preservation, construction quality and safety, well-being of local community, employers' interests, the client's interests, and CSR institutional arrangement. Part of these six factors are regulated clearly in the contract between the client and contractors, and part of them are beyond the expectation of the client. The six key factors can echo the attributes of CSR in construction, and they also shed some lights on an effective way of performing CSR on a construction site. Therefore, this is useful for a construction management team to fulfil CSR properly if they are required to embed social responsibility in the construction planning.

9.2.3. Formulating a set of SPCP indicators

Sustainability performance of the construction process mirrors the efforts that contractors put to attain sustainable development. Since the construction process usually takes long time and a diversity of stakeholders are involved, it is quite hard to formulate a set of SPCP indicators to measure such efforts of contractors. In effect, different contractors might be devoted to a number of issues they consider valuable. In the meantime, they are confused about how to perceive the attributes of SPCP exactly.

In this study, it is highlighted that the development of SPCP indicators should adhere to the tenets of sustainable construction, which are divided into three parts, namely economic, environmental and social. With this in mind, SPCP is presented in light of the input-activity-output model and indicators are reorganized to be decomposed of three groups, namely construction inputs, construction activities and construction outputs. Thereby, SPCP indicators can be found more associated with CSR fulfilment at the project level.

9.2.4. Modelling the effects of CSR fulfilment on SPCP

The complexity of construction activities together with the abstractness of social responsibility in the construction context suggests that contractors may not be able to detect the relationship between these two variables. On one hand, they have little knowledge of sustainable construction activities and social responsibility that a project management team has to share with their companies. On the other hand, they may be felt pressure of how to improve sustainability performance of the construction process. SPCP is well recognized as it describe the efforts that the construction community put to the attainment of sustainability.

In this study, the effects of CSR fulfilment are modelled with an aim to identify how to improve SPCP levels. The model is built on the system dynamic principle, which treats CSR fulfilment as a cause and improvement of SPCP as a sequence. Variables of the proposed model consist of two groups, namely CSR activities and SPCP indicators. Cause-loop diagrams and stock-flow diagrams are developed to image the inherent cause-sequence relationships. The proposed system dynamics model addresses multidimensional impacts of socially responsible activities on the achievement of construction project goals as well as their devotion to social progress and environmental protection. The inherent relationships are useful to motivate the enthusiasm of contractors in conducting CSR and sustainable construction can be implemented in due manners.

9.2.5. Validating the proposed model about the effects of CSR activities on SPCP

The proposed model about the effects of CSR activities on SPCP is validated using a major transport infrastructure project from western China. The typicality of the case project is appreciated and found it representative to detect the effectiveness of the proposed model in mirroring the effect. A couple of scenarios are simulated to identify the effectiveness. It is found that an increase in initial input of resources for CSR activities can give rise to a better level of SPCP. All of the 37 CSR activities can generate impacts on SPCP, CIP, CAP and COP. This suggests that socially responsible activities deserve much attention and the contractors must adopt a combination of CSR activities to ensure a satisfactory level of sustainability.

9.3 Contributions

9.3.1. Contributions to the body of knowledge of corporate social responsibility

The contributions to the body of knowledge of CSR are two-faceted. An in-depth investigation of CSR is presented in the study to show a sphere of activities that contractors can refer to in line with the principle of sustainable construction. More specifically, the derivation of CSR activities provides a useful guideline for contractors to adopt directly in China. While CSR concept has been developed well in this study, it is also extended to connect to SPCP.

9.3.2. A better perception of sustainable construction

Sustainable construction has a number of definitions; nevertheless, the richness in definitions is a barrier inhibiting contractors from operating sustainable business. Contractors might get lost if they are required to execute CSR along the construction process. In this study, a revised term of sustainable construction is offered to depict the efforts that a contractor can put to secure sustainable practices. It is highlighted that a well-defined concept of sustainable construction should be useful for the project team to manage the project they are working on and show a useful way for them to receive supports from local communities.

9.3.3. Provision of a new research paradigm

A research paradigm is shaped in the study to bridge CSR fulfilment and sustainability performance of the construction process. The demonstration of the system dynamics model suggests that adopting a relatively static perspective to examine the effectiveness of CSR activities on construction project management performance must be partial. The covert complicated relationships between these two camps of variables imply that contractors have to view them in a dynamic way. This will open a new research paradigm to investigate the extent to which sustainable construction can be conducted if contractors adopt some kinds of unprofitable business.

9.3.4. Offering a useful framework for developing CSR policies

By directing CSR fulfilment to SPCP, it reversely offers a benchmark for contractors to formulate CSR policies on a construction site. The rule of thumb is that any endeavours for CSR activities should not sacrifice the attainability of sustainability on a construction site. Thus, contractors can determine appropriate socially responsible activities in line with their needs. In summary, the framework connecting CSR to sustainable construction can lay a solid foundation for contractors to embark on sustainable construction.

9.4 Limitations and recommendations

9.4.1. Limitations

The limitations of the model proposed in the study are necessarily presented in order to ensure a broader application.

(a) Both CSR and sustainable construction is subject to overlapped interpretation if different contexts are adopted. Research works in this study are situated in China. Research findings as a result from this fast developing industry might not be applicable to other developing countries.

(b) The case study is placed from an analysis on infrastructure project. As infrastructure project is different from other construction projects such as building and factory facilities, the proposed model describing the effects of CSR on SPCP must await more amendment.

(c) The proposed SD models are validated merely using one case, which might weaken the sufficiency of the model results.

(d) Many variables of CSR and SPCP cannot be quantified precisely in the study. Questionnaire survey is adopted as a second optimal means to collect data.

9.4.2. Recommendations

In responding to the limitations mentioned above, recommendations are given as follows.

(a) Contractors are better to view CSR and sustainable construction in an integrated way. Thereby, they will be more efficient and effective.

(b) More cases from other places like Singapore or Hong Kong are suggested to adopt to test the applicability of the proposed models, as the Chinese construction industry is characterised by a large number of state-owned enterprises.

(c) The proposed model assumes a lump sum of resource measured by money for CSR and the simulation is conducted without changing the total amount of resources. Future studies are recommended to derive a more flexible paradigm.

(d) What if one approach can lead to greener construction but is more costly or time consuming? Therefore, future works are recommended to show contractors how to strike the trade-offs between social, environment, and economic sustainability when implementing CSR strategies.

APPENDICES

Appendix A   Acronyms

(1) CSR activities

Acronyms	Definitions
B64	Setting up special units or/and positions to conduct daily environmental management
B45	Implementing/optimizing environmental training scheme to improve employees' environmental awareness and skills
B04	Applying/optimizing an environmental impacts assessment and precaution system prior to construction
B19	Applying a saving and recycling system for resources and energy utilization
B16	Applying pollution emission control systems (e.g. gas, dust, noise, sewage and waste)
B12	Applying environmental technology and green energy to promote energy saving and emission reduction
B51	Implementing emergency mechanism and scheme for environmental pollution accidents
B61	Protecting biological diversity and ecological systems
B23	Conducting green office
B18	Applying quality management certification
B46	Implementing/optimizing a quality management system to strictly prevent quality accidents
B47	Implementing/optimizing quality training to improve employees' quality awareness and skills
B21	Applying a strict quality inspection system for material and equipment procurement
B20	Applying a selection, management and supervision system for sub-contractors
B48	Implementing/optimizing a safety management system to prevent safety accidents
B06	Applying/optimizing precaution mechanism for safety management
B25	Conducting research development and technological innovation to improve quality and safety management level
B13	Applying evaluation mechanism for collaborators to implement CSR
B36	Establishing effective communication channels with local community
B58	Organizing/supporting occupational skills training programs for local community
B42	Giving priority to the procurement of local products and services
B62	Respecting and protecting cultural tradition and heritage of the community

B50	Implementing disaster prevention/ relief activities for the society and local community
B67	Supporting the development of infrastructure and public services of local community
B69	Taking care of low-income groups (e.g. Build-transferring low-income housing without charge)
B10	Applying/optimizing a training and education system for occupational skills
B44	Guiding employees in career development and establishing employee promotion mechanism
B35	Establishing/improving employer-employee communication and negation mechanism (e.g. labour union)
B68	Taking care of employees and their families and help employees to achieve work-life balance
B03	Applying/optimizing a customer satisfaction management system in responding to customers' claims
B02	Applying/optimizing a confidentiality system for customers' information
B37	Establishing regular and effective communication mechanism with customers
B17	Applying a post-construction service system and providing customers with proper post-construction services
B66	Strengthening communication with collaborators and improving collaboration space and efficiency
B63	Setting up special division(s) for CSR management
B41	Formulating/implementing a CSR training scheme
B40	Formulating/implementing CSR crisis precautionary and response mechanisms

(2) SPCP variables

Acronyms	Definitions
SPCPV	SPCP Values
RWCAP	Rate of weighted value of CAP
WCAP	Weighted value of CAP
RWCOP	Rate of weighted value of COP
WCOP	Weighted value of COP
RWCIP	Rate of weighted value of CIP
WCIP	Weighted value of CIP
TCIP	Total performance of construction inputs management
WLRIP	Weighted value of LRIP
LRIP	Performance of land resource inputs
WWRIP	Weighted value of WRIP
WRIP	Performance of water resource inputs
WEIP	Weighted value of EIP
EIP	Performance of energy input
WMIP	Weighted value of MIP
MIP	Performance of materials input
TCAP	Total performance of construction activities management
WIBP	Weighted value of IBP
IBP	Performance of infrastructure burdening management
WCDP	Weighted value of CDP
CDP	Performance of comfort disturbance control
WNPP	Weighted value of NPP
NPP	Performance of noise pollution control
WDEP	Weighted value of DEP
DEP	Performance of dust emission control
WLPP	Weighted value of LPP
LPP	Performance of lighting pollution control
WHSP	Weighted value of HSP
HSP	Performance of health and safety management
WELP	Weighted value of ELP
ELP	Performance of employment added
WCCHP	Weighted value of CCHP
CCHP	Performance of cultural and heritage protection
WBPP	Weighted value of BPP
BPP	Performance of biodiversity protection
WCWP	Weighted value of CWP
CWP	Performance of construction waste management
TCOP	Total performance of construction outputs

WCQP	Weighted value of CQP
CQP	Performance of construction quality management
WCCP	Weighted value of CCP
CCP	Performance of construction cost management
WCSP	Weighted value of CSP
CSP	Performance of construction schedule management
ENC	Effects of noise control
ELC	Effects of lighting control
EDC	Effects of dust control
ECDC	Effects of comfort disturbance control
EIC	Effects of infrastructure control
EWM	Effects of waste management
EBP	Effects of biodiversity protection
ECHP	Effects of cultural and heritage protection
EEO	Effects of employment opportunities
EHSM	Effects of health and safety management
ELS	Effects of land saving
EWS	Effects of water saving
EES	Effects of energy saving
EMS	Effects of materials saving
EQM	Effects of quality management
ECM	Effects of cost management
ESM	Effects of schedule management

(3) CAP variables

Acronyms	Definitions
PDNC	Performance of daily noise control
TPDNC	Total performance of daily noise control
EB04NC	Effects of B04 on noise control
IEB04NC	Coefficient for effects of B04 on noise control
EB51NC	Effects of B51 on noise control
IEB51NC	Coefficient for effects of B51 on noise control
EB40NC	Effects of B40 on noise control
IEB40NC	Coefficient for effects of B40 on noise control
EB12NC	Effects of B12 on noise control
IEB12NC	Coefficient for effects of B12 on noise control
EB45NC	Effects of B45 on noise control
IEB45NC	Coefficient for effects of B45 on noise control
EB13NC	Effects of B13 on noise control
IEB13NC	Coefficient for effects of B13 on noise control
EB16NC	Effects of B16 on noise control
IEB16NC	Coefficient for effects of B16 on noise control
EB41NC	Effects of B41 on noise control
IEB41NC	Coefficient for effects of B41 on noise control
EB63NC	Effects of B63 on noise control
IEB63NC	Coefficient for effects of B63 on noise control
EB64NC	Effects of B64 on noise control
IEB64NC	Coefficient for effects of B64 on noise control
EB20NC	Effects of B20 on noise control
IEB20NC	Coefficient for effects of B20 on noise control
EB04NC	Effects of B04 on noise control
IEB04NC	Coefficient for effects of B04 on noise control
EB51NC	Effects of B51 on noise control
IEB51NC	Coefficient for effects of B51 on noise control
EB40NC	Effects of B40 on noise control
IEB40NC	Coefficient for effects of B40 on noise control
EB12NC	Effects of B12 on noise control
IEB12NC	Coefficient for effects of B12 on noise control
EB45NC	Effects of B45 on noise control
IEB45NC	Coefficient for effects of B45 on noise control
EB13NC	Effects of B13 on noise control
IEB13NC	Coefficient for effects of B13 on noise control
EB16NC	Effects of B16 on noise control
IEB16NC	Coefficient for effects of B16 on noise control
EB41NC	Effects of B41 on noise control
IEB41NC	Coefficient for effects of B41 on noise control

EB63NC	Effects of B63 on noise control
IEB63NC	Coefficient for effects of B63 on noise control
EB64NC	Effects of B64 on noise control
IEB64NC	Coefficient for effects of B64 on noise control
EB20NC	Effects of B20 on noise control
IEB20NC	Coefficient for effects of B20 on noise control
PDLC	Performance of daily lighting control
TPDLC	Total performance of daily lighting control
EB16LC	Effects of B16 on lighting control
IEB16LC	Coefficient for effects of B16 on lighting control
EB41LC	Effects of B41 on lighting control
IEB41LC	Coefficient for effects of B41 on lighting control
EB40LC	Effects of B40 on lighting control
IEB40LC	Coefficient for effects of B40 on lighting control
EB12LC	Effects of B12 on lighting control
IEB12LC	Coefficient for effects of B12 on lighting control
EB66LC	Effects of B66 on lighting control
IEB66LC	Coefficient for effects of B66 on lighting control
EB64LC	Effects of B64 on lighting control
IEB64LC	Coefficient for effects of B64 on lighting control
EB20LC	Effects of B20 on lighting control
IEB20LC	Coefficient for effects of B20 on lighting control
EB51LC	Effects of B51 on lighting control
IEB51LC	Coefficient for effects of B51 on lighting control
EB04LC	Effects of B04 on lighting control
IEB04LC	Coefficient for effects of B04 on lighting control
EB45LC	Effects of B45 on lighting control
IEB45LC	Coefficient for effects of B45 on lighting control
EB63LC	Effects of B63 on lighting control
IEB63LC	Coefficient for effects of B63 on lighting control
PDDC	Performance of daily dust control
TPDDC	Total performance of daily dust control
EB45DC	Effects of B45 on dust control
IEB45DC	Coefficient for effects of B45 on dust control
EB13DC	Effects of B13 on dust control
IEB13DC	Coefficient for effects of B13 on dust control
EB41DC	Effects of B41 on dust control
IEB41DC	Coefficient for effects of B41 on dust control
EB12DC	Effects of B12 on dust control
IEB12DC	Coefficient for effects of B12 on dust control
EB63DC	Effects of B63 on dust control
IEB63DC	Coefficient for effects of B63 on dust control
EB64DC	Effects of B64 on dust control

IEB64DC	Coefficient for effects of B64 on dust control
EB51DC	Effects of B51 on dust control
IEB51DC	Coefficient for effects of B51 on dust control
EB16DC	Effects of B16 on dust control
IEB16DC	Coefficient for effects of B16 on dust control
EB04DC	Effects of B04 on dust control
IEB04DC	Coefficient for effects of B04 on dust control
EB40DC	Effects of B40 on dust control
IEB40DC	Coefficient for effects of B40 on dust control
EB20DC	Effects of B20 on dust control
IEB20DC	Coefficient for effects of B20 on dust control
PDCDC	Performance of daily comfort disturbance control
TPDCDC	Total performance of daily comfort disturbance control
EB16CDC	Effects of B16 on comfort disturbance control
IEB16CDC	Coefficient for effects of B16 on comfort disturbance control
EB19CDC	Effects of B19 on comfort disturbance control
IEB19CDC	Coefficient for effects of B19 on comfort disturbance control
EB64CDC	Effects of B64 on comfort disturbance control
IEB64CDC	Coefficient for effects of B64 on comfort disturbance control
EB45CDC	Effects of B45 on comfort disturbance control
IEB45CDC	Coefficient for effects of B45 on comfort disturbance control
EB12CDC	Effects of B12 on comfort disturbance control
IEB12CDC	Coefficient for effects of B12 on comfort disturbance control
EB63CDC	Effects of B63 on comfort disturbance control
IEB63CDC	Coefficient for effects of B63 on comfort disturbance control
EB20CDC	Effects of B20 on comfort disturbance control
IEB20CDC	Coefficient for effects of B20 on comfort disturbance control
EB67CDC	Effects of B67 on comfort disturbance control
IEB67CDC	Coefficient for effects of B67 on comfort disturbance control
EB04CDC	Effects of B04 on comfort disturbance control
IEB04CDC	Coefficient for effects of B04 on comfort disturbance control
EB36CDC	Effects of B36 on comfort disturbance control
IEB36CDC	Coefficient for effects of B36 on comfort disturbance control
EB13CDC	Effects of B13 on comfort disturbance control

IEB13CDC	Coefficient for effects of B13 on comfort disturbance control
EB41CDC	Effects of B41 on comfort disturbance control
IEB41CDC	Coefficient for effects of B41 on comfort disturbance control
EB40CDC	Effects of B40 on comfort disturbance control
IEB40CDC	Coefficient for effects of B40 on comfort disturbance control
EB51CDC	Effects of B51 on comfort disturbance control
IEB51CDC	Coefficient for effects of B51 on comfort disturbance control
EB66CDC	Effects of B66 on comfort disturbance control
IEB66CDC	Coefficient for effects of B66 on comfort disturbance control
PDIC	Performance of daily infrastructure control
TPDIC	Total performance of daily infrastructure control
EB63IC	Effects of B63 on infrastructure control
IEB63IC	Coefficient for effects of B63 on infrastructure control
EB19IC	Effects of B19 on infrastructure control
IEB19IC	Coefficient for effects of B19 on infrastructure control
EB67IC	Effects of B67 on infrastructure control
IEB67IC	Coefficient for effects of B67 on infrastructure control
EB66IC	Effects of B66 on infrastructure control
IEB66IC	Coefficient for effects of B66 on infrastructure control
EB42IC	Effects of B42 on infrastructure control
IEB42IC	Coefficient for effects of B42 on infrastructure control
EB40IC	Effects of B40 on infrastructure control
IEB40IC	Coefficient for effects of B40 on infrastructure control
EB36IC	Effects of B36 on infrastructure control
IEB36IC	Coefficient for effects of B36 on infrastructure control
EB41IC	Effects of B41 on infrastructure control
IEB41IC	Coefficient for effects of B41 on infrastructure control
EB13IC	Effects of B13 on infrastructure control
IEB13IC	Coefficient for effects of B13 on infrastructure control
PDWM	Performance of daily waste management
TPDWM	Total performance of daily waste management

EB20WM	Effects of B20 on waste management
IEB20WM	Coefficient for effects of B20 on waste management
EB40WM	Effects of B40 on waste management
IEB40WM	Coefficient for effects of B40 on waste management
EB16WM	Effects of B16 on waste management
IEB16WM	Coefficient for effects of B16 on waste management
EB13WM	Effects of B13 on waste management
IEB13WM	Coefficient for effects of B13 on waste management
EB41WM	Effects of B41 on waste management
IEB41WM	Coefficient for effects of B41 on waste management
EB45WM	Effects of B45 on waste management
IEB45WM	Coefficient for effects of B45 on waste management
EB12WM	Effects of B12 on waste management
IEB12WM	Coefficient for effects of B12 on waste management
EB63WM	Effects of B63 on waste management
IEB63WM	Coefficient for effects of B63 on waste management
EB64WM	Effects of B64 on waste management
IEB64WM	Coefficient for effects of B64 on waste management
EB51WM	Effects of B51 on waste management
IEB51WM	Coefficient for effects of B51 on waste management
EB04WM	Effects of B04 on waste management
IEB04WM	Coefficient for effects of B04 on waste management
PDBM	Performance of daily biodiversity management
TPDBM	Total performance of daily biodiversity management
EB41BM	Effects of B41 on biodiversity management
IEB41BM	Coefficient for effects of B41 on biodiversity management
EB45BM	Effects of B45 on biodiversity management
IEB45BM	Coefficient for effects of B45 on biodiversity management
EB64BM	Effects of B64 on biodiversity management
IEB64BM	Coefficient for effects of B64 on biodiversity management
EB63BM	Effects of B63 on biodiversity management

IEB63BM	Coefficient for effects of B63 on biodiversity management
EB13BM	Effects of B13 on biodiversity management
IEB13BM	Coefficient for effects of B13 on biodiversity management
EB20BM	Effects of B20 on biodiversity management
IEB20BM	Coefficient for effects of B20 on biodiversity management
EB61BM	Effects of B61 on biodiversity management
IEB61BM	Coefficient for effects of B61 on biodiversity management
EB04BM	Effects of B04 on biodiversity management
IEB04BM	Coefficient for effects of B04 on biodiversity management
PDCHP	Performance of daily cultural and heritage protection
TPDCHP	Total performance of daily cultural and heritage protection
EB40CHP	Effects of B40 on cultural and heritage protection
IEB40CHP	Coefficient for effects of B40 on cultural and heritage protection
EB41CHP	Effects of B41 on cultural and heritage protection
IEB41CHP	Coefficient for effects of B41 on cultural and heritage protection
EB04CHP	Effects of B04 on cultural and heritage protection
IEB04CHP	Coefficient for effects of B04 on cultural and heritage protection
EB45CHP	Effects of B45 on cultural and heritage protection
IEB45CHP	Coefficient for effects of B45 on cultural and heritage protection
EB64CHP	Effects of B64 on cultural and heritage protection
IEB64CHP	Coefficient for effects of B64 on cultural and heritage protection
EB13CHP	Effects of B13 on cultural and heritage protection
IEB13CHP	Coefficient for effects of B13 on cultural and heritage protection
EB63CHP	Effects of B63 on cultural and heritage protection
IEB63CHP	Coefficient for effects of B63 on cultural and heritage protection
EB20CHP	Effects of B20 on cultural and heritage protection
IEB20CHP	Coefficient for effects of B20 on cultural and heritage protection
EB62CHP	Effects of B62 on cultural and heritage protection
IEB62CHP	Coefficient for effects of B62 on cultural and heritage protection

PDEOA	Performance of daily employment opportunities added
TPDEOA	Total performance of daily employment opportunities added
EB41EOA	Effects of B41 on employment opportunities added
IEB41EOA	Coefficient for effects of B41 on employment opportunities added
EB40EOA	Effects of B40 on employment opportunities added
IEB40EOA	Coefficient for effects of B40 on employment opportunities added
EB63EOA	Effects of B63 on employment opportunities added
IEB63EOA	Coefficient for effects of B63 on employment opportunities added
EB13EOA	Effects of B13 on employment opportunities added
IEB13EOA	Coefficient for effects of B13 on employment opportunities added
EB67EOA	Effects of B67 on employment opportunities added
IEB67EOA	Coefficient for effects of B67 on employment opportunities added
EB10EOA	Effects of B10 on employment opportunities added
IEB10EOA	Coefficient for effects of B10 on employment opportunities added
EB69EOA	Effects of B69 on employment opportunities added
IEB69EOA	Coefficient for effects of B69 on employment opportunities added
EB20EOA	Effects of B20 on employment opportunities added
IEB20EOA	Coefficient for effects of B20 on employment opportunities added
PDHSM	Performance of daily health and safety management
TPDHSM	Total performance of daily health and safety management
EB20HSM	Effects of B20 on health and safety management
IEB20HSM	Coefficient for effects of B20 on health and safety management
EB04HSM	Effects of B04 on health and safety management
IEB04HSM	Coefficient for effects of B04 on health and safety management
EB64HSM	Effects of B64 on health and safety management

IEB64HSM	Coefficient for effects of B64 on health and safety management
EB10HSM	Effects of B10 on health and safety management
IEB10HSM	Coefficient for effects of B10 on health and safety management
EB51HSM	Effects of B51 on health and safety management
IEB51HSM	Coefficient for effects of B51 on health and safety management
EB40HSM	Effects of B40 on health and safety management
IEB40HSM	Coefficient for effects of B40 on health and safety management
EB41HSM	Effects of 41B on health and safety management
IEB41HSM	Coefficient for effects of B41 on health and safety management
EB48HSM	Effects of B48 on health and safety management
IEB48HSM	Coefficient for effects of B48 on health and safety management
EB13HSM	Effects of B13 on health and safety management
IEB13HSM	Coefficient for effects of B13 on health and safety management
EB63HSM	Effects of B63 on health and safety management
IEB63HSM	Coefficient for effects of B63 on health and safety management
EB25HSM	Effects of B25 on health and safety management
IEB25HSM	Coefficient for effects of B25 on health and safety management
EB23HSM	Effects of B23 on health and safety management
IEB23HSM	Coefficient for effects of B23 on health and safety management
EB06HSM	Effects of B06 on health and safety management
IEB06HSM	Coefficient for effects of B06 on health and safety management

(4) CIP variables

Acronyms	Definitions
PDLS	Performance of daily land saving
TPDLS	Total performance of daily land saving
EB66LS	Effects of B66 on land saving
IEB66LS	Coefficient for effects of B66 on land saving
EB40LS	Effects of B40 on land saving
IEB40LS	Coefficient for effects of B40 on land saving
EB41LS	Effects of B41 on land saving
IEB41LS	Coefficient for effects of B41 on land saving
EB63LS	Effects of B63 on land saving
IEB63LS	Coefficient for effects of B63 on land saving
EB13LS	Effects of B13 on land saving
IEB13LS	Coefficient for effects of B13 on land saving
EB64LS	Effects of B64 on land saving
IEB64LS	Coefficient for effects of B64 on land saving
EB20LS	Effects of B20 on land saving
IEB20LS	Coefficient for effects of B20 on land saving
EB19LS	Effects of B19 on land saving
IEB19LS	Coefficient for effects of B19 on land saving
EB42LS	Effects of B42 on land saving
IEB42LS	Coefficient for effects of B42 on land saving
EB10LS	Effects of B10 on land saving
IEB10LS	Coefficient for effects of B10 on land saving
PDWS	Performance of daily water saving
TPDWS	Total performance of daily water saving
EB23WS	Effects of B23 on water saving
IEB23WS	Coefficient for effects of B23 on water saving
EB20WS	Effects of B20 on water saving
IEB20WS	Coefficient for effects of B20 on water saving
EB66WS	Effects of B66 on water saving
IEB66WS	Coefficient for effects of B66 on water saving
EB63WS	Effects of B63 on water saving
IEB63WS	Coefficient for effects of B63 on water saving
EB40WS	Effects of B40 on water saving
IEB40WS	Coefficient for effects of B40 on water saving
EB64WS	Effects of B64 on water saving
IEB64WS	Coefficient for effects of B64 on water saving
EB13WS	Effects of B13 on water saving
IEB13WS	Coefficient for effects of B13 on water saving
EB19WS	Effects of B19 on water saving
IEB19WS	Coefficient for effects of B19 on water saving

EB41WS	Effects of B41 on water saving
IEB41WS	Coefficient for effects of B41 on water saving
EB10WS	Effects of B10 on water saving
IEB10WS	Coefficient for effects of B10 on water saving
PDES	Performance of daily energy saving
TPDES	Total performance of daily energy saving
EB12ES	Effects of B12 on energy saving
IEB12ES	Coefficient for effects of B12 on energy saving
EB20ES	Effects of B20 on energy saving
IEB20ES	Coefficient for effects of B20 on energy saving
EB66ES	Effects of B66 on energy saving
IEB66ES	Coefficient for effects of B66 on energy saving
EB63ES	Effects of B63 on energy saving
IEB63ES	Coefficient for effects of B63 on energy saving
EB40ES	Effects of B40 on energy saving
IEB40ES	Coefficient for effects of B40 on energy saving
EB64ES	Effects of B64 on energy saving
IEB64ES	Coefficient for effects of B64 on energy saving
EB13ES	Effects of B13 on energy saving
IEB13ES	Coefficient for effects of B13 on energy saving
EB23ES	Effects of B23 on energy saving
IEB23ES	Coefficient for effects of B23 on energy saving
EB41ES	Effects of B41 on energy saving
IEB41ES	Coefficient for effects of B41 on energy saving
EB10ES	Effects of B10 on energy saving
IEB10ES	Coefficient for effects of B10 on energy saving
EB19ES	Effects of B19 on energy saving
IEB19ES	Coefficient for effects of B19 on energy saving
PDMS	Performance of daily materials saving
TPDMS	Total performance of daily materials saving
EB19MS	Effects of B19 on materials saving
IEB19MS	Coefficient for effects of B19 on materials saving
EB10MS	Effects of B10 on materials saving
IEB10MS	Coefficient for effects of B10 on materials saving
EB66MS	Effects of B66 on materials saving
IEB66MS	Coefficient for effects of B66 on materials saving
EB63MS	Effects of B63 on materials saving
IEB63MS	Coefficient for effects of B63 on materials saving
EB40MS	Effects of B40 on materials saving

IEB40MS	Coefficient for effects of B40 on materials saving
EB64MS	Effects of B64 on materials saving
IEB64MS	Coefficient for effects of B64 on materials saving
EB13MS	Effects of B13 on materials saving
IEB13MS	Coefficient for effects of B13 on materials saving
EB23MS	Effects of B23 on materials saving
IEB23MS	Coefficient for effects of B23 on materials saving
EB41MS	Effects of B41 on materials saving
IEB41MS	Coefficient for effects of B41 on materials saving
EB20MS	Effects of B20 on materials saving
IEB20MS	Coefficient for effects of B20 on materials saving

(5) COP variables

Acronyms	Definitions
PDQM	Performance of daily quality management
TPDQM	Total performance of daily quality management
EB66QM	Effects of B66 on quality management
IEB66QM	Coefficient for effects of B66 on quality management
EB21QM	Effects of B21 on quality management
IEB21QM	Coefficient for effects of B21 on quality management
EB25QM	Effects of B25 on quality management
IEB25QM	Coefficient for effects of B25 on quality management
EB20QM	Effects of B20 on quality management
IEB20QM	Coefficient for effects of B20 on quality management
EB40QM	Effects of B40 on quality management
IEB40QM	Coefficient for effects of B40 on quality management
EB41QM	Effects of B41 on quality management
IEB41QM	Coefficient for effects of B41 on quality management
EB02QM	Effects of B02 on quality management
IEB02QM	Coefficient for effects of B02 on quality management
EB63QM	Effects of B63 on quality management
IEB63QM	Coefficient for effects of B63 on quality management
EB46QM	Effects of B46 on quality management
IEB46QM	Coefficient for effects of B46 on quality management
EB47QM	Effects of B47 on quality management
IEB47QM	Coefficient for effects of B47 on quality management
EB18QM	Effects of B18 on quality management
IEB18QM	Coefficient for effects of B18 on quality management
EB10QM	Effects of B10 on quality management
IEB10QM	Coefficient for effects of B10 on quality management
EB03QM	Effects of B03 on quality management
IEB03QM	Coefficient for effects of B03 on quality management
EB37QM	Effects of B37 on quality management

IEB37QM	Coefficient for effects of B37 on quality management
EB17QM	Effects of B17 on quality management
IEB17QM	Coefficient for effects of B17 on quality management
PDCM	Performance of daily cost management
TPDCM	Total performance of cost management
EB67CM	Effects of B67 on cost management
IEB67CM	Coefficient for effects of B67 on cost management
EB37CM	Effects of B37 on cost management
IEB37CM	Coefficient for effects of B37 on cost management
EB25CM	Effects of B25 on cost management
IEB25CM	Coefficient for effects of B25 on cost management
EB35CM	Effects of B35 on cost management
IEB35CM	Coefficient for effects of B35 on cost management
EB03CM	Effects of B03 on cost management
IEB03CM	Coefficient for effects of B03 on cost management
EB63CM	Effects of B63 on cost management
IEB63CM	Coefficient for effects of B63 on cost management
EB68CM	Effects of B68 on cost management
IEB68CM	Coefficient for effects of B68 on cost management
EB17CM	Effects of B17 on cost management
IEB17CM	Coefficient for effects of B17 on cost management
EB62CM	Effects of B62 on cost management
IEB62CM	Coefficient for effects of B62 on cost management
EB19CM	Effects of B19 on cost management
IEB19CM	Coefficient for effects of B19 on cost management
EB45CM	Effects of B45 on cost management
IEB45CM	Coefficient for effects of B45 on cost management
EB12CM	Effects of B12 on cost management
IEB12CM	Coefficient for effects of B12 on cost management
EB46CM	Effects of B46 on cost management
IEB46CM	Coefficient for effects of B46 on cost management

EB18CM	Effects of B18 on cost management
IEB18CM	Coefficient for effects of B18 on cost management
EB10CM	Effects of B10 on cost management
IEB10CM	Coefficient for effects of B10 on cost management
EB20CM	Effects of B20 on cost management
IEB20CM	Coefficient for effects of B20 on cost management
EB51CM	Effects of B51 on cost management
IEB51CM	Coefficient for effects of B51 on cost management
EB47CM	Effects of B47 on cost management
IEB47CM	Coefficient for effects of B47 on cost management
EB48CM	Effects of B48 on cost management
IEB48CM	Coefficient for effects of B48 on cost management
EB50CM	Effects of B50 on cost management
IEB50CM	Coefficient for effects of B50 on cost management
EB13CM	Effects of B13 on cost management
IEB13CM	Coefficient for effects of B13 on cost management
EB58CM	Effects of B58 on cost management
IEB58CM	Coefficient for effects of B58 on cost management
EB41CM	Effects of B41 on cost management
IEB41CM	Coefficient for effects of B41 on cost management
EB66CM	Effects of B66 on cost management
IEB66CM	Coefficient for effects of B66 on cost management
EB36CM	Effects of B36 on cost management
IEB36CM	Coefficient for effects of B36 on cost management
EB02CM	Effects of B02 on cost management
IEB02CM	Coefficient for effects of B02 on cost management
EB21CM	Effects of B21 on cost management
IEB21CM	Coefficient for effects of B21 on cost management
EB69CM	Effects of B69 on cost management
IEB69CM	Coefficient for effects of B69 on cost management
EB06CM	Effects of B06 on cost management

IEB06CM	Coefficient for effects of B06 on cost management
EB64CM	Effects of B64 on cost management
IEB64CM	Coefficient for effects of B64 on cost management
EB16CM	Effects of B16 on cost management
IEB16CM	Coefficient for effects of B16 on cost management
EB40CM	Effects of B40 on cost management
IEB40CM	Coefficient for effects of B40 on cost management
EB04CM	Effects of B04 on cost management
IEB04CM	Coefficient for effects of B04 on cost management
EB61CM	Effects of B61 on cost management
IEB61CM	Coefficient for effects of B61 on cost management
EB44CM	Effects of B44 on cost management
IEB44CM	Coefficient for effects of B44 on cost management
EB23CM	Effects of B23 on cost management
IEB23CM	Coefficient for effects of B23 on cost management
EB42CM	Effects of B42 on cost management
IEB42CM	Coefficient for effects of B42 on cost management
PDSM	Performance of daily schedule management
TPDSM	Total performance of daily schedule management
EB40SM	Effects of B40 on schedule management
IEB40SM	Coefficient for effects of B40 on schedule management
EB25SM	Effects of B25 on schedule management
IEB25SM	Coefficient for effects of B25 on schedule management
EB68SM	Effects of B68 on schedule management
IEB68SM	Coefficient for effects of B68 on schedule management
EB63SM	Effects of B63 on schedule management
IEB63SM	Coefficient for effects of B63 on schedule management
EB64SM	Effects of B64 on schedule management
IEB64SM	Coefficient for effects of B64 on schedule management
EB13SM	Effects of B13 on schedule management

IEB13SM	Coefficient for effects of B13 on schedule management
EB20SM	Effects of B20 on schedule management
IEB20SM	Coefficient for effects of B20 on schedule management
EB50SM	Effects of B50 on schedule management
IEB50SM	Coefficient for effects of B50 on schedule management
EB58SM	Effects of B58 on schedule management
IEB58SM	Coefficient for effects of B58 on schedule management
EB44SM	Effects of B44 on schedule management
IEB44SM	Coefficient for effects of B44 on schedule management
EB66SM	Effects of B66 on schedule management
IEB66SM	Coefficient for effects of B66 on schedule management
EB04SM	Effects of B04 on schedule management
IEB04SM	Coefficient for effects of B04 on schedule management
EB06SM	Effects of B06 on schedule management
IEB06SM	Coefficient for effects of B06 on schedule management
EB41SM	Effects of B41 on schedule management
IEB41SM	Coefficient for effects of B41 on schedule management
EB03SM	Effects of B03 on schedule management
IEB03SM	Coefficient for effects of B03 on schedule management
EB35SM	Effects of B35 on schedule management
IEB35SM	Coefficient for effects of B35 on schedule management
EB36SM	Effects of B36 on schedule management
IEB36SM	Coefficient for effects of B36 on schedule management

Appendix B Equations

(1) SPCP equations

Variables	Equations
SPCPV	(RWCOP+RWCAP+RWCIP)/48
RWCAP	TCAP*WCAP
RWCOP	TCIP*WCIP
RWCIP	TCOP*WCOP
ENC	(EB20NC+EB13NC+EB66NC+EB41NC+EB64NC+ EB12NC+EB04NC+EB16NC+ EB45NC+ EB51NC+EB40NC+EB63NC)/12
ELC	(EB20LC+ EB13LC +EB66LC +EB41LC+ EB64LC+ EB12LC+EB04LC+ EB16LC+EB45LC+EB51LC+ EB40LC+ EB63LC)/12
EDC	(EB20DC+EB13DC+EB66DC+EB41DC+EB64DC+EB12DC+ EB04DC+EB16DC+EB45DC+ EB51DC+EB40DC+ EB63DC)/12
ECDC	(EB20CDC+EB67CDC+EB13CDC+EB66CDC+EB41CDC+ EB64CDC+EB12CDC+EB04CDC+EB16CDC+EB45CDC+ EB51CDC+EB40CDC+EB36CDC+ EB63CDC+EB19CDC)/15
EIC	(EB67IC+EB13IC+EB66IC+EB42IC+EB41IC+EB40IC+ EB36IC+EB63IC+EB19IC)/9
EWM	(EB20WM+EB13WM+EB66WM+EB41WM+ EB64WM+EB12WM+EB04WM+ EB16WM+EB45WM+EB51WM+EB40WM+EB63WM)/12
EBP	(EB20BM+EB13BM+ EB66BM+EB41BM+EB64BM+EB04BM +EB45BM+ EB40BM+EB63BM+EB61BM)/10
ECHP	(EB20CHP+EB13CHP+ EB66CHP+EB41CHP+EB64CHP+EB04CHP +EB45CHP+EB40CHP+EB63CHP+EB62CHP)/10
EEO	(EB69EOA+EB20EOA+EB13EOA+ EB66EOA +EB10EOA+EB41EOA +EB40EOA+EB63EOA+EB67EOA)/9
EHSM	(EB20HSM+EB13HSM+ EB66HSM+EB25HSM+EB41HSM+EB64HSM +EB04HSM+EB51HSM+EB06HSM+EB40HSM+EB63HSM+EB23 HSM +EB48HSM+EB10HSM)/14
ELS	(EB20LS+EB13LS+EB66LS+EB42LS+EB41LS+EB64LS+EB40LS +EB63LS+EB19LS+EB10LS)/14
EWS	(EB20WS+EB13WS+EB66WS+EB41WS+EB64WS+EB40WS+EB6 3WS +EB23WS+EB19WS+EB10WS)/10
EES	(EB20ES+EB13ES+EB66ES+EB41ES+EB64ES+EB12ES+EB40ES +EB63ES+EB23ES+EB19ES+EB10ES)/11

EMS	(EB20MS+EB13MS+EB66MS+EB41MS+EB64MS+EB40MS+EB63MS +EB23MS+EB19MS+EB10MS)/10
EQM	(EB20QM+EB25QM+EB02QM+EB37QM+EB47QM+EB46QM+EB41QM +EB21QM+EB40QM+EB63QM+EB18QM+EB10QM+EB03QM +EB17QM+EB66QM)/15
ECM	(EB62CM+EB44CM+EB69CM+EB35CM+EB67CM+EB13CM +EB66CM+EB68CM+EB10CM+EB25CM+EB02CM+EB37CM +EB03CM+EB17CM+EB47CM+EB46CM+EB41CM)/17
ESM	(EB44SM+EB20SM+EB35SM+EB13SM+EB66SM+EB68SM +EB03SM+EB41SM+EB64SM+EB40SM+EB36SM+EB58SM +EB63SM+EB50SM+EB04SM+EB06SM+EB25SM)/17

(2) CAP equations

Variables	Equations
PDNC	ENC
TPDNC	INTEG [PDNC]
EB04NC	B04*IEB04NC
IEB04NC	RANDOM UNIFORM(0, 0.13, 0.005)
EB51NC	B51*IEB51NC
IEB51NC	RANDOM UNIFORM(0, 0.05, 0.005)
EB40NC	B40*IEB40NC
IEB40NC	RANDOM UNIFORM(0, 0.063, 0.005)
EB12NC	B12*IEB12NC
IEB12NC	RANDOM UNIFORM(0, 0.05, 0.005)
EB45NC	B45*IEB45NC
IEB45NC	RANDOM UNIFORM(0, 0.14, 0.005)
EB13NC	B13*IEB13NC
IEB13NC	RANDOM UNIFORM(0, 0.1, 0.005)
EB16NC	B16*IEB16NC
IEB16NC	RANDOM UNIFORM(0, 0.19, 0.005)
EB41NC	B41*IEB41NC
IEB41NC	RANDOM UNIFORM(0, 0.07, 0.005)
EB63NC	B63*IEB63NC
IEB63NC	RANDOM UNIFORM(0, 0.07, 0.005)
EB64NC	B64*IEB64NC
IEB64NC	RANDOM UNIFORM(0, 0.1, 0.005)
EB20NC	B20*IEB20NC
IEB20NC	RANDOM UNIFORM(0, 0.1, 0.005)
PDLC	ELC
TPDLC	INTEG [PDLC]
EB16LC	B16*IEB16LC
IEB16LC	RANDOM UNIFORM(0, 0.19, 0.005)
EB41LC	B41*IEB41LC
IEB41LC	RANDOM UNIFORM(0, 0.07, 0.005)
EB40LC	B40*IEB40LC
IEB40LC	RANDOM UNIFORM(0, 0.063, 0.005)
EB12LC	B12*IEB12LC
IEB12LC	RANDOM UNIFORM(0, 0.05, 0.005)
EB66LC	B66*IEB66LC
IEB66LC	RANDOM UNIFORM(0, 0.1, 0.005)
EB64LC	B64*IEB64LC
IEB64LC	RANDOM UNIFORM(0, 0.1, 0.005)
EB20LC	B20*IEB20LC
IEB20LC	RANDOM UNIFORM(0, 0.03, 0.005)

EB51LC	B51*IEB51LC
IEB51LC	RANDOM UNIFORM(0, 0.15, 0.005)
EB04LC	B04*IEB04LC
IEB04LC	RANDOM UNIFORM(0, 0.12, 0.005)
EB45LC	B45*IEB45LC
IEB45LC	RANDOM UNIFORM(0, 0.139, 0.005)
EB63LC	B63*IEB63LC
IEB63LC	RANDOM UNIFORM(0, 0.07, 0.005)
PDDC	EDC
TPDDC	INTEG [PDDC]
EB45DC	B45*IEB45DC
IEB45DC	RANDOM UNIFORM(0, 0.16, 0.005)
EB13DC	B13*IEB13DC
IEB13DC	RANDOM UNIFORM(0, 0.08, 0.005)
EB41DC	B41*IEB41DC
IEB41DC	RANDOM UNIFORM(0, 0.07, 0.005)
EB12DC	B12*IEB12DC
IEB12DC	RANDOM UNIFORM(0, 0.3, 0.01)
EB63DC	B63*IEB63DC
IEB63DC	RANDOM UNIFORM(0, 0.07, 0.005)
EB64DC	B64*IEB64DC
IEB64DC	RANDOM UNIFORM(0, 0.16, 0.005)
EB51DC	B51*IEB51DC
IEB51DC	RANDOM UNIFORM(0, 0.3, 0.005)
EB16DC	B16*IEB16DC
IEB16DC	RANDOM UNIFORM(0, 0.19, 0.005)
EB04DC	B04*IEB04DC
IEB04DC	RANDOM UNIFORM(0, 0.135, 0.005)
EB40DC	B40*IEB40DC
IEB40DC	RANDOM UNIFORM(0, 0.063, 0.005)
EB20DC	B20*IEB20DC
IEB20DC	RANDOM UNIFORM(0, 0.09, 0.005)
PDCDC	EDC
TPDCDC	INTEG [DCDC]
EB16CDC	B16*IEB16CDC
IEB16CDC	RANDOM UNIFORM(0, 0.11, 0.005)
EB19CDC	B19*IEB19CDC
IEB19CDC	RANDOM UNIFORM(0, 0.05, 0.005)
EB64CDC	B64*IEB64CDC
IEB64CDC	RANDOM UNIFORM(0, 0.08, 0.005)
EB45CDC	B45*IEB45CDC
IEB45CDC	RANDOM UNIFORM(0, 0.111, 0.005)
EB12CDC	B12*IEB12CDC

IEB12CDC	RANDOM UNIFORM(0, 0.114, 0.005)
EB63CDC	B63*IEB63CDC
IEB63CDC	RANDOM UNIFORM(0, 0.065, 0.005)
EB20CDC	B20*IEB20CDC
IEB20CDC	RANDOM UNIFORM(0, 0.075, 0.005)
EB67CDC	B67*IEB67CDC
IEB67CDC	RANDOM UNIFORM(0, 0.2, 0.005)
EB04CDC	B04*IEB04CDC
IEB04CDC	RANDOM UNIFORM(0, 0.13, 0.005)
EB36CDC	B36*IEB36CDC
IEB36CDC	RANDOM UNIFORM(0, 0.35, 0.01)
EB13CDC	B13*IEB13CDC
IEB13CDC	RANDOM UNIFORM(0, 0.08, 0.005)
EB41CDC	B41*IEB41CDC
IEB41CDC	RANDOM UNIFORM(0, 0.065, 0.005)
EB40CDC	B40*IEB40CDC
IEB40CDC	RANDOM UNIFORM(0, 0.063, 0.005)
EB51CDC	B51*IEB51CDC
IEB51CDC	RANDOM UNIFORM(0, 0.05, 0.005)
EB66CDC	B66*IEB66CDC
IEB66CDC	RANDOM UNIFORM(0, 0.2, 0.005)
PDIC	EIC
TPDIC	INTEG [DIC]
EB63IC	B63*IEB63IC
IEB63IC	RANDOM UNIFORM(0, 0.063, 0.005)
EB19IC	B19*IEB19IC
IEB19IC	RANDOM UNIFORM(0, 0.07, 0.005)
EB67IC	B67*IEB67IC
IEB67IC	RANDOM UNIFORM(0, 0.07, 0.005)
EB66IC	B66*IEB66IC
IEB66IC	RANDOM UNIFORM(0, 0.2, 0.005)
EB42IC	B42*IEB42IC
IEB42IC	RANDOM UNIFORM(0, 0.333, 0.01)
EB40IC	B40*IEB40IC
IEB40IC	RANDOM UNIFORM(0, 0.02, 0.005)
EB36IC	B36*IEB36IC
IEB36IC	RANDOM UNIFORM(0, 0.35, 0.01)
EB41IC	B41*IEB41IC
IEB41IC	RANDOM UNIFORM(0, 0.063, 0.005)
EB13IC	B13*IEB13IC
IEB13IC	RANDOM UNIFORM(0, 0.2, 0.005)
PDWM	EWM
TPDWM	INTEG [DWM]

EB20WM	B20*IEB20WM
IEB20WM	RANDOM UNIFORM(0, 0.08, 0.005)
EB40WM	B40*IEB40WM
IEB40WM	RANDOM UNIFORM(0, 0.04, 0.005)
EB16WM	B16*IEB16WM
IEB16WM	RANDOM UNIFORM(0, 0.17, 0.005)
EB13WM	B13*IEB13WM
IEB13WM	RANDOM UNIFORM(0, 0.1, 0.005)
EB41WM	IEB41WM*B41
IEB41WM	RANDOM UNIFORM(0, 0.059, 0.005)
EB45WM	B45*IEB45WM
IEB45WM	RANDOM UNIFORM(0, 0.13, 0.005)
EB12WM	B12*IEB12WM
IEB12WM	RANDOM UNIFORM(0, 0.143, 0.005)
EB63WM	B63*IEB63WM
IEB63WM	RANDOM UNIFORM(0, 0.059, 0.005)
EB64WM	B64*IEB64WM
IEB64WM	RANDOM UNIFORM(0, 0.09, 0.005)
EB51WM	B51*IEB51WM
IEB51WM	RANDOM UNIFORM(0, 0.29, 0.01)
EB04WM	B04*IEB04WM
IEB04WM	RANDOM UNIFORM(0, 0.12, 0.005)
PDBM	EBM
TPDBM	INTEG [DBM]
EB41BM	B41*IEB41BM
IEB41BM	RANDOM UNIFORM(0, 0.01, 0.005)
EB45BM	B45*IEB45BM
IEB45BM	RANDOM UNIFORM(0, 0.08, 0.005)
EB64BM	B64*IEB64BM
IEB64BM	RANDOM UNIFORM(0, 0.067, 0.005)
EB63BM	B63*IEB63BM
IEB63BM	RANDOM UNIFORM(0, 0.01, 0.005)
EB13BM	B13*IEB13BM
IEB13BM	RANDOM UNIFORM(0, 0.02, 0.005)
EB20BM	B20*IEB20BM
IEB20BM	RANDOM UNIFORM(0, 0.02, 0.005)
EB61BM	B61*IEB61BM
IEB61BM	RANDOM UNIFORM(0, 0.65, 0.01)
EB04BM	B04*IEB04BM
IEB04BM	RANDOM UNIFORM(0, 0.04, 0.005)
PDCHP	ECHP
TPDCHP	INTEG [DCHP]
EB40CHP	B40*IEB40CHP

IEB40CHP	RANDOM UNIFORM(0, 0.03, 0.005)
EB41CHP	B41*IEB41CHP
IEB41CHP	RANDOM UNIFORM(0, 0.01, 0.005)
EB04CHP	B04*IEB04CHP
IEB04CHP	RANDOM UNIFORM(0, 0.03, 0.005)
EB45CHP	B45*IEB45CHP
IEB45CHP	RANDOM UNIFORM(0, 0.04, 0.005)
EB64CHP	B64*IEB64CHP
IEB64CHP	RANDOM UNIFORM(0, 0.03, 0.005)
EB13CHP	B13*IEB13CHP
IEB13CHP	RANDOM UNIFORM(0, 0.02, 0.005)
EB63CHP	B63*IEB63CHP
IEB63CHP	RANDOM UNIFORM(0, 0.01, 0.005)
EB20CHP	B20*IEB20CHP
IEB20CHP	RANDOM UNIFORM(0, 0.02, 0.005)
EB62CHP	B62*IEB62CHP
IEB62CHP	RANDOM UNIFORM(0, 0.6, 0.02)
PDEOA	EOA
TPDEOA	INTEG [DEOA]
EB41EOA	B41*IEB41EOA
IEB41EOA	RANDOM UNIFORM(0, 0.059, 0.005)
EB40EOA	B40*IEB40EOA
IEB40EOA	RANDOM UNIFORM(0, 0.01, 0.005)
EB63EOA	B63*IEB63EOA
IEB63EOA	RANDOM UNIFORM(0, 0.059, 0.005)
EB13EOA	B13*IEB13EOA
IEB13EOA	RANDOM UNIFORM(0, 0.03, 0.005)
EB67EOA	B67*IEB67EOA
IEB67EOA	RANDOM UNIFORM(0, 0.3, 0.01)
EB10EOA	B10*IEB10EOA
IEB10EOA	RANDOM UNIFORM(0, 0.01, 0.005)
EB69EOA	B69*IEB69EOA
IEB69EOA	RANDOM UNIFORM(0, 0.5, 0.02)
EB20EOA	B20*IEB20EOA
IEB20EOA	RANDOM UNIFORM(0, 0.03, 0.005)
PDHSM	EHSM
TPDHSM	INTEG [DHSM]
EB20HSM	B20*IEB20HSM
IEB20HSM	RANDOM UNIFORM(0, 0.08, 0.005)
EB04HSM	B04*IEB04HSM
IEB04HSM	RANDOM UNIFORM(0, 0.035, 0.005)
EB64HSM	B64*IEB64HSM
IEB64HSM	RANDOM UNIFORM(0, 0.03, 0.005)

EB10HSM	B10*IEB10HSM
IEB10HSM	RANDOM UNIFORM(0, 0.25, 0.005)
EB51HSM	B51*IEB51HSM
IEB51HSM	RANDOM UNIFORM(0, 0.06, 0.005)
EB40HSM	B40*IEB40HSM
IEB40HSM	RANDOM UNIFORM(0, 0.06, 0.005)
EB41HSM	B41*IEB41HSM
IEB41HSM	RANDOM UNIFORM(0, 0.059, 0.005)
EB48HSM	B48*IEB48HSM
IEB48HSM	RANDOM UNIFORM(0, 0.6, 0.02)
EB13HSM	B13*IEB13HSM
IEB13HSM	RANDOM UNIFORM(0, 0.06, 0.005)
EB63HSM	B63*IEB63HSM
IEB63HSM	RANDOM UNIFORM(0, 0.059, 0.005)
EB25HSM	B25*IEB25HSM
IEB25HSM	RANDOM UNIFORM(0, 0.4, 0.01)
EB23HSM	B23*IEB23HSM
IEB23HSM	RANDOM UNIFORM(0, 0.35, 0.005)
EB06HSM	B06*IEB06HSM
IEB06HSM	RANDOM UNIFORM(0, 0.6, 0.02)

(3) CIP equations

Variables	Equations
PDLS	ELS
TPDLS	INTEG [DLS]
EB66LS	B66*IEB66LS
IEB66LS	RANDOM UNIFORM(0, 0.08, 0.005)
EB40LS	B40*IEB40LS
IEB40LS	RANDOM UNIFORM(0, 0.01, 0.005)
EB41LS	B41*IEB41LS
IEB41LS	RANDOM UNIFORM(0, 0.059, 0.005)
EB63LS	B63*IEB63LS
IEB63LS	RANDOM UNIFORM(0, 0.059, 0.005)
EB13LS	B13*IEB13LS
IEB13LS	RANDOM UNIFORM(0, 0.08, 0.005)
EB64LS	B64*IEB64LS
IEB64LS	RANDOM UNIFORM(0, 0.06, 0.005)
EB20LS	B20*IEB20LS
IEB20LS	RANDOM UNIFORM(0, 0.063, 0.005)
EB19LS	B19*IEB19LS
IEB19LS	RANDOM UNIFORM(0, 0.15, 0.005)
EB42LS	B42*IEB42LS
IEB42LS	RANDOM UNIFORM(0, 0.233, 0.01)
EB10LS	B10*IEB10LS
IEB10LS	RANDOM UNIFORM(0, 0.1, 0.01)
PDWS	EWS
TPDWS	INTEG [DWS]
EB23WS	B23*IEB23WS
IEB23WS	RANDOM UNIFORM(0, 0.2, 0.01)
EB20WS	B20*IEB20WS
IEB20WS	RANDOM UNIFORM(0, 0.063, 0.005)
EB66WS	B66*IEB66WS
IEB66WS	RANDOM UNIFORM(0, 0.01, 0.005)
EB63WS	B63*IEB63WS
IEB63WS	RANDOM UNIFORM(0, 0.059, 0.005)
EB40WS	B40*IEB40WS
IEB40WS	RANDOM UNIFORM(0, 0.08, 0.005)
EB64WS	B64*IEB64WS
IEB64WS	RANDOM UNIFORM(0, 0.03, 0.005)
EB13WS	B13*IEB13WS
IEB13WS	RANDOM UNIFORM(0, 0.08, 0.005)
EB19WS	B19*IEB19WS
IEB19WS	RANDOM UNIFORM(0, 0.18, 0.005)

EB41WS	B41*IEB41WS
IEB41WS	RANDOM UNIFORM(0, 0.059, 0.005)
EB10WS	B10*IEB10WS
IEB10WS	RANDOM UNIFORM(0, 0.1, 0.005)
PDES	EES
TPDES	INTEG [DES]
EB12ES	B12*IEB12ES
IEB12ES	RANDOM UNIFORM(0, 0.3, 0.005)
EB20ES	B20*IEB20ES
IEB20ES	RANDOM UNIFORM(0, 0.063, 0.005)
EB66ES	B66*IEB66ES
IEB66ES	RANDOM UNIFORM(0, 0.01, 0.005)
EB63ES	B63*IEB63ES
IEB63ES	RANDOM UNIFORM(0, 0.059, 0.005)
EB40ES	B40*IEB40ES
IEB40ES	RANDOM UNIFORM(0, 0.09, 0.005)
EB64ES	B64*IEB64ES
IEB64ES	RANDOM UNIFORM(0, 0.04, 0.005)
EB13ES	B13*IEB13ES
IEB13ES	RANDOM UNIFORM(0, 0.08, 0.005)
EB23ES	B23*IEB23ES
IEB23ES	RANDOM UNIFORM(0, 0.2, 0.01)
EB41ES	B41*IEB41ES
IEB41ES	RANDOM UNIFORM(0, 0.059, 0.005)
EB10ES	B10*IEB10ES
IEB10ES	RANDOM UNIFORM(0, 0.1, 0.005)
EB19ES	B19*IEB19ES
IEB19ES	RANDOM UNIFORM(0, 0.2, 0.01)
PDMS	EMS
TPDMS	INTEG [DMS]
EB19MS	B19*IEB19MS
IEB19MS	RANDOM UNIFORM(0, 0.15, 0.005)
EB10MS	B10*IEB10MS
IEB10MS	RANDOM UNIFORM(0, 0.1, 0.005)
EB66MS	B66*IEB66MS
IEB66MS	RANDOM UNIFORM(0, 0.01, 0.005)
EB63MS	B63*IEB63MS
IEB63MS	RANDOM UNIFORM(0, 0.059, 0.005)
EB40MS	B40*IEB40MS
IEB40MS	RANDOM UNIFORM(0, 0.09, 0.005)
EB64MS	B64*IEB64MS
IEB64MS	RANDOM UNIFORM(0, 0.04, 0.005)
EB13MS	B13*IEB13MS

IEB13MS	RANDOM UNIFORM(0, 0.08, 0.005)
EB23MS	B23*IEB23MS
IEB23MS	RANDOM UNIFORM(0, 0.1, 0.005)
EB41MS	B41*IEB41MS
IEB41MS	RANDOM UNIFORM(0, 0.059, 0.005)
EB20MS	B20*IEB20MS
IEB20MS	RANDOM UNIFORM(0, 0.075, 0.005)

(4) COP equations

Acronyms	Equations
PDQM	EQM
TPDQM	INTEG [DQM]
EB66QM	B66*IEB66QM
IEB66QM	RANDOM UNIFORM(0, 0.24, 0.01)
EB21QM	B21*IEB21QM
IEB21QM	RANDOM UNIFORM(0, 0.7, 0.025)
EB25QM	B25*IEB25QM
IEB25QM	RANDOM UNIFORM(0, 0.4, 0.02)
EB20QM	B20*IEB20QM
IEB20QM	RANDOM UNIFORM(0, 0.07, 0.005)
EB40QM	B40*IEB40QM
IEB40QM	RANDOM UNIFORM(0, 0.1, 0.05)
EB41QM	B41*IEB41QM
IEB41QM	RANDOM UNIFORM(0, 0.06, 0.005)
EB02QM	B02*IEB02QM
IEB02QM	RANDOM UNIFORM(0, 0.5, 0.02)
EB63QM	B63*IEB63QM
IEB63QM	RANDOM UNIFORM(0, 0.06, 0.005)
EB46QM	B46*IEB46QM
IEB46QM	RANDOM UNIFORM(0, 0.8, 0.025)
EB47QM	B47*IEB47QM
IEB47QM	RANDOM UNIFORM(0, 0.9, 0.03)
EB18QM	B18*IEB18QM
IEB18QM	RANDOM UNIFORM(0, 0.8, 0.025)
EB10QM	B10*IEB10QM
IEB10QM	RANDOM UNIFORM(0, 0.15, 0.005)
EB03QM	B03*IEB03QM
IEB03QM	RANDOM UNIFORM(0, 0.6, 0.02)
EB37QM	B37*IEB37QM
IEB37QM	RANDOM UNIFORM(0, 0.5, 0.02)
EB17QM	B17*IEB17QM
IEB17QM	RANDOM UNIFORM(0, 0.3, 0.01)
PDCM	ECM
TPDCM	INTEG [DCM]
EB67CM	B67*IEB67CM
IEB67CM	-RANDOM UNIFORM(0, 0.5, 0.02)
EB37CM	B37*IEB37CM
IEB37CM	-RANDOM UNIFORM(0, 0.5, 0.025)
EB25CM	B25*IEB25CM
IEB25CM	-RANDOM UNIFORM(0, 0.1, 0.005)

EB35CM	B35*IEB35CM
IEB35CM	-RANDOM UNIFORM(0, 0.6, 0.025)
EB03CM	B03*IEB03CM
IEB03CM	-RANDOM UNIFORM(0, 0.2, 0.005)
EB63CM	B63*IEB63CM
IEB63CM	-RANDOM UNIFORM(0, 0.1, 0.005)
EB68CM	B68*IEB68CM
IEB68CM	-RANDOM UNIFORM(0, 0.4, 0.02)
EB17CM	B17*IEB17CM
IEB17CM	-RANDOM UNIFORM(0, 0.7, 0.025)
EB62CM	B62*IEB62CM
IEB62CM	-RANDOM UNIFORM(0, 0.4, 0.015)
EB19CM	B19*IEB19CM
IEB19CM	RANDOM UNIFORM(0, 0.2, 0.05)
EB45CM	B45*IEB45CM
IEB45CM	-RANDOM UNIFORM(0, 0.05, 0.005)
EB12CM	B12*IEB12CM
IEB12CM	-RANDOM UNIFORM(0, 0.043, 0.005)
EB46CM	B46*IEB46CM
IEB46CM	-RANDOM UNIFORM(0, 0.2, 0.01)
EB18CM	B18*IEB18CM
IEB18CM	-RANDOM UNIFORM(0, 0.2, 0.01)
EB10CM	B10*IEB10CM
IEB10CM	-RANDOM UNIFORM(0, 0.2, 0.01)
EB20CM	B20*IEB20CM
IEB20CM	-RANDOM UNIFORM(0, 0.08, 0.005)
EB51CM	B51*IEB51CM
IEB51CM	-RANDOM UNIFORM(0, 0.1, 0.005)
EB47CM	B47*IEB47CM
IEB47CM	-RANDOM UNIFORM(0, 0.1, 0.005)
EB48CM	B48*IEB48CM
IEB48CM	-RANDOM UNIFORM(0, 0.2, 0.01)
EB50CM	B50*IEB50CM
IEB50CM	-RANDOM UNIFORM(0, 0.7, 0.025)
EB13CM	IEB13CM*B13
IEB13CM	-RANDOM UNIFORM(0, 0.09, 0.005)
EB58CM	B58*IEB58CM
IEB58CM	-RANDOM UNIFORM(0, 0.7, 0.025)
EB41CM	B41*IEB41CM
IEB41CM	-RANDOM UNIFORM(0, 0.01, 0.005)
EB66CM	B66*IEB66CM
IEB66CM	-RANDOM UNIFORM(0, 0.2, 0.01)
EB36CM	B36*IEB36CM

IEB36CM	-RANDOM UNIFORM(0, 0.15, 0.005)
EB02CM	B02*IEB02CM
IEB02CM	-RANDOM UNIFORM(0, 0.5, 0.02)
EB21CM	B21*IEB21CM
IEB21CM	-RANDOM UNIFORM(0, 0.3, 0.01)
EB69CM	B69*IEB69CM
IEB69CM	-RANDOM UNIFORM(0, 0.5, 0.02)
EB06CM	B06*IEB06CM
IEB06CM	RANDOM UNIFORM(0, 0.2, 0.01)
EB64CM	B64*IEB64CM
IEB64CM	-RANDOM UNIFORM(0, 0.077, 0.005)
EB16CM	B16*IEB16CM
IEB16CM	-RANDOM UNIFORM(0, 0.15, 0.005)
EB40CM	B40*IEB40CM
IEB40CM	-RANDOM UNIFORM(0, 0.14, 0.005)
EB04CM	B04*IEB04CM
IEB04CM	-RANDOM UNIFORM(0, 0.08, 0.005)
EB61CM	B61*IEB61CM
IEB61CM	-RANDOM UNIFORM(0, 0.35, 0.015)
EB44CM	B44*IEB44CM
IEB44CM	RANDOM UNIFORM(0, 0.6, 0.02)
EB23CM	B23*IEB23CM
IEB23CM	RANDOM UNIFORM(0, 0.15, 0.005)
EB42CM	B42*IEB42CM
IEB42CM	-RANDOM UNIFORM(0, 0.517, 0.025)
PDSM	ESM
TPDSM	INTEG[DSM]
EB40SM	B40*IEB40SM
IEB40SM	-RANDOM UNIFORM(0, 0.1, 0.005)
EB25SM	B25*IEB25SM
IEB25SM	-RANDOM UNIFORM(0, 0.1, 0.005)
EB68SM	B68*IEB68SM
IEB68SM	RANDOM UNIFORM(0, 0.6, 0.02)
EB63SM	B63*IEB63SM
IEB63SM	RANDOM UNIFORM(0, 0.07, 0.005)
EB64SM	B64*IEB64SM
IEB64SM	-RANDOM UNIFORM(0, 0.067, 0.005)
EB13SM	B13*IEB13SM
IEB13SM	-RANDOM UNIFORM(0, 0.08, 0.005)
EB20SM	B20*IEB20SM
IEB20SM	RANDOM UNIFORM(0, 0.063, 0.005)
EB50SM	B50*IEB50SM
IEB50SM	-RANDOM UNIFORM(0, 0.3, 0.015)

EB58SM	B58*IEB58SM
IEB58SM	-RANDOM UNIFORM(0, 0.3, 0.015)
EB44SM	B44*IEB44SM
IEB44SM	-RANDOM UNIFORM(0, 0.4, 0.02)
EB66SM	B66*IEB66SM
IEB66SM	-RANDOM UNIFORM(0, 0.1, 0.005)
EB04SM	B04*IEB04SM
IEB04SM	-RANDOM UNIFORM(0, 0.05, 0.005)
EB06SM	B06*IEB06SM
IEB06SM	-RANDOM UNIFORM(0, 0.2, 0.01)
EB41SM	B41*IEB41SM
IEB41SM	-RANDOM UNIFORM(0, 0.07, 0.005)
EB03SM	B03*IEB03SM
IEB03SM	RANDOM UNIFORM(0, 0.2, 0.01)
EB35SM	B35*IEB35SM
IEB35SM	-RANDOM UNIFORM(0, 0.4, 0.02)
EB36SM	B36*IEB36SM
IEB36SM	-RANDOM UNIFORM(0, 0.08, 0.005)

(5) Inputs of CSR activities

Variables	Equations
B02	(9.6386+RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 14.4578, 0), 0))*100/24.0964
B03	(9.6386+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDSM<=87.0783 :AND: TPDQM<=185.02, 14.4578, 0), 0))*100/24.0964
B04	(9.6386+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND: TPDWM<=36.0403 :AND: TPDBM<=13.4538 :AND: TPDCHP<=11.5663 :AND: TPDHSM<=90.4063 :AND: TPDCM<=272.663 :AND: TPDSM<=87.0783, 14.4578, 0), 0))*100/24.0643
B06	(17.6707+ RANDOM UNIFORM (0, IF THEN ELSE(TPDHSM<=90.4063 :AND: TPDCM<=272.663 :AND: TPDSM<=87.0783, 28.9157, 0), 0))*100/44.1767
B10	(24.0964*0.4+RANDOM UNIFORM(0, IF THEN ELSE(TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND: TPDWS<=20.6172 :AND: TPDHSM<=90.4063 :AND: TPDLS<=26.1714 :AND: TPDCDC<=43.299 :AND: TPDQM<=185.02 :AND: TPDEOA<=23.9806 :AND: TPDCM<=272.663, 24.0964*(1-0.4), 0), 0))*100/24.0964
B12	(12.8514 +RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND: TPDWM<=36.0403 :AND: TPDES<=31.0589 :AND: TPDCM<=272.663, 19.2771, 0), 0))*100/32.1285
B13	(8.0321+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND:TPDIC<=29.0281 :AND: TPDWM<=36.0403 :AND: TPDBM<=13.4538 :AND: TPDCHP<=11.5663 :AND: TPDEOA<=23.9806 :AND: TPDHSM<=90.4063 :AND: TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND:TPDWS<=20.6172 :AND: TPDLS<=26.1714 :AND: TPDSM<=87.0783 :AND: TPDQM<=185.02 :AND:TPDCM<=272.663, 12.0482, 0), 0))*100/20.0803
B16	(40.1606*0.4+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND: TPDWM<=36.0403 :AND: TPDCM<=272.663, 40.1606*(1-0.4), 0), 0))*100/40.1606

B17	(8.0321+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 12.0482, 0), 0))*100/20.0803
B18	(9.6386+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 14.4578, 0), 0))*100/24.0964
B19	(11.245+RANDOM UNIFORM(0, IF THEN ELSE(TPDIC<=29.0281 :AND: TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND: TPDWS<=20.6172 :AND: TPDLS<=26.1714 :AND: TPDCDC<=43.299 :AND: TPDCM<=272.663, 16.8675, 0), 0))*100/28.1124
B20	(14.4578+RANDOM UNIFORM(0, IF THEN ELSE(TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND: TPDDC<=44.2972 :AND: TPDBM<=13.4538 :AND: TPDWS<=20.6172 :AND: TPDHSM<=90.4063 :AND: TPDWM<=36.0403 :AND: TPDCHP<=11.5663 :AND: TPDLS<=26.1714 :AND: TPDCDC<=43.299 :AND: TPDSM<=87.0783 :AND: TPDQM<=185.02 :AND: TPDLC<=29.1807 :AND: TPDNC<=29.5582 :AND: TPDEOA<=23.9806 :AND: TPDCM<=272.663, 21.6867, 0), 0))*100/36.1446
B21	(14.4578+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 21.6868, 0), 0))*100/36.1446
B23	(6.4257+RANDOM UNIFORM(0, IF THEN ELSE(TPDHSM<=90.4063 :AND: TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND:TPDWS<=20.6172 :AND: TPDCM<=272.663, 9.6386, 0), 0))*100/16.0643
B25	(11.245+ RANDOM UNIFORM (0, IF THEN ELSE(TPDHSM<=90.4063 :AND: TPDCM<=272.663 :AND: TPDQM<=185.02, 16.8675, 0), 0))*100/28.1124
B35	(6.4257+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 9.6386, 0), 0))*100/16.0643
B36	(6.4257+RANDOM UNIFORM(0, IF THEN ELSE(TPDIC<=29.0281 :AND: TPDCM<=272.663 :AND: TPDSM<=87.0783 :AND: TPDCDC<=43.299, 9.6386, 0), 0))*100/16.0643
B37	(36.1446*0.4+RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 36.1446*(1-0.4), 0), 0))*100/36.1446
B40	(6.4257+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND:TPDIC<=29.0281 :AND: TPDWM<=36.0403 :AND: TPDCHP<=11.5663 :AND: TPDEOA<=23.9806 :AND: TPDHSM<=90.4063 :AND: TPDMS<=18.8601 :AND:

	TPDES<=31.0589 :AND:TPDWS<=20.6172 :AND: TPDLS<=26.1714 :AND: TPDSM<=87.0783 :AND: TPDQM<=185.02 :AND:TPDCM<=272.663, 9.6386, 0), 0))*100/16.643
B41	(9.6386+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND:TPDIC<=29.0281 :AND: TPDWM<=36.0403 :AND: TPDBM<=13.4538 :AND: TPDCHP<=11.5663 :AND: TPDEOA<=23.9806 :AND: TPDHSM<=90.4063 :AND: TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND: TPDWS<=20.6172 :AND: TPDLS<=26.1714 :AND: TPDSM<=87.0783 :AND: TPDQM<=185.02 :AND:TPDCM<=272.663, 14.4578, 0), 0))*100/24.0964
B42	(44.1767*0.4+ RANDOM UNIFORM (0, IF THEN ELSE(TPDLS<=26.1714 :AND: TPDCM<=272.663 :AND: TPDIC<=29.0281, (44.1767-44.1767*0.4), 0), 0))*100/44.1767
B44	(8.0321+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 12.0482, 0), 0))*100/20.0803
B45	(6.4257 +RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND: TPDWM<=36.0403 :AND: TPDBM<=13.4538 :AND: TPDCHP<=11.5663 :AND: TPDCM<=272.663, 9.6386, 0), 0))*100/16.0643
B46	(48.1928*0.4+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, (48.1928-48.1928*0.4), 0), 0))*100/48.1928
B47	(9.6386+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 14.4578, 0), 0))*100/24.0964
B48	(19.2771+ RANDOM UNIFORM (0, IF THEN ELSE(TPDHSM<=90.4063 :AND: TPDCM<=272.663 :AND: TPDSM<=87.0783, 28.9157, 0), 0))*100/48.1928
B50	(14.4578+RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDSM<=87.0783, 21.6867, 0), 0))*100/36.1446
B51	(11.245+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND: TPDWM<=36.0403 :AND: TPDHSM<=90.4063 :AND: TPDCM<=272.663, 16.8675, 0), 0))*100/28.1124
B58	(9.6386+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 14.4578, 0), 0))*100/24.0964

B61	(4.8193+RANDOM UNIFORM(0, IF THEN ELSE(TPDBM<=13.4538 :AND: TPDCM<=272.663, 7.2289, 0), 0))*100/12.0482
B62	(4.8193+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCHP<=11.5663 :AND: TPDCM<=272.663, 7.2289, 0), 0))*100/12.0482
B63	(40.1606*0.4+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND:TPDIC<=29.0281 :AND: TPDWM<=36.0403 :AND: TPDBM<=13.4538 :AND: TPDCHP<=11.5663 :AND: TPDEOA<=23.9806 :AND: TPDHSM<=90.4063 :AND: TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND:TPDWS<=20.6172 :AND: TPDLS<=26.1714 :AND: TPDSM<=87.0783 :AND: TPDQM<=185.02 :AND:TPDCM<=272.663, 40.1606*(1-0.4), 0), 0))*100/40.1606
B64	(9.6386+RANDOM UNIFORM(0, IF THEN ELSE(TPDNC<=29.5582 :AND: TPDLC<=29.1807 :AND: TPDDC<=44.2972 :AND: TPDCDC<=43.299 :AND: TPDWM<=36.0403 :AND: TPDBM<=13.4538 :AND: TPDCHP<=11.5663 :AND: TPDHSM<=90.4063 :AND: TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND: TPDWS<=20.6172 :AND: TPDLS<=26.1714 :AND: TPDSM<=87.0783 :AND: TPDCM<=272.663, 14.4578, 0), 0))*100/24.0964
B66	(11.245+RANDOM UNIFORM(0, IF THEN ELSE(TPDIC<=29.0281 :AND: TPDMS<=18.8601 :AND: TPDES<=31.0589 :AND: TPDWS<=20.6172 :AND: TPDEOA<=23.9806 :AND: TPDQM<=185.02 :AND: TPDCDC<=43.299 :AND: TPDCM<=272.663 :AND: TPDSM<=87.0783, 16.8675, 0), 0))*100/28.1124
B67	(9.6386+RANDOM UNIFORM(0, IF THEN ELSE(TPDCDC<=43.299 :AND: TPDEOA<=23.9806 :AND: TPDCM<=272.663, 14.4578, 0), 0))*100/24.0964
B68	(8.0321+ RANDOM UNIFORM (0, IF THEN ELSE(TPDCM<=272.663 :AND: TPDQM<=185.02, 12.0482, 0), 0))*100/20.0803
B69	(8.0321+RANDOM UNIFORM(0, IF THEN ELSE(TPDEOA<=23.9806 :AND: TPDCM<=272.663, 12.0482, 0), 0))*100/20.0803

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