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Sustainable performance criteria for construction method selection in concrete buildings

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ABSTRACT

The use of prefabrication offers significant advantages, yet appropriate criteria for applicability assessments to a given building have been found to be deficient. Decisions to use prefabrication are still largely based on anecdotal evidence or simply cost-based evaluation when comparing various construction methods. Holistic criteria are needed to assist with the selection of an appropriate construction method in concrete buildings during early project stages. Following a thorough literature review and comprehensive comparisons between prefabrication and on-site construction method, a total of 33 sustainable performance criteria (SPC) based on the triple bottom line and the requirements of different project stakeholders were identified. A survey of U.S. experienced practitioners including clients/developers, engineers, contractors, and precast concrete manufacturers was conducted to capture their perceptions on the importance of the criteria. The ranking analysis of survey results shows that social awareness and environmental concerns were considered as increasingly important in construction method selections. Factor analysis reveals that these SPCs can be grouped into seven dimensions, namely, economic factors: "long-term cost," "constructability," "quality," and "first cost"; social factors: "impact on health and community," "architectural impact"; and environmental factor: "environmental impact." The resultant list of SPCs provides team members a new way to select a construction method, thereby facilitating the sustainable development of built environment.

1. Introduction

With heightened awareness of environmental pollution, natural resource depletion and accompanying social problems, sustainable development and sustainable construction have become a growing concern throughout the world. Buildings are one of the heaviest consumers of natural resources and account for a significant portion of the greenhouse gas emissions. In the U.S., buildings account for 38.9% of primary energy use, 38% of all carbon dioxide emissions, and 30% of waste output [1]. Conventional on-site construction methods have long been criticized for low productivity, poor quality and safety records, long construction time, and large quantities of waste in the industry.

Prefabrication is a manufacturing process, generally taking place at a specialized facility, with which various materials are joined to form a component part of the final installation [2]. Several benefits of applying prefabrication technology in construction were commonly discussed in previous literature [3–15], including: shortened construction time, lower overall construction cost, improved quality, enhanced durability, better architectural appearance, enhanced occupational health and safety, material conservation, less construction site waste, less environmental emissions, and reduction of energy and water consumption. These advantages provide opportunities for prefabrication to better serve sustainable building projects. Worldwide, the highest precast levels in 1996 were located in Denmark (43%), the Netherlands (40%), Sweden and Germany (31%) [16]. In the United States, the share of reinforced concrete construction supplied by precast producers is only 6% while the average across the European Union is 18% [8]. Although the U.S. precast concrete industry produces technologically and architecturally complex buildings and building elements, such as double tees, hollow-core slab elements, inverted tee and ledger beams, and facade panels, in building construction market, the percentage of precast concrete systems is pretty low (approximately 1.2%) [7,8]. It is more urgent to address prefabrication issues in concrete buildings while achieving sustainable construction in the United States.

Pasquire and Connolly demonstrated that decisions to use prefabrication are still largely based on anecdotal evidence rather than rigorous data, as no formal measurement criteria or strategies are available [17]. Blismas et al. also indicated that holistic and methodical assessments of the prefabrication applicability to a particular project

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have been found to be deficient, and common methods of evaluation simply take material, labor and transportation costs into account when comparing various construction methods, without explicit regard for the long-term cost or soft issues, such as life cycle cost, health and safety, effects on energy consumption, and environmental impact of a project [10]. Additionally, for individual building projects, prefabrication technology is not always the only available option, nor is it always better than on-site construction method due to various project characteristics and available resources. If not employed appropriately, change orders, severe delays in production, erection schedules, substantial cost overruns, and constructability problems may be encountered in the use of precast concrete systems. All of these demonstrate that criteria for decisions regarding construction methods are unclear and unrecorded. There is a need to establish holistic criteria to select an appropriate construction method and stimulate the suitable use of prefabrication for a given building project.

In this research, two prominent methods in building construction are reviewed and discussed: the conventional on-site reinforced concrete construction method, and the precast concrete building method. In the sections that follow, the former method is referred as the 'on-site' construction method, and the latter the 'prefabrication' method. The main objective of the research was to develop a holistic sustainable performance criteria (SPC) set to assist design team members in the selection of appropriate construction methods in concrete buildings during early project stages. These criteria enable applications of IT to support and automate the complex considerations of prefabrication on concrete building projects. As a result, the likelihood of sustainable construction is enhanced, both to meet society's environmental goals and account for the social and economic impacts of the project.

2. Research methodology

Methodology selected for this research comprised of a questionnaire design, a questionnaire survey and interviews of the U.S. construction industry practitioners, and a statistical analysis of the survey data. Fig. 1 illustrates the methodology for the research.

2.1. Questionnaire design

A wide scope review of literature revealed that there was no comprehensive list of performance criteria developed specifically for construction method selection in concrete buildings. To compile a meaningful list of criteria, several researches in related areas were conducted. To ensure that prefabrication and on-site construction method are clearly distinguishable by the selected criteria, the comparison between the two methods was thoroughly explored. Combined with sustainable concerns and requirements of project stakeholders on construction method selection, a list of initial criteria was developed.

Based on the derived criteria, an industry questionnaire survey was designed by Adobe Livecycle Designer, which enables user to create dynamic and interactive forms that are filled out on a computer. The survey, which consisted of two main parts, aims at investigating the perspective of the construction industry on the importance of the criteria. Part one sought background information about the respondents and their organizations, such as the experience of the respondent in the construction industry, and the number of projects using prefabrication the respondent has been involved in. In part two, respondents were asked to rate the level of importance of the derived criteria based on a scale of 1–5, where 1 is 'least important', 2 'fairly important', 3 'important', 4 'very important', and 5 'extremely important'. To ensure a better understanding of the criteria, definition of each criterion was clarified and guidance on completion was given in the questionnaire. At the same time, respondents were encouraged to provide supplementary criteria that they consider to influence construction method selections but were not listed in the provided questionnaire (refer to Appendix A for questionnaire details).

2.2. Questionnaire survey

A pilot survey was conducted with experienced contractors and engineers to validate the final questionnaire. The questionnaire was then administered by email to 412 selected industry practitioners within the U.S. construction industry who are primary participants in the precast concrete supply chain, including construction clients/ developers, engineers, contractors, and precast concrete manufacturers. All of them have different opinions and focus on construction method selection. Obtaining views from the four categories ensures a holistic criteria set for construction method selection.

Survey questionnaires were emailed to 84 construction clients/ developers, 71 engineers, 145 contractors, and 112 precast concrete manufactures in the United States. The email addresses of precast manufactures were obtained from the PCI's (Precast/Prestressed Concrete Institute) Membership Directory [18] and NPCA's (National Precast Concrete Association) Membership Directory [19] by selecting manufacturers who produce architectural precast units, such as architectural beams, facades, slabs, and stairs. Contact information for the construction clients/developers, engineers, and contractors were obtained from the Partnership for Achieving Construction Excellence (PACE) database. PACE is based in the Department of Architectural Engineering at The Pennsylvania State University and is a working partnership between Penn State students, faculty, and building industry practitioners. The developers, engineers, and contractors for the survey were selected from those who had worked on building projects and also had experience in prefabrication.

To gain further understanding of the survey results, five selected respondents who had rich experience in concrete prefabrication and construction method selection process were interviewed after returning survey responses. Specifically, they were asked how they considered their selections, such as why some criteria are less or more important than others etc.

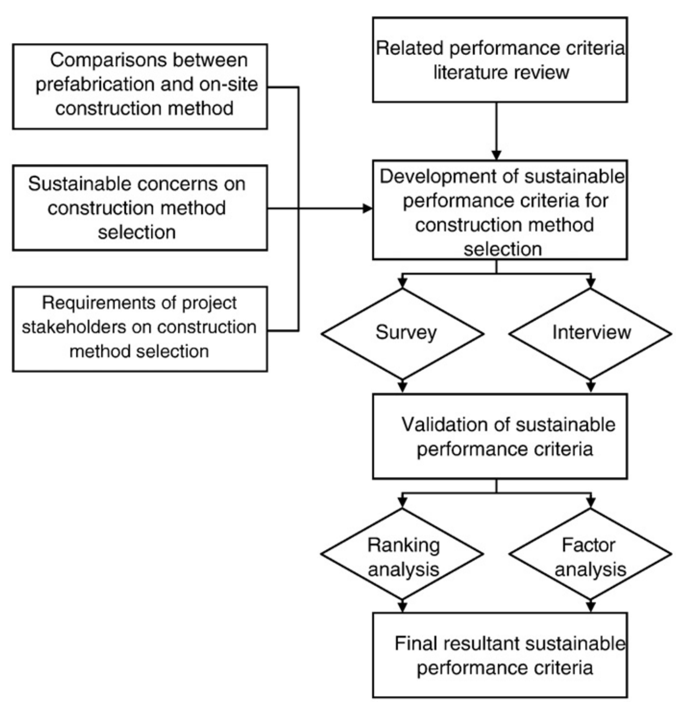

Fig. 1. Research framework and methodology.