A FRAMEWORK FOR COMPARISON STUDY ON THE MAJOR METHODS IN PROMOTING SUSTAINABLE CONSTRUCTION PRACTICE

Khairul Anuar Bakhtiar[1], Li Yin Shen[2] and Siti Hajar Misnan[3]
[1,3] *PhD Candidate, Building & Real Estate Department, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*
[2] *Professor, Building & Real Estate Department, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*
khairul1982@yahoo.com, bsshen@inet.polyu.edu.hk, ct_aj82@yahoo.com

ABSTRACT: *Sustainable development concept has opened a broad range of understanding and interpretation among people. Researchers have been adopting the concept in various disciplines within their interests of studies. In line with this, the urge to adopt the concept of sustainable development has drawn interests among construction professionals. The construction industry is considered having a major role to play in implementing the principles of sustainable development, which leads to the development of the discipline of sustainable construction. A large number of research works have been conducted in investigating the methods for promoting sustainable construction. However there is no study done to look at the effectiveness of these methods developed previously. This paper therefore presents a comprehensive understanding on various methodologies proposed in the existing studies for promoting sustainable construction. An analysis is given on the effectiveness between several typical sustainable construction methods.*

Keywords: *Sustainable development, sustainable construction, sustainability, sustainable construction methodology*

Introduction

The importance of pursuing the mission of sustainable development has urged mankind to make an effort and find better solutions to achieve it. Sustainable means lasting or perpetual, and there hardly seems any points to developing if the effort to do so is not sustained (Pearce, 2006). Mankind is under threat as environmental degradation has been continuing in both developed and developing countries (Du Plessis, 2007). Therefore the mission of sustainable development involves all nations. Literatures have presented various types of methods for promoting sustainable construction practice and these typical methods are listed (see Table 1). Whilst the method for practising sustainable construction has been growing, there is a need to comparatively understand their characteristics and their advantages and effectiveness can be fully utilized. The construction industry has been recognised to have major effects on environment degradation, and has gained concerns among researchers on how to mitigate the environmental impact related to construction industry activities (Spence and Mulligan, 1995; Ofori, 1998; Shen and Tam, 2002; Manoliadis et al., 2006). One of the major reasons contributing to environmental impacts is lack of environment awareness from all parties involved in the construction industries (Hill and Bowen, 1997; Kein et al., 1999; Shen et al., 2006; Osmani et al., 2008). Furthermore, the government has been playing active roles in order to reduce the environmental impact of construction industries, for example through the establishment of regulation and controls, economics incentives, and non-regulatory activity (Spence and Mulligan, 1995). It is the aim of this paper to provide a comparative understanding on the key characteristics between the major methodologies for promoting sustainable construction practice.

Table 1: Typical methods for promoting sustainable construction practise

Code	Methods	Key references
SC-M_1	Education and training	Ekanayake and Ofori (2000); A21 SCDC (2002); Manoliadis et al. (2006).
SC-M_2	Environmental management system	BSI (1994); Hill and Bowen (1997); Ofori (1998); Kein et al. (1999); Shen and Tam (2002); Christini et al. (2004); Yao et al. (2006).
SC-M_3	Green building	Stum (2000); Kibert (2007); Nelms et al. (2007); Kibert (2008).
SC-M_4	Green design	Al-Momani (2000); Ekanayake and Ofori (2000); Begum et al. (2007); Poon (2007); Osmani et al. (2008).
SC-M_5	Green procurement	Ngowi (1998); Rwelamila and Meyer (1998); Ekanayake and Ofori (2000); Ngowi (2000); Rwelamila et al. (2000); Teo and Loosemore (2001); Sterner (2002); Carter and Fortune (2008).
SC-M_6	Green roof technologies	Nelms et al. (2007).
SC-M_7	Lean construction	Huovila and Koskela (1998); Ballard et al. (2003); Lapinski et al. (2006).
SC-M_8	Prefabrication	Tam el al. (2007b); Jaillon et al. (2008); Silva and Vithana (2008).
SC-M_9	Waste management	Bossink and Brouwers (1996); CIB (1999); Kein et al. (1999); Kulatunga et al. (2006); Tam et al. (2007a); Tam et al. (2007b); Poon (2007); Jaillon et al. (2008).

Sustainable Development and Sustainable Construction

Sustainable development is a broad issue and the debate is still on its principles. The concept of sustainable development is widely related to environmental degradation with limited debates on economic and social agenda. Report of the World Commission on Environment and Development (WECD, 1987), has defined sustainable development as development, which meets the needs of the present with out compromising the ability of future generation to meet their own needs. The definition is the most frequently cited definition among researchers. According to De Graaf et al. (1996), any complete strategy for reaching sustainable development should be able to consider all possible activities and all their side-effects such as social, economics, cultural, or ecological problems. In order to promote sustainable development progression, Department of the Environment, Transport and the Regions (DETR) (1999) identified four objectives, (1) social progress; (2) protection of the environment; (3) prudent use of natural resources; and (4) economic growth and employment. The political and academic discussion about sustainable development has sprouted enormously and the idea now enjoys a broad support by governments, non-governmental organization, businesses, and those within the scientific community (Seidl, 2000). Gutberlet (2000) has proposed a paradigm shift with the corporate world internalising the sustainability concept based on dematerialisation which have tendency to use less material and energy inputs per unit of output and eco-efficiency which are strategies to provide goods and services while continuously reducing ecological impacts.

Sustainable construction has become an important topic among researchers since the late 1980s but the movement is still relatively new, and the progress is difficult to measure (Kibert, 2007). The first international conference on sustainable construction was held in Tampa of USA (Kibert, 1994a), in which, Kibert (1994b) introduced a typical definition of sustainable construction as creating a healthy built environment using resource-efficient and ecologically-based principles. Kibert (1994c) proposed principles for sustainable construction which is, conserve, reuse, renew or recycle, protect nature, non-toxics, economics and quality. Other studies consider sustainable construction also as a subset of sustainable development and introduced by the multinational engineering, construction and architectural firms originating in Europe and the USA (Du Plessis, 2001). Kibert (2007), recently suggested that sustainable construction may best be defined as how the construction industry together with its product the 'built environment', among many sectors of the economy and human activity, can contribute to the sustainability of the earth including its human and non-human inhabitants. On the other hand, it has been increasingly appreciated that the construction activity risks the earth sustainability though contributing environmental degradation and reducing non-renewable materials in the earth. Construction industry consumes a significant percentage of the world's major resources and generates a huge percentage of solid waste. Nevertheless, human needs construction activities to sustain their civilization growth. Hill and Bowen (1997) proposed framework of process-oriented principles of sustainable construction, including four pillars of sustainability (1) social sustainability; (2) economic sustainability; (3) biophysical sustainability; and (4) technical sustainability. This framework addresses sustainability fundamental line in the construction sector. However, a comment by Ofori (1998) suggested that, regarding the 'pillars' and principles offered by Hill and Bowen (1997), improvement can be made only through a concerted effort by participants and following good-practice guidelines. The roles of different parties and collaboration are therefore emphasised. Furthermore, Shen et al. (2006) extended the study to four strategies for a better implementation of sustainable construction practise, including (1) regulation; (2) enabling and supporting mechanism; (3) incentives; and (4) example demonstration and partnership. There are still other studies about the principles of sustainable construction, such as Du Plessis (2001); Pearce (2006); Nelms et al. (2007).

Major Methodologies for Promoting Sustainable Construction

Previous studies have introduced various methodologies for promoting sustainable construction. These methods can be broadly classified into the following categories below:

Education and Training

Education and training for promoting sustainable construction practice are important to all construction industry stakeholders (A21 SCDC, 2002; Manoliadis et al., 2006). Curricula and training programmes in the construction industry need to be revised to provide more knowledge and materials on sustainable construction practise (Manoliadis et al., 2006). There is a need to fill in the gap between education of construction clients, the public, decision makers, professionals and others involved directly and indirectly within construction industries. Contractors need to educated and advised about the methods of cost savings from reducing construction wastage (Ekanayake and Ofori, 2000). Academicians need to develop methods of auditing curricula to be adopted by educational institutions in attainment of sustainable practice. Training programs can empower construction professionals to benefit from practising sustainable construction principles. It is also important to provide funding for training and education for those who cannot afford the costs themselves, and setting up incentive and rewards schemes.

Environmental Management System

In 1992, the world first environmental management standard was introduced by the British Standard of Institution (BSI, 1994). Construction activities contribute to environmental problems and they have been criticised as being behind other sectors in its response to the problems of the environment (Ofori, 1998). Various methods have been introduced to tackle environmental issue, for example the Hong Kong construction industry has been promoting some measures such as establishing waste management plans, reducing and recycling construction and demolition wastes, providing in-house training on environmental management, and legal measures on environmental protection. Nevertheless, the effectiveness of these measures can only be gained if all construction professionals apply them (Shen and Tam, 2002). Hill and Bowen (1997) proposed the application of Environmental Assessment (EA) and Environmental Management System (EMS) to deal with environmental issues in construction. Environmental protective measures and environmental management system (EMS) have become common in many manufacturing and industrial industries, but only a small number of construction firms consider using EMS system in their construction projects (Kein et al., 1999; Christini et al., 2004). Researchers such as Yao et al. (2006), proposed a framework to improve the project environmental performance, which consists environmental policy, planning, implementation and operation, and checking and corrective action. The existence of barriers to implement environmental management have been demonstrated, and major barriers are identified as increasing management costs, lack of trained staffs and expertise, lack of sub-contractors cooperation, lack of clients support and time-consuming for improving environmental performance (Shen and Tam, 2002).

Green Building

Green buildings are typically defined as healthy facilities designed and built in a resource-efficient manner, using ecologically based principles (Kibert, 2008). They consume significantly less energy, materials, and water; provide healthy living and working environments; and greatly improve the quality of the built environment (Kibert, 2007). According to Stum (2000), a green building is designed, constructed and used in a way that minimizes negative environmental consequences from both an economic and a life cycle perspective thus contributed to sustainable development. In applying green building, one major challenge is how to access whether a building is green or not. This has attracted a lot of studies internationally for developing assessment methods. These assessment methods have been developed in many countries in defining a green building such as CASBEE in Japan, LEED® in the US, LEED™ Canada in Canada, NABERS in Australia, and BREEAM in the United Kingdom (Kibert, 2007; Nelms et al.,2007; Kibert, 2008).

Green Design

It is well appreciated that construction design plays an important role in promoting sustainable construction practise. Design changes may contribute to many consequences such as extra energy consumption, overruns in cost and construction time (Al-Momani, 2000). Designs changes particularly in construction stage can cause major waste generation because of unnecessary extra work during construction period and therefore contribute time delay as well (Ekanayake and Ofori, 2000). All parties who are involved in the construction process must identify proper methods of construction processes such as in design stage and in tender stage to minimize construction wastage (Begum et al., 2007). This is echoed in another typical study by Poon (2007), arguing that construction waste reduction should be considered at an early stage and by all parties involved in the building process. Nevertheless, it is interesting to note that most UK architects reported reluctance to adopt waste design minimization strategies in their design practice (Osmani et al., 2008).

Green Procurement

Ekanayake and Ofori (2000) promoted appropriate green procurement systems for clients to adopt for mitigating construction wastage problem. The construction industry in United Kingdom has moved significantly forward to a more advanced method in selecting appropriate procurement system to innovative hybrids of traditional and other construction procurement systems in order to practise sustainable construction principles (Rwelamila et al., 2000). Teo and Loosemore (2001) suggested that it is important to explore the impact of procurement and contractual systems upon the generation of construction waste. Furthermore, Rwelamila and Meyer (1998) promoted appropriate procurement system for different projects and suggested that procurement system must be tailored to meet different projects aims. The research by Ngowi (1998) found that the majority of the professionals in Botswana construction industry coined that the traditional procurement system (TPS) and design and build systems (D&B) do not meet the expectation of the users. Rwelamila et al. (2000), suggested that there is a need within construction sector to perform a paradigm shift in its choice of construction procurement system rather than using traditional construction procurement system as a 'default system'. Sterner (2002) promoted green procurement of a building in construction procurement practice, supported by a survey result at both public and private building clients in Sweden. Ngowi (2000) suggested using concurrent engineering principles which has been successfully deployed in the manufacturing industry can offer a viable possibility in order to achieve a better performance in procurement system delivery in construction sector. Carter and Fortune (2008) proposed consensual sustainability model, a decision support tools for use in procuring building projects towards sustainable practice.

Green Roof Technologies

Technology is important for sustainable construction to become effective and efficient. Nelms et al. (2007), proposed a green roof technology framework in promoting sustainable construction technology. The technology can lead to improving services life and protection of the roof membrane, reduction in space-conditioning requirement of building, improved storm water quality, and improved building marketability. In the same study, it is argued that the construction industry is interested in the green roof technology because of the potential benefit across economics, environmental, and social benefit perspectives.

Lean Construction

Huovila and Koskela (1998), suggested the use of lean construction principle to enable material wastage and add value to the customer. Research is now under way in exploring various types of engineered-to-order to see what techniques can help reduce lead times and achieve other performance improvements that increase customer and stakeholder value, while minimizing waste (Ballard et al., 2003). Lapinski et al. (2006) proposed using car industry methodology in construction industries by employing the concept of Toyota production system in producing good quality car. Lean construction methodologies are commonly applied in structural prefabrication of walls, beams, and columns and can be extended to other non prefabricated components for example plumbing, structural steel, curtain wall, elevators and others.

Prefabrication

Prefabrication can provide a better solution compared to traditional in-situ construction to reduce construction wastes on site activities (Tam et al., 2007b; Jaillon et al., 2008; Silva and Vithana, 2008). However, the implementation of using prefabrication has its weaknesses as it needs specification change and this conflicts with traditional design process (Jaillon et al., 2008). By using prefabrication, it offers a higher profit margin to the contractor which may reduce the benefits from reducing wastage.

Waste Management

Bossink and Brouwers (1996) found that 9% of the totally purchased construction materials end up as waste (by weight) in the Netherlands. In CIB (1999) report from the Europe Union, construction sector contributes approximately 40% of all wastage in the Union. However, it seems that waste issue has not been given proper attention. Kein et al. (1999) stated that reduced resource or energy wastage in construction project are not likely to become a priority issue at the project planning stage among contractor in Singapore. Kulatunga et al. (2006) pointed out that the amounts of wastage in actual site operation are much higher than the allowance given by the estimator in pre-construction stage for waste compensation in Sri Lanka. Reducing construction waste is becoming a key environmental issue in construction industry (Poon, *2007).*

Reducing building material wastage is the key point to reducing construction wastage. Building material wastage can be defined as the remains of the materials delivered on site after being used in the construction works (Tam et al., 2007a). Construction waste is considered as one of the main factors having an impact on the environment (Tam et al., 2007b). In Hong Kong, when selecting construction method, waste reduction is not a major concern compare to cost and time (Jaillon et al., 2008).

Indicators for measuring effectiveness of sustainable construction practice

Indicators are important and effective in promoting sustainable construction practice if designed with care and used properly. Otherwise, like statistics, it can be used to mislead and misinform (Mitchell, 1996). In order to comparatively examine the characteristics between the major sustainable construction methods addressed in the previous section, it is necessary to select appropriate indicators. Past literature studies have provided various references, and from which typical indicators for measuring the effectiveness of sustainable construction methods can be identified as listed in Table 2.

Table 2: Typical sustainability indicators

Code	Indicator	Key references
SI-X_1	Waste reduction	Spence and Mulligan (1995); Kein et al. (1999); A21 SCDC (2002); Kibert (2008).
SI-X_2	Cost saving	Love et al. (1998); Kein et al. (1999); Ekanayake and Ofori (2000); Tam (2008).
SI-X_3	Time saving	Love et al. (1998); Kein et al. (1999); Tam (2008).
SI-X_4	Quality	Kibert (1994c); Kein et al. (1999); Hill and Bowen (1997); Kibert (2007); A21 SCDC (2002); Kibert (2008).
SI-X_5	Material recycling	Kibert (1994c); A21 SCDC (2002); Kibert (2008).
SI-X_6	Flora and fauna protection	Kibert (1994c); A21 SCDC (2002); Ou et al. (2006); Kibert (2008).
SI-X_7	Air pollution control	Hill and Bowen (1997); Kein et al. (1999); A21 SCDC (2002); Ou et al. (2006).
SI-X_8	Noise pollution control	Hill and Bowen (1997); Kein et al. (1999); A21 SCDC (2002); Ou et al. (2006).
SI-X_9	Water pollution control	Hill and Bowen (1997); Kein et al. (1999); A21 SCDC (2002); Ou et al. (2006).

Code	Indicator	Key references
SI-X_{10}	Energy saving	Spence and Mulligan (1995); A21 SCDC (2002); Kibert (2007).

Discussion Framework

Whilst there are many indicators used to examine sustainable construction in the past literatures, the typical indicators are identified as waste reduction, quality, material recycling, flora and fauna protection, air pollution control, noise pollution control, water pollution control and energy saving. On top of these, cost and time are also considered as important indicators. Little consideration has been given in the existing studies to cost and time saving as a major technical barrier of promoting sustainable construction performance. This study proposes a framework for examining the effectiveness of these indicators when different sustainable construction methodologies are applied. This framework is elaborated by employing the data and findings available in past literatures as shown in Table 3. The data in the Table provide a valuable indication about the application of specific sustainable construction methodologies to some specific indicators.

Methods	Indicators									
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
SC-M_1	○	○	Δ	○	○	○	○	○	○	○
SC-M_2	○	Δ	Δ	Δ	○	○	○	○	○	Δ
SC-M_3	○	○	Δ	○	○	○	○	Δ	Δ	○
SC-M_4	○	○	○	○	○	○	Δ	Δ	Δ	○
SC-M_5	○	○	○	○	○	○	○	○	○	○
SC-M_6	Δ	○	Δ	○	Δ	○	○	○	Δ	○
SC-M_7	○	○	○	○	Δ	○	Δ	Δ	Δ	Δ
SC-M_8	○	Δ	○	○	Δ	Δ	○	○	Δ	Δ
SC-M_9	○	○	Δ	Δ	○	○	○	○	○	Δ

○ - Adopted
Δ - Not adopted

Table 3: Sustainable construction methods and their contributions to sustainability

Code	Indicator	Key references
SI-X_{10}	Energy saving	Spence and Mulligan (1995); A21 SCDC (2002); Kibert (2007).

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	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
SC-M_1	○	○	Δ	○	○	○	○	○	○	○
SC-M_2	○	Δ	Δ	Δ	○	○	○	○	○	Δ
SC-M_3	○	○	Δ	○	○	○	○	Δ	Δ	○
SC-M_4	○	○	○	○	○	○	Δ	Δ	Δ	○
SC-M_5	○	○	○	○	○	○	○	○	○	○
SC-M_6	Δ	○	Δ	○	Δ	○	○	○	Δ	○
SC-M_7	○	○	○	○	Δ	○	Δ	Δ	Δ	Δ
SC-M_8	○	Δ	○	○	Δ	Δ	○	○	Δ	Δ
SC-M_9	○	○	Δ	Δ	○	○	○	○	○	Δ

○ - Adopted
Δ - Not adopted

Table 3: Sustainable construction methods and their contributions to sustainability

Notes:

M = Methods	X = Indicator
SC-M_1 = Education and training	SI-X_1 = Waste reduction
SC-M_2 = Environmental management system	SI-X_2 = Cost saving
SC-M_3 = Green building	SI-X_3 = Time saving
SC-M_4 = Green design	SI-X_4 = Quality
SC-M_5 = Green procurement	SI-X_5 = Material recycling
SC-M_6 = Green roof technologies	SI-X_6 = Flora and fauna protection
SC-M_7 = Lean construction	SI-X_7 = Air pollution control
SC-M_8 = Prefabrication	SI-X_8 = Noise pollution control
SC-M_9 = Waste management	SI-X_9 = Water pollution control
	SI-X_{10} = Energy saving

Summary

Decision-making for the promotion of a sustainable construction practice involves all stakeholders in construction industry. This paper provides an overall view on the typical sustainable construction methods which have been developed in the past. It also highlights the typical indicators used to measure the performance level of the effectiveness in the application of various methodologies in meeting various sustainability indicators. The proposed framework is a tool for examining the effectiveness of different sustainable construction methods. It will lead the research to the next stage, which will be a pilot study to investigate the effectiveness in applying various methodologies in meeting various sustainability indicators.

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