EXPLORING CRITICAL SUCCESS FACTORS FOR WASTE MANAGEMENT IN CONSTRUCTION PROJECTS OF CHINA

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Abstract

The enormous amount of construction activity in China associated with its rapid economic development has produced a large amount of construction and demolition (C&D) waste over the past three decades. The majority of this waste has not been well processed, which has led to severe damage to the environment. Although there is clearly a need for better C&D waste management (WM) in China, the best ways to achieve this have yet to be fully explored. This paper is based on a study by the authors that aimed to identify the Critical Success Factors (CSFs) for C&D WM in China. A questionnaire survey and 14 semi-structured interviews with practitioners, researchers and government officials were conducted in Shenzhen, a leading city in southern China for tackling C&D WM. Seven factors were identified as the CSFs for managing C&D waste: (1) WM regulations, (2) Waste management system (WMS), (3) Awareness of C&D WM, (4) Low-waste building technologies, (5) Fewer design changes, (6) Research & Development in WM, and (7) Vocational training in WM. These CSFs can serve as

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valuable references for stakeholders to develop effective C&D WM strategies. The research also adds to the knowledge on how to reduce adverse environmental impacts caused by construction activities in rapidly developing economies.

Keywords: Construction and demolition waste, critical success factors, waste management, construction projects, China

1. Introduction

Over the past thirty years, China has enjoyed exceptionally rapid economic growth, achieving a GDP growth of up to 9.8% annually (NBS, 2007). However, in parallel with this impressive economic development has been a severe degradation of China's environment caused in part by the large amount of waste generated by construction activities associated with expanding urbanization and infrastructure programmes. Dong et al. (2001) found that China produced approximately 30% of the world's municipal solid waste (MSW), and more recently Wang et al. (2008) found that amongst China's MSW, construction activities were responsible for nearly 40%, having consumed about 40% of total natural resources and around 40% of energy. The majority of that waste has not been well processed, which has caused heavy ecological damage and environmental pollution. Even though effective management of C&D waste in China's fast-developing construction sector is urgently needed, there has yet to be any substantial research into ways to achieve this. There are not even any published statistics on the amount of C&D construction waste at national or municipal level.

From the many factors that impact the effectiveness of WM, such as regulations and technologies, this paper identifies the critical success factors (CSFs) for C&D WM in China. Since China is such a big country with many different levels of economic development, the CSFs developed in one region may not be suitable for others. However, by focusing on Shenzhen as the most advanced city in terms of C&D WM in Mainland China, findings are more likely to be relevant to other parts of China. The remainder of the paper comprises four parts. The first part provides a general introduction to C&D WM both worldwide and in China, the second part outlines the research methodology used for identifying the CSFs, the third part analyses and discusses the CSFs for C&D WM based on the questionnaire and interviews, and the last part draws conclusions. It is anticipated that the identified CSFs will serve as valuable references for stakeholders, including government departments, contractors, clients and engineers, to use when devising effective C&D WM strategies. Findings from the study will also contribute to the understanding of how to reduce the adverse impact of construction activities in rapidly expanding economies.

2. Construction and demolition waste management

Whilst it significantly contributed to the economy of any country, the construction industry has a negative impact on the natural environment. Construction by its nature is not environmentally friendly as the various activities involved, such as excavation, building and civil works, site clearance, demolition activities, road works, and building renovation, generates a tremendous amount of C&D waste. (EPD, 1998; Shen, et al., 2004; Tam and Tam, 2008). C&D waste is typically in the form of building debris, rubble, earth, concrete, steel, timber and mixed site clearance material; it is often a mixture of inert and organic materials. The United States (US) Environmental Protection Agency (2002) estimated that approximately 136 million tons of building-related C&D debris was generated in the US in 1996 - the majority from demolition and renovation activities (48% and 44% respectively) In the United Kingdom (UK) it was found that in the late nineties around 70 million tons of C&D materials and soil ended up as waste and that the wastage rate in the UK construction industry was as high as 10-15% (McGrath and Anderson, 2000). In Australia in the mid-nineties, nearly one ton of solid waste was sent to landfill per person each year (Reddrop and Ryan, 1997), and C&D waste was estimated to have accounted for 16% to 40% of all waste generated in that country (Bell, 1998). In Hong Kong, the annual generation of C&D waste more than doubled in nine years from 1993, reaching 20 million tons in 2004 (Poon, 2007). Since the acceptance of sustainable development as a desirable concept (WCED, 1987), the construction industry has taken measures to alleviate its adverse impact on the environment so much so that C&D WM is now an established discipline worldwide.

The research and practice of C&D WM can be best understood by putting it into a spectrum ranging from hard technologies to soft management. For example, low level technologies can be introduced to reduce C&D waste, such as using prefabrication instead of in-situ. Also, new technologies have been developed to reuse and recycle, for example, using recycled aggregates for different concrete applications (Poon and Chan, 2007). At the other end of this spectrum various managerial measures, such as promoting best WM practices, have been developed to manage C&D waste based on the view that it is a behavioral and social process. Using a process description approach, Shen et al. (2004) examined the waste handling process during construction and developed a good practice WM mapping model, while Jallion and Poon (2008) examined the technical, managerial, and marketing aspects of prefabrication technology in Hong Kong.

C&D WM research and practice have been guided by the 3Rs principle, which is also known as the hierarchy of C&D WM. The 3Rs refer to the three desirable strategies of reduce, reuse and recycle (Peng et al., 1997; Faniran and Caban, 1998; Tam and Tam, 2006), which are hierarchically arranged in order of importance. Reduction is considered as the most effective and efficient method for C&D WM as it offers the dual benefits of preventing the generation of C&D waste and of reducing the cost of higher charges for waste transportation, disposal and recycling (Poon, 2007; Esin and Cosgun, 2007). Reuse includes using a construction material more than once for the same function, such as reusing formwork, and for a new function (new-life reuse) such as using the cut-corner of a steel bar for supporting shelves. When reduction and reuse is not feasible, recycling can offer the benefits of reduced demand for new resources, a reduction of transport and production energy costs, and the utilization of waste that would otherwise be lost to landfill sites (Tam, 2008a).

C&D WM includes the whole lifecycle of a project and involves all stakeholders. Although most waste is generated at the construction and demolition stages, it is generally considered that each stage of a project's lifecycle contributes to C&D waste (Osmani et al., 2008; Esin and Cosgun, 2007; Hao et al., 2008). Therefore C&D WM practice emphasizes the integration of a project's whole lifecycle (Craighill and Powell, 1999; Ekanayake and Ofori, 2004; Osmani et al., 2008). The overall efficiency of C&D WM will largely depend on how the information and processes involved in managing C&D waste throughout a project's lifecycle is integrated (Hao et al., 2007b). In line with the whole lifecycle approach to C&D WM, it is highly desirable to have the active participation of all stakeholders including government, clients, contractors (both construction and demolition), suppliers, and facilities management companies This concept was highlighted in the Rio de Janeiro Declaration that came out of the United Nations Conference on Environment and Development (UNCED, 1992). Clients may ultimately have to pay for WM as in some cases it is included in bidding documents and main contractors often involve subcontractors and suppliers in their waste management plans (Tam, 2008b). Sometimes, the general public significantly influences a construction project for environmental reasons (Zyglidopoulos, 2002). However, implementation of the stake-holder-involved whole lifecycle concept for C&D WM is still relatively slow.

3. C&D waste management in China

C&D WM in China came into focus in the 1990s when China sped up its economic reforms and the environmental degradation caused by the consequential increased manufacturing and construction activities reached an alarming point. This led to the promulgation of many laws and regulations such as the *Environment Law of the People's Republic of China* (1989), the *Law of the P.R.C. on Prevention of Environmental Pollution Caused by Solid Waste* (1995, revised 2004), *Regulations on the Urban Environmental Sanitation Management* (1992), and the *Administrative Measures for Urban Living Waste* (2007), that placed C&D WM under scrutiny and promoted its practice.

Studies over the past fifteen years have provided a better understanding of C&D WM. For example, Zhang et al. (1995) investigated the practice and benefits of construction waste reduction on-site. Li et al. (1999 and 2001) examined C&D waste reuse technology and investigated the measures for C&D WM through site investigation. Wang et al. (2004) analyzed the major factors affecting the generation of C&D waste in different regions, while Wang and Yuan (2008) attempted to deal with the complexity of on-site WM by using a system dynamics approach. Research has also revealed the problems associated with WM including the use of traditional construction techniques and a lack of sufficient WM skills (Wang and Yuan, 2006), a lack of incentives for implementing C&D waste reduction on-site (Wang and Yuan, 2008), and a lack of government rules on WM along with relatively low landfill charges in China (Yuan, 2008).

Although research on C&D WM in China has been conducted in several major cities, including Beijing, Shanghai and Shenzhen, little attention has been paid to the handling of C&D waste in other regions. This is understandable in view of China's territorial size and the fact that developed regions will show more concern for environmental issues, whilst in less developed regions, environmental protection is often low on the agenda for fear of slowing down economic growth. This regional variation means that knowledge of C&D WM developed in one region cannot be simply applied to other regions without considering their contextual differences.

The authors chose to investigate C&D WM practice in Shenzhen which is a coastal city located in southern China adjacent to Hong Kong. It was established as a Special Economic Zone (SEZ) in 1980 under China's 'open door' policy. For many years before China officially adopted a market economy, Shenzhen was the experimental zone for China's economic reforms. During the past two decades, Shenzhen's economy has developed rapidly transforming it from a small fishing village into a modern 1,952 km^2 city with a population of around 8.46 million. In 2008, Shenzhen's GDP was about 780.65 billion Yuan (US$114.30 billion) with the value of the construction sector accounting for 19.75 billion Yuan (US$2.89 billion) or 2.5% of that value (NBS, 2009).

The large-scale construction activities that have occurred in Shenzhen region over the past few years have produced an overwhelming amount of C&D waste in the region. According to the Shenzhen Environmental Department, the total volume of C&D waste generated in 2005 was around 6 million tons, which is an average of about 17,000 tons per day (Li, 2006). The way in which the city is dealing with this enormous amount of C&D waste may not provide an indication of the state of C&D WM in China. (Kang, 2005). Although the practices in Shenzhen may not be readily applied to all other regions, the knowledge developed in this city could be an important reference for effective C&D WM.

4. Research methodology

The critical success factors (CSFs) approach has been a popular technique in construction research (Sanvido et al., 1992; Shen and Liu, 2003; Aksorn and Hadikusumo, 2008; Lu et al., 2008). Rockart (1979) proposed that CSFs are ". . . for any business, the limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organization. They are the few key areas where 'things must go right' for the business to flourish." Although the definition of CSFs varies across disciplines (Ferguson and Dickinson, 1982; Boynton and Zmund, 1984; Tiong et al., 1992), Benchtell (2002) suggested that *few* and *vital* are the two key words of the CSF approach. Lu et al. (2008) argued that using CSFs is an effective method in the following two situations: (1) when the task is to make a complex system manageable by reducing the number of factors; and (2) when a large number of success factors are competing for limited resources and it is necessary to identify the vital ones that should be given more attention. Accordingly, the CSF approach was considered appropriate for investigating C&D WM in this study.

While some studies have adopted systematic procedures for the identification of CSFs (e.g. Chau et al., 1999; Shen and Liu, 2003), Lu et al. (2008) summarized the procedures for identifying CSFs into five steps: (1) identify a full set of selected success factors (SSFs); (2) conduct a survey to investigate each SSF's importance by referring to a given goal; (3) calculate each factor's importance index value based on the survey data; (4) extract CSFs from the pool of SSFs according to the value of importance index; and (5) interpret and analyze the extracted CSFs. This research followed those steps for identification of CSFs for C&D WM.

4.1. Selected success factors for C&D WM

From the body of literature covering C&D WM around the world (e.g. Esin and Cosgun, 2007; Faniran and Caban, 1998; Treloar et al., 2003; Poon et al., 2004b, c; Tam et al., 2003; Tam et al., 2007; Tam, 2008b; Kang, 2005), this study identified 13 factors for successful C&D WM

A pilot study was then carried out with eight construction professionals in order to ensure the suitability and comprehensiveness of the factors for China's construction industry. Three of the professionals were from contractors (including one C&D waste contractor), one was from a building developer, two were from on-site supervision companies, one from a government department, and one from a construction research institute. They were all carefully selected to ensure that they would reflect the views of different stakeholders and professionals involved in managing C&D waste. In addition to the 13 factors identified from the literature review, 5 additional factors were recommended by pilot study respondents. The resulting 18 factors along with their sources are shown in Table 1.

Insert Table 1 Here

4.2. Questionnaire survey

The 18 listed factors vary in their significance; they are not all critical for conducting C&D WM successfully. Also, it is possible that a factor may be critical in a certain region but not in Shenzhen, and vice versa. Critical factors should be identified and given extra consideration.

A questionnaire survey was conducted to solicit opinions of these factors. The questionnaire comprised two sections. The first section was designed to collect information about respondents, such as their position, experience, type of enterprise, etc. In the second section, respondents were invited to evaluate the 18 individual factors in terms of their importance for C&D WM. The level of importance was measured on a 5-point Likert scale, where 5 denoted extremely important, 4 important, 3 neutral, 2 unimportant, and 1 negligible. A space was provided for respondents to suggest factors that had not been covered in the questionnaire and finally respondents were asked to provide their contact information if they agreed to being interviewed. The questionnaire (written in Chinese) was piloted in March 2008, following which revisions were made to its format and the factor descriptions.

The full survey was conducted in Shenzhen over a two month period from May to

June 2008. A total of 75 questionnaires were distributed by post to the survey sample which was randomly selected from the target population of contractors, research institutions and the Construction Bureau in Shenzhen. The composition of the survey sample is shown in Figure 1.

Considering that a relatively small number of questionnaires were sent out for data collection, measures were taken to ensure a high response rate. These included phoning each person in the survey sample prior to distribution of the questionnaires in order to ask for their participation, and follow up calls to those who had not responded after one month of the questionnaires having been sent out. Initially 35 responses were received but after the follow up calls another 16 were received making a total of 51 valid responses. This number of responses reflects a response rate of 68%, which according to Moser and Kalton (1971) is considered satisfactory.

The respondents included 7 experienced project managers, 34 engineers comprising structural engineers and supervision engineers, 4 researchers, and 6 government officers. Of those, 5 project managers and 24 engineers were working for state-owned construction enterprises; 2 project managers and 10 engineers were from local private enterprises; the 4 researchers were from a local university, and the 6 government officers were mainly in charge of C&D waste disposal and landfill management.

Insert Figure 1 Here

4.3. Data processing

To evaluate the relative importance between the 18 factors listed in Table 1, an index value for each factor was calculated using the following quantitative model:

$$V_i = \frac{\sum_{j=1}^{5} M_{ij} S_j}{\sum_{j=1}^{5} M_{ij}} \qquad (i=1, 2, \ldots, 18; j=1, 2, \ldots, 5) \qquad (1)$$

Where V_i = importance level of a factor to effective C&D WM; S_j = the effectiveness rating of each factor to successful C&D WM (S_1=1, …, S_5=5); and M_{ij} = the number of respondents who chose the *j*-th effectiveness rating (S_j) for the *i*-th C&D WM factor. This equation has been widely adopted to identify the relative importance amongst variables by calculating its importance index value (Shen and Liu, 2003; Tam, 2008b).

By feeding the survey results into SPSS 15.0, the total score, mean, and standard deviation of each factor were calculated. The success factors were then ranked according to their mean score values. If two or more factors happened to have the same mean value, the one with lower standard deviation was assigned a higher rank. The ranking results are shown in Table 2. The factors with the index values that are larger than the average value of all values (3.297) are identified as the CSFs for C&D WM. The seven factors that meet this criteria are: ‘WM regulations’ (S-5), ‘Waste management system’ (S-13), ‘Awareness of C&D WM’ (S-10), ‘Low-waste construction technologies’ (S-9), ‘Fewer design changes’ (S-2), ‘Research & development in WM’ (S-15), and ‘Vocational training in WM’ (S-16). They are referred to as CSF1 to CSF7 in the following sections.

Insert Table 2 Here

4.4. In-depth interviews

This research did not rely purely on a questionnaire survey to collect data. The survey results were cross-referenced by in-depth interviews that helped to better interpret the identified CSFs. At the "questionnaire" stage, 14 respondents accepted our in-depth interviews. Amongst the 14 respondents who agreed to be interviewed, one was from the Shenzhen Construction Bureau, one from an environmental professional association, and others were from construction contractors. The interviews were conducted in July and August 2008 and each lasted about 30-45 minutes. The aim of the interviews was to gather further and more in-depth information to supplement the data gathered from the questionnaires. In order to minimize factor bias, none of the CSFs identified from the statistical analysis were revealed to the interviewees, and to ensure a common understanding among interviewees, the definition of CSFs in the context of C&D WM was clearly explained to each of them prior to the interview.

5. Analyses, discussion, and findings

5.1. CSF1 – WM regulations

It is not surprising to see that a good policy system formulated by WM regulations is ranked as the most significant success factor for conducting C&D WM in Shenzhen. This is in line with Jaillon and Poon (2008) and Karavezyris (2007) who suggested that government generally plays a crucial role in promoting C&D WM practice by enforcing policies for the whole industry. One of the purposes of the in-depth interviews conducted for our research was to arrive at a an understanding of the effectiveness of current C&D WM policies and the regulatory environment operating in Shenzhen.

Interviewees reflected that current policies for C&D WM are generally ineffective, although the promulgation of various C&D WM laws and regulations since 1990s has improved the situation. The biggest problem is that most current policies are not detailed enough for guiding and enforcing C&D WM. That the rules are too general is probably due to the relatively recent development of a modern system of law in China. Interviewees expressed the view that the Shenzhen government should implement an operable C&D WM policy to effectively guide waste sorting, reduction, reuse, recycling, and disposal. At this stage, waste managers are not able to benchmark their WM practice in line with specific norms and standards. The implication is that for the management of C&D waste to be truly regulated, regions need to develop their own detailed regulations, norms, and standards. Interviewees complained that the allocation of responsibility for C&D WM is ambiguous under current policies. Normally there are three ways to handle waste generated from a project: (a) by specialist waste contractors, (b) by the contractors themselves, and (c) by the local Environment Bureau. Since the collection and disposal of C&D waste by specialist waste contractors saves both time and cost, it is increasingly popular in Shenzhen. After C&D waste has been transported off a construction site, the contractor rarely cares about its destination. Consequently, interviewees claimed that there is extensive illegal dumping of C&D waste in Shenzhen. More specific policies, such as the “trip-ticket” system implemented in Hong Kong, should be adopted to clearly specify the responsibilities of involved stakeholders and prevent illegal dumping in China.

Imposing charges for C&D waste dumping under the "Polluter-Pays-Principle" is generally considered to be an effective measure for reducing waste (Tam, 2008b). Although this policy has been implemented in Shenzhen, the charge for dumping into landfills there is significantly less than it is in other jurisdictions. For example, in 2008 the charge in Shenzhen was RMB5.88 (US$0.86) per ton (Yuan, 2008) as compared to HK$125 (US$16.13) per ton in Hong Kong (Yuan, 2008; Hao et al., 2008). A questionnaire conducted by Yuan and Hao (2008) revealed that when the rate rises to RMB80-100 (US$11.68-US$14.60) per ton, more than 90% of respondents are willing to reduce C&D waste by methods other than dumping directly into landfills. Experiences in other regions have shown that market-based instruments, such as incentive or waste charging schemes, are more effective in managing C&D WM (Duran et al., 2006; Craighill and Powell, 1999). This implies that more research should be conducted to devise an effective landfill charge for reducing the generation of C&D waste.

5.2. CSF2 - Waste management system (WMS)

The establishment of a C&D WMS is ranked as the 2nd CSF for C&D WM in Shenzhen. As a clear definition of the term WMS appears to be absent in the literature, the working definition for this research was taken from the following definition of a Environment Management System (EMS) as stated in ISO 14000: ***an overall management system which includes organization structure, plan responsibilities, practices, procedures, processes and resources for managing C&D waste.*** It formulates an internal system for contractors to conduct C&D WM. Given that C&D

waste is one of the major pollutants of the environment, a WMS for construction can be considered as a sub-system of a EMS.

Although most big construction companies in Shenzhen have obtained ISO 14001 certification in order to meet project tendering criteria or achieve environmental excellence, our interviewees suggested that the WMSs in Shenzhen are not sufficiently developed for successful C&D WM. They claimed that there are no systematic approaches within companies, such as the allocation of resources for C&D WM; temporary arrangements will be made only when C&D waste issues emerge. In 2003, the authors of this paper helped a top construction company in Shenzhen to obtain ISO 14000 accreditation but in 2008 when we conducted interviews for this study, its CEO admitted that "there was no systematic measure to manage C&D waste in the company." This in accord with Shen et al. (2006) who reported that Chinese contractors place the environment as the least important, behind cost, time, quality, and safety. It is also in accordance with prevailing C&D WM practice that is by and large a remedial measure. Without waste control plans, C&D WM is only conducted after its generation, or when complaints are received.

The interviewees emphasized the importance of a waste management plan (WMP), which has already been implemented in Hong Kong. According to Poon et al. (2001), effective on-site WM usually involves scheduling the waste clearance, arranging collection, and scheming removal to appropriate disposal sites. All this can be developed in a pre-arranged WMP by project managers. The plan should clarify the possible WM issues and actions in advance, for example, waste streams being encountered, necessary resources and suitable scheme for dealing with possible waste problems, and selected waste disposal sites. The most important step for developing a WMS is to encourage the development of a C&D WMP for construction projects.

5.3. CSF3 - Awareness of C&D WM

Awareness of C&D WM is ranked as the 3rd CSF amongst the 18 factors. This resonates with the studies which have pointed out that the practitioners' awareness of resource saving and environment protection is a vital driver for C&D waste minimization (Osmani et al., 2008; Yuan, 2008). Nonetheless, during the interviews, we observed that both managers and constructors have little awareness of saving resources and protecting the environment through WM. Interviewees perceived that conducting C&D WM usually means increased project costs and therefore a reduction of company profits. They made it very clear that they care more about cost, time, and the quality specified in the contract than C&D waste reduction.

The development of C&D WM awareness is a lengthy process that requires vocational training and education for practitioners. Our research shows that C&D WM is incorporated in many training courses provided by universities, research institutions, and government departments. In addition, interviewees suggested that a change of the current C&D WM mindset can be enhanced by the enforcement of government policies, the development of C&D WM systems within companies, and recognition of the importance of WM by clients and the general public.

The authors of this paper suggest that raising C&D WM awareness will be more effective if economic concerns can be recognized in developing regions. The economy is often high on the agenda of these local governments and they believe that environmental protection will slow down economic development. Conversely, research in other regions shows that good WM through reducing, reusing, and recycling does not necessarily add to project costs (Tam, 2008). In developing economies, it might be more effective to provide companies with solid evidences of the benefits and cost savings of C&D WM.

5.4. CSF4 - Low-waste construction technologies

Interviewees suggested that low-waste construction technologies could help reduce, reuse, or recycle C&D waste. Such technologies include prefabrication, innovative formwork and falsework, and low-waste structures. These have been explored in Hong Kong and can therefore provide a useful reference for investigating low-waste construction technologies in Shenzhen as an adjacent city.

Prefabrication is viewed as a building technology that contributes significantly to the reduction of construction waste (e.g. Tam et al., 2003; Wang et al, 2008; Poon, 2007; Jaillon and Poon, 2008). Although the prefabrication factories providing components for Hong Kong are located in Shenzhen due to its relatively low material and labor costs, prefabrication is not widely used in Shenzhen. From the interviews it is apparent that the obstacles for adopting prefabrication in Shenzhen typically include inadequate techniques for handling current prefabricated components, higher costs, the difficulty of accepting prefabrication in Shenzhen’s construction sector, and insufficient incentives from government departments. Interviewees were in agreement that conventional in-situ construction is still the preferable technique in Shenzhen.

Formwork and falsework that are mainly used in conventional construction account for a large proportion of construction waste. Poon (2007) reported that timber formwork constitutes 30% of the waste generated on-site in Hong Kong and the results of survey conducted for this research revealed that Shenzhen is faced with similar problems. Timber formwork can only be used for at most 6-7 times, which results in large amount of timber waste as well as the extra cost of buying new formwork. Although the use of metal formwork can minimize on-site construction waste, it will increase the capital cost of a project.

Other low-waste construction technologies recommended are adopting steel structure, using dry-wall instead of traditional structural walls, reusing concrete for pavements, and using bulk cement. The use of bulk cement is recommended because packaging is a major contributor to waste in the construction industry. Waste from the packaging of construction materials is first generated at the beginning of the construction process and the amount increases as the project progresses. It has been reported that approximately 5% of package cement waste is caused by broken bags together with cement left behind in the packages. Currently the rate of bulk cement in China is only about 24%, which is so much lower than the 70% in some Western countries (Jiang, 2003).

This CSF resonates with a study conducted by the authors that investigated the waste generation rate (WGR) in four on-going high-rise projects in Shenzhen (Lu et al., 2009). The research derived a WGR of 3.275-8.791 kg/m^2. The three major causes of the WGR were found to be concrete, timber, and miscellaneous brick and mortar, which are all heavily related to high-waste building technologies. It is suggested that low-waste building technologies which have been experimented with in Hong Kong and

Japan should be promoted in Shenzhen as a part of C&D WM practice.

5.5. CSF5 - Fewer design changes

A change of design in a construction project is acceptable for correcting design defects, for adding value to clients, or for meeting new design specifications. However, in order to meet the requirements of high-speed development in Shenzhen, the design of a construction project is hastily implemented without sufficient time to scrutinize it closely. According to Zhu (2009), this practice can be traced back to the 1950s when the People Republic of China (PRC) was founded and the Top Ten Beijing Buildings program was launched; even the design of the Great Hall of the People had not been completed when construction commenced. Some interviewees suggested that another reason for too many design changes during construction is that clients usually fail to conduct a sufficiently thorough market analysis before investing in a project. A quick design and insufficient market investigation often leads to design changes at the construction stage, which in turn can lead to cost overruns and more C&D waste. Constructive suggestions for reducing design alterations were provided by some of the interviewees, such as sufficient development of the feasibility study, enhancing design management, better coordination among all designers, close communication between designers and contractors, and reducing the gap between “what is wanted, “what is designed” and “what is built.”

5.6. CSF6 – Research & development in WM

Identification of research and development (R&D) as a CSF for conducting C&D

WM resonates with research by by Weng and Liu (2008) and Yuan (2008) suggesting that R&D can provide guidelines and technical support for waste reduction, reuse, recycling and disposal. An academic interviewee reported that there is a lack of reliable statistics (e.g. waste rate and the total amount of C&D waste produced annually) for understanding the status quo of C&D WM in Shenzhen.

Interviewees indicated that R&D should focus on the following: (1) government policies; (2) effective WMS within companies; and (3) waste management technologies. Interviewees also strongly suggested that government should take a leading role in promoting R&D on WM. Without a strong lead by government, other parties such as clients and contractors might not bother to conduct C&D WM. Universities and research institutes should work closely with government and other stakeholders of C&D WM, to develop, and more importantly, to promote effective WM practices and new WM technologies. An important point made by interviewees was that the relevant parties in Shenzhen can collaborate with their counterparts in Hong Kong, where knowledge of C&D WM has been better developed through extensive R&D.

5.7. CSF7 - Vocational training in WM

In support of this CSF, other studies have also revealed that the skill-level of construction workers has a major influence on C&D waste generation (Tam and Tam, 2008; Yuan, 2008). Activities such as constructing formwork, plastering, and handling deliveries will cause large amounts of waste if the workers involved are unskilled (Wang et al., 2008). Most workers in the construction industry in China are from rural areas. They are essentially farmers with limited skills who have not been trained sufficiently before starting work on construction projects. Findings from our research indicate that the training time for most construction workers is less than one week. Interviewees suggested that the training time for construction workers should be substantially increased. Figure 2 shows the current and expected training time for construction workers, and that most respondents consider a reasonable training time to be at least one month.

Insert Figure 2 Here

Currently, vocational training is mainly conducted by training organizations accredited by the Shenzhen Construction Bureau. The training programmes mainly cover construction project management, construction techniques, construction materials, on-site construction supervision, engineering evaluation, and construction safety. It was suggested by our interviewees that sustainable development and C&D WM skills should be added to the training programmes.

6. Conclusions

Managing C&D waste is high on the agenda for reducing the negative impact of construction on China's environment. Through a series of analytical processes, this research identified 7 CSFs for conducting C&D WM in Shenzhen, China. They are: (1) WM regulations, (2) waste management system (WMS), (3) awareness of C&D WM, (4) low-waste building technologies, (5) fewer design changes, (6) R&D, and (7) vocational training. The identification of CSFs reduces the complex nature of C&D WM into manageable but critical factors that need to be taken into consideration when devising successful C&D WM strategies for Shenzhen. The CSFs represent state-of-the-art WM practice in China. Some factors, such as WMS, awareness of C&D WM, and R&D, are applicable to other cities and regions in China, while other factors are unique to Shenzhen, such as WM regulations, low-waste building technologies, design changes, and vocational training. The dilemma in relation to C&D WM in Shenzhen is caused by the requirements of fast economic development and the need to pay more attention to C&D waste that is perceived to negatively impact such development. Findings from this research suggest that in order to foster greater acceptance of C&D WM, it will be necessary to show that it does not necessarily undermine economic development. It was also found that activities that are conducted in haste, such as fast-track design and insufficient training for labor do not necessarily help companies to keep up with the fast pace of development. On the contrary, they can lead to budget and time overruns, low quality, and bad environmental performance.

It should be remembered that the CSFs in this study were identified within the context of Shenzhen's construction industry and that China is a large country with many different regions and levels of economic development. The CSFs cannot therefore simply be applied to other parts of China without considering the regional variations. However, further research could be conducted to investigate C&D WM problems in different regions by using the CSFs as a reference. The CSFs could also be used as a reference to conduct research in other fast-developing economies, such as India and Brazil, with the aim of helping those countries reduce the negative impact of C&D activities on their environments.

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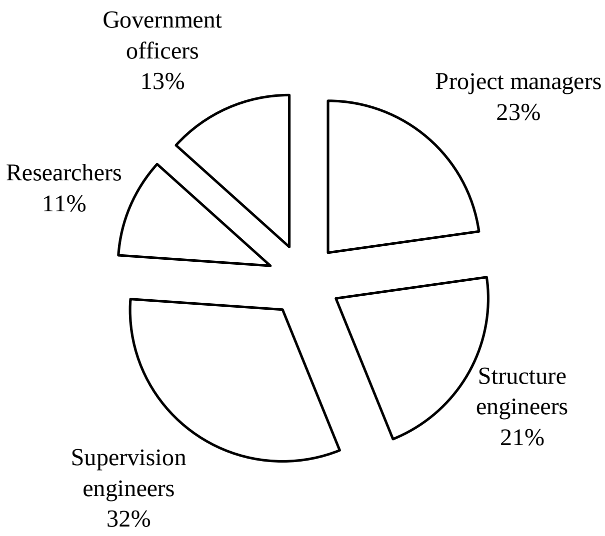

Figure 1 A demography of respondents in the questionnaire

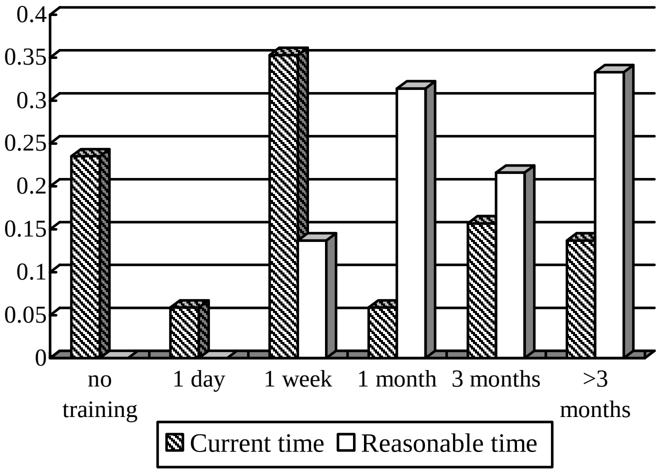

Figure 2 Vocational training time for construction workers

Table 1 Tentative success factors for C&D WM.

No.	Factors for C&D WM	Sources
S-1	Material usage and storage system	Faniran and Caban, 1998; Poon et al., 2004b.
S-2	Fewer design changes	Faniran and Caban, 1998; Poon et al., 2004b.
S-3	Improving communication amongst project participants	Faniran and Caban, 1998.
S-4	Lifecycle waste management	Faniran and Caban, 1998; Poon, 2007.
S-5	WM regulations	Faniran and Caban, 1998.
S-6	C&D waste recycling and reuse	Esin and Cosgun, 2007; Tam, 2008b; Poon, 2007; Poon et al., 2004b; Eikelboom et al., 2001.
S-7	On-site C&D waste supervision system	Tam, 2008b; Peng et al., 1997.
S-8	On-site C&D waste sorting	Tam, 2008b; Poon et al., 2004b, c; McGrath, 2001.
S-9	Low-waste construction technologies	Hao et al., 2008; Tam, 2008b; Poon et al., 2004c; McDonald and Smithers, 1998.
S-10	Awareness of C&D WM	Poon, 2007; Tam et al., 2007; Tam, 2008b; Treloar et al., 2003.
S-11	Improving conventional construction process	Tam, 2008b; Poon et al., 2004b; Wong and Yip, 2004.
S-12	Environmental management system	Poon et al., 2004c;
S-13	Waste management system (WMS)	Rodriguez et al., 2007; Treloar et al., 2003.
S-14	Housing industrialization programme	From pilot study
S-15	Research & Development in WM	
S-16	Vocational training in WM	
S-17	Measuring C&D WM	
S-18	Taking WM into consideration in bidding and tendering	

Table 2 Rank of factors for the successful C&D waste management

No.	Factors for C&D WM	Vi	Standard deviation	Rank	
S-5	WM regulations	3.745	0.32	1	CSF1
S-13	Waste management system (WMS)	3.745	0.54	2	CSF2
S-10	Awareness of C&D WM	3.529	0.45	3	CSF3
S-9	Low-waste construction technologies	3.510	0.84	4	CSF4
S-2	Fewer design changes	3.471	0.73	5	CSF5
S-15	Research & Development in WM	3.451	0.67	6	CSF6
S-16	Vocational training in WM	3.412	0.78	7	CSF7
S-14	Housing industrialization programme	3.294	0.90	8	
S-1	Material usage and storage system	3.270	0.82	9	
S-17	Measuring C&D WM	3.268	0.69	10	
S-11	Improving conventional construction process	3.196	0.37	11	
S-7	On-site C&D waste supervision system	3.196	0.59	12	
S-6	C&D waste recycling and reuse	3.176	0.66	13	
S-3	Improving communication amongst project participants	3.157	0.72	14	
S-4	Lifecycle waste management	3.039	0.78	15	
S-12	Environmental management system	3.000	0.53	16	
S-8	On-site C&D waste sorting	3.000	0.62	17	
S-18	Taking WM into consideration in bidding and tendering	2.882	0.39	18	