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Critical factors in effective construction waste minimization at the design stage: A Shenzhen case study, China

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ABSTRACT

Construction waste minimization at the design stage is a key strategy in effective waste reduction. However, it seems that few studies focus on exploratory factors that can significantly improve the design of construction waste minimization. This paper addresses this research gap by presenting a set of critical factors that inform and improve the practice of waste minimization design, particularly in the context of Shenzhen, China. Nineteen potential factors which can influence effective waste minimization are presented based on related official guidelines, reports and literature. Top institutions in Shenzhen that have received a Grade A building design certification were surveyed through a questionnaire. From this survey, six critical factors are derived: (1) large-panel metal formworks, (2) prefabricated components, (3) fewer design modifications, (4) modular design, (5) waste reduction investment and (6) economic incentive. The applicability and significance of the identified critical factors for effectively designing waste minimization are also explored. These critical factors not only provide designers and project managers with a useful set of criteria for effective design strategies to reduce construction waste, but also serve as valuable references for the government to formulate related construction waste minimization regulations.

1. Introduction

Continuous development and urbanization of an old town inevitably generates a large amount of construction waste from construction and demolition activities. Such waste has a serious effect on human life. For instance, in China, annual construction waste accounts for about 40% of the total municipal waste (Li, 2007), that is, more than 200 million tons, of which 100 million tons are generated from new buildings (Huang and Xu, 2011). Construction waste represents a large amount of construction material, which is a waste of valuable natural resources. Moreover, it occupies a large landfill area, which further diminishes scarce land resources. It also contains toxic substances that endanger human health and the surrounding environment (Li and Xu, 2007).

One of the best way to reduce the impact of waste on the environment is simply to avoid producing waste (Ekanayake and Ofori, 2004; Yuan and Shen, 2011). Among the solutions, implementing construction waste minimization at the design stage is commonly identified as a key strategy in effective waste minimization (Baldwin et al., 2009), as this solution entails the consideration of every single detail of the overall construction project ahead of operation, which therefore prevents unnecessary material waste. In line with the construction waste minimization strategies at the design stage proposed by Housing and Construction Bureau of Shenzhen (2011), many local design institutions have taken actions to implement their strategies in the past several years. Practical experience shows that no guidance is available as effective instructions and development of related design strategies to reduce construction waste at the design stage. To address such practical needs, this study aims to identify a set of critical factors that can significantly influence the effectiveness of construction waste minimization at the design stage from a holistic perspective that spans architectural technologies, architectural design, external mechanism and aspects of the designer's capacity and attitude.

These critical factors are identified based on certain urbanization development practices in Shenzhen City, China. Shenzhen is a major city in the south of Southern China's Guangdong Province, situated immediately north of Hong Kong, covering an area of about 2050 km^2 including urban and rural areas, with a total population of approximately 14 million in 2008. In 2012, the Chinese National Housing and Urban–Rural Ministry listed Shenzhen as the national pilot city for construction waste minimization and comprehensive utilization. Shenzhen is the first city to implement various construction waste minimization-related design guidelines which require modular design and awareness of dimensional coordination and standardization, (Housing and Construction Bureau of Shenzhen, 2011). Shenzhen is also the first city to closely cooperate with typical construction waste utilization institutions. In this

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regard, Shenzhen is a typical microcosm of China if we focus on construction waste reduction-related issues, that is, if Shenzhen succeeds in exploring a new path to effective construction waste minimization at the design stage, it may be used as a representative model which significantly drives national reform.

2. Construction waste minimization at the design stage

Construction waste minimization at the design phase minimizes waste generation in the construction process by refining architectural design with the use of advanced architectural technologies and reclaimed materials, thereby achieving resource conservation and environmental protection (Kun and Hong, 2010). Many researchers have argued that a large amount of construction waste is generated because of inappropriate consideration in the design phase (Ekanayake and Ofori, 2004; Kulathunga et al., 2006; Baldwin et al., 2009). According to a case study published in (Tam et al., 2007b), waste generation can be reduced by up to 100% by adapting prefabrication, which can save up to 84.7% of wastage. This strategy compels construction waste designers to consider waste reduction early in the design stage and throughout the design of construction projects (Baldwin et al., 2009).

Previous research on construction waste minimization at the design stage mainly involves four components: (i) reasons for construction waste generation at the design stage, including provisional design change as a result of customers' request, designer's lack of experience, increased construction design requirements, lack of necessary design information, inability to foresee actual construction conditions, and policy change (Bossink and Brouwers, 1996; Faniran and Caban, 1998; Keys et al., 2000; Yucesan et al., 2002; Ekanayake and Ofori, 2004; Poon et al., 2004); (ii) applications of new architectural technologies and methods of construction waste reduction in the design phase, including the optimization of building design life to delay demolition waste, reduction of material loss by reasonable procurement planning, dimensional coordination and standardization, applications of low-waste construction technologies, and avoidance of late design modifications (Cheung, 1993; Moore, 1994; Ekanayake and Ofori, 2004; Batayneh and Asi, 2007; Tam et al., 2007a; Baldwin et al., 2009); (iii) architect's attitude toward construction waste minimization (Turner, 1991; Faniran and Caban, 1998; Lingard et al., 2000; Teo and Loosemore, 2001; Poon et al., 2004; Kulathunga et al., 2006) and (iv) obstructive factors in the implementation of construction waste reduction in the design stage (Poon et al., 2001b; Osmani et al., 2008a; Zhang et al., 2012b).

The references above show contributions of various studies to the overall body of knowledge on construction waste minimization at the design stage. They also show that limited attention has been given to the identification of critical factors which influence the implementation of effective design for construction waste reduction. As effective design is, to a large extent, influenced and determined by many variables involved in design practice, identifying variables that are potentially significant to construction waste minimization at the design stage is vitally important before architects and policymakers can understand how to implement efficient waste reduction measures in the early stages of a project.

3. Research methodology

A hybrid research methodology is applied to identify a set of significant factors in construction waste minimization design. A preliminary list of factors from the literature is presented through semi-structured interviews with invited researchers and industry practitioners who were asked to provide their comments. The final list of optional variables is obtained from these interviews.

A questionnaire is designed for and answered by consulting professionals to determine the soundness and significance of each optional variable. Professionals are invited to rank the significance of each factor based on a five-point Likert scale, with 5 indicating the most significant and 1 indicating the least significant. Through a calculation of the mean importance ratings based on the data obtained from the survey, a statistical test of the mean for each variable is conducted to determine if the variable is significant or not. In-depth interviews are conducted to gather further information to supplement the data gathered from the questionnaires.

3.1. Identifying factors in effective construction waste minimization

Twenty factors in construction waste minimization at the design stage were identified through an intensive literature review using important databases such as Scopus, ABI, EI compendexWeb and ISI Web of Knowledge. To ensure the adequacy and comprehensiveness of these variables, nine construction design professionals from Shenzhen were invited for a preliminary study that consists of semi-structured interviews. The five respondents were two architects, two mechanical designers and one professor in architecture. These professionals were carefully selected who have had at least 20 years of experience in the construction industry, which ensures valuable discussions on the identification of a list of variables. After removing one controversial factor, 19 preliminary factors were determined. The resulting factors along with their sources are shown in Table 1.

3.2. Questionnaire survey

The initially identified 19 factors vary in their significance. Not all of them may be critical in effective construction waste minimization design. Therefore, a questionnaire is designed based on the list above to determine the adequacy and significance of each factor. In this study, the questionnaire is adopted as an appropriate quantitative data collection method. This method has been widely used in previous studies to derive critical success factors in different contexts and can also reach a broader group of respondents (Lu and Yuan, 2010; Wang et al., 2010; Shen et al., 2012).

Construction waste minimization at the design stage is a relatively new concept. Ordinary design institutions may not have much experience in relation to this context. As such, the main participants selected for the survey come from top companies whose buildings have been awarded a Grade A building design certification. They were invited to rank the significance of each variable under five categories, namely, architectural technologies, architectural design, external mechanism, designer's capacity and designer's behavior and attitude, on a five-point Likert scale, with 5 indicating the most significant and 1 indicating the least significant. Likert scales are widely used and considered suitable to measure the importance of factors (Wang et al., 2010). The respondents were provided space to suggest factors that were not covered in the questionnaire. They were also asked to provide their contact information if they agreed to being interviewed.

The full survey was conducted in Shenzhen over a one-month period from June to July 2012. A total of 142 copies of the questionnaire, along with small gifts, were distributed by a survey team of four graduate students. Of this total, 86 responses were received, which indicates a response rate of 60.6%. The questionnaire respondents include structural designers (about 32%), architects (about 50%), mechanical designers (about 13%), and related project managers (about 5%). Most of them received university or higher education (about 83%) and have more than five years of working experience (about 75%). Overall, the selected subjects possess profound professional knowledge and rich construction design