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A Multi-Dimensional Subcontractor Evaluation Framework for Nonconventional Housing Systems

Riddha Basu[a]*, VPS Nihar Nanyam[a], Anil Sawhney[b]

[a]*RICS School of Built Environment, Amity University, Sector 126, Noida, India*
[b]*Department of Built Environment, Liverpool John Moores University, Liverpool, UK*

Abstract

For any building construction project, it is crucial at the outset to select an appropriate subcontractor to achieve the objectives in terms of affordability and quality. But selection of a competent subcontractor becomes even more important when it comes to housing-construction with non-conventional materials and technologies, as their implementation requires unique skills and proficiencies. In the first phase of this research, the subcontractor selection attributes were identified. Apart from literature review, divergent stakeholders of Indian real-estate value-chain were also surveyed for identification of subcontractor selection attributes. While some of the identified attributes are generic, others are specific towards selection of subcontractors for building construction with new materials and technologies. However, the identified attributes can be broadly classified into five categories: "*technical experience", "financial competency", "resource adequacy", "job quality and safety"* and "*local and other factors"*. In the next phase of the research, a multidimensional framework was developed using Analytical Hierarchy Process (AHP) for evaluation of subcontractors based on the identified attributes. The developed framework can also be used as a decision making protocol for selection of subcontractors for non-conventional building construction. The developed framework was validated by implementing it for subcontractor selection in a residential project site where emerging construction technologies were being implemented.

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Keywords: analytical-hierarchy-process; emerging-housing-technologies; multi-dimensional-evaluation-framework; subcontractor-selection;

1. Introduction

Rapid expansion of urban areas leading to the subsequent growth of economic base has created new prospects for Indian real-estate sector. A recent study by KPMG suggests that nearly 18.9 million housing units are required to be

* Corresponding author. Tel.: +91 120 667 3064; fax: +91 120 667 3050.
E-mail address: rbasu@rics.org

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constructed in urban India [1]. By 2022, the need for urban housing units will further increase by 26 to 29 million [2]. Evidently, provision of houses to urban population has become both a great opportunity and a critical challenge in India. But Indian housing value chain is quite complex. Over the last few decades, housing construction philosophy in India has changed radically. In modern Indian cities, tall buildings have supplanted individual villas and row-housings. Today, both government and private housing initiatives focus more on construction of mass housings rather than catering to individual dwelling units. To strike a balance between speed and quality, building constructors must take resort to non-conventional materials and innovative technologies (like rapid wall system, speed floor system, monolithic concrete construction with aluminum formwork, light gauge steel frame structure, modular coordination, prefab-construction etc.) as viable and cost-effective alternatives of conventional building techniques.

But unfortunately while there is no dearth in availability of alternate building systems, in India their adoption remains still low. One of the key reasons behind this is the risk of failure associated with the implementation of these technologies. Like all other construction projects, building construction projects are also labor intensive. About 90% of the total project value is executed by outsourcing in construction projects [3]. So the implementation of any building system (both conventional and emerging) largely depends upon the skills and efficiency of the labor involved in its implementation. So it is axiomatic that selection of an appropriate subcontractor is of utmost importance for successful completion of any building project in terms of time, cost, quality and safety. But selection of a competent subcontractor becomes even more important when it comes to implementation of innovative and alternate building systems as it involves unique skills and proficiencies. In other words, potential savings in time and cost, or the enhanced construction quality expected from the emerging/ alternate building systems can only be realized when competent subcontractors are engaged in their implementation.

However, still now in India evaluation of the subcontractors (especially labor contractors) is done in a subjective and rather intuitive way. In many organizations the work contract is awarded primarily based upon the financial quotation of the subcontractor. Other factors like technical experience, adequacy of resources required or the quality of work that the subcontractor is capable of rendering, are often not taken into account or given very less importance in the time of decision making. Consequently many projects fail to realize the fullest benefit of the building construction systems they adopt. Driven by the motive of rationalizing subcontractor-selection-process for non-conventional building systems, this research work aims at developing a holistic framework for evaluation of building subcontractors.

2. Literature Review

Researchers across the globe have extensively worked on rationalizing the evaluation and selection procedure of subcontractors. Almost all the previous researchers have tried to capture the dynamics in subcontractor selection process by identifyting the factors that should be taken into account for evaluation of subcontractors. Marzouk et. al. identified forty attributes that should be considered for selection of suppliers and subcontractors [4]. They categoried these attributes in ten principal factors: *time, cost, quality, safety, tender, dispute and risk, insurrance, repair and warrantry for employees and equipment, experience of the company, staff's behaviour and experience* and *others* (like site proximity, ongoing work committement, relationship with client etc.). In a study conducted in Singapore, Hartmann et al. found that out of the four major factors of subcontractor selection, *namely price, technical knowhow, quality* and *cooperation*, the most important factor is *price*. But it is usually accepted that both *price* and *quality* should be taken into account for selection of subcontractors [5]. Based upon these attributes, many researchers have already developed quantitative decision support systems for increasing the objectivity in the subcontractor selection process. To name a few, Fong and Choi developed a model using the Analytical Hierarchy Process (AHP) with a view to establish a trade-off between time, cost and quality while selecting the subcontractors [6]. Yin et al. applied a data envelopment analysis for the evaluation of subcontractors [7]. Abbasianjahromi et al. developed a model which calculates a parameter called FPSI (Fuzzy Preference Selection Index) for selection of subcontractors [8]. But as suggested by Lavelle et. al. the selection procedure for subcontractor's, in terms of both the selection criteria and their weightages, varies largely with the project dynamics [9]. For instance, in their study Oluwaseyi et. al. suggested that in building construction projects of Lagos state, Nigeria availability of required equipment is a major factor for

evaluation of subcontrctors [10]. However this might not be true for Indian building projects where major construction equipment are either provided by the main contractor or rented. Cleary despite the availability of a plethora of subcontractor selection models, there still remains the need to develop a framework which is particularly suitable for evaluation and selection of subcontractors for residential building construction in India with non-conventional and alternative building sytems.

3. Research Outline

The over-arching goal of this research work is to rationalize the selection protocol of subcontractors for residential construction in India with nonconventional and alternative building-systems. In order to achieve this objective a quantitative framework has been developed for the evaluation of subcontractors.

The methodology adopted for development of the proposed framework is illustrated in the research outline shown in figure 1. The first step towards developing the framework was to identify the factors that should be taken into considerations for evaluation of subcontractors. For this, an advisory committee was established with members representing various stakeholders of Indian housing value-chain. The preliminary attributes identified from literature review were presented to the advisory committee. After incorporating the suggestions/ modifications proposed by the advisory committee, the attribute-list was circulated to around thirty five practicing construction professionals for industry expert review. The suggestions and feedback obtained from expert review were again presented to the advisory committee for their consideration. The attributes finalized by the advisory committee were then represented in a hierarchical structure which was used as the decision tree for the proposed evaluation framework.

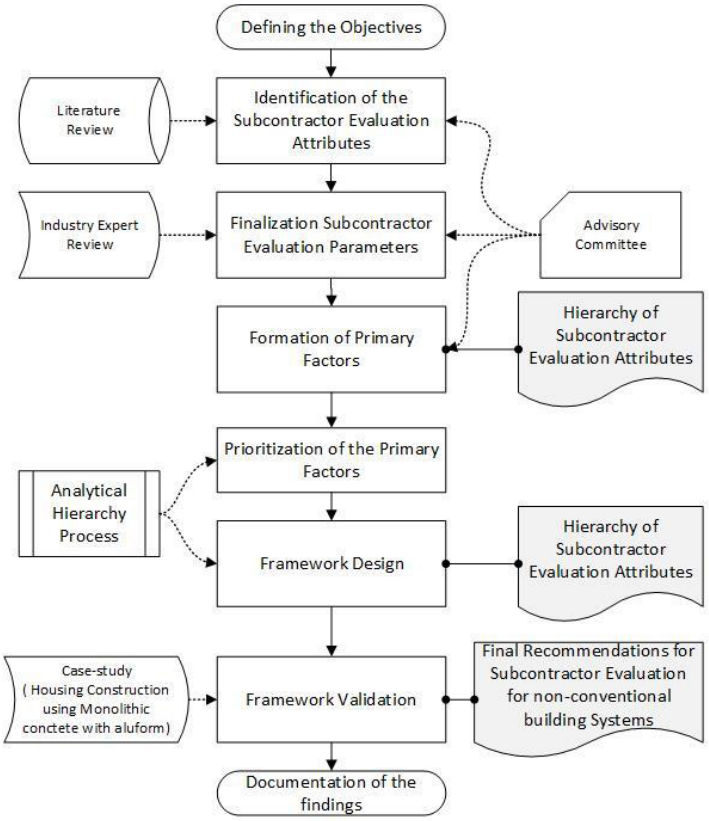

Figure 1. Research Outline

In the second phase of this research, an evaluation framework was developed using analytical hierarchy process. The framework is essentially founded on the subcontractor evaluation factors identified during the first phase of this research. The relative weightages of these attributes were determined through questionnaire survey.

In third phase of this research the proposed framework was implemented at an affordable and mass housing project located in eastern region of India for selection of subcontractors for monolithic concrete construction with aluminum formwork system. The results of the performance test were satisfactory and the implementers found that the decision making process became easier after implementing the proposed framework.

4. Subcontractor Evaluation Attributes

Evaluation of subcontractors is a complex process. A plethora of attributes (shown in Table 1) needs to be considered in tandem for this. After a thorough investigation of the existing literature and the industry expert reviews, total nineteen attributes were identified which the advisory committee found relevant for evaluation of subcontractors in the context of residential construction with non-conventional building systems in India.

Table 1. Subcontractor Evaluation Attributes

Attribute	Description
Tender Price	The value and feasibility of quotations provided by the subcontractors should be assessed. Still now in India, the usual practice is to give maximum preference to the lowest bidder. So in many cases, the subcontractors provide unrealistically low quotations for winning the bid.
Financial Capacity	This attribute assesses the capacity of the subcontractor to bear the monetary investments required for the work. The research suggests to evaluate last three year's average turn-over and the average job-values of the subcontractor.
Years of Experience	This attribute measures the years of experience of the subcontractor in residential building construction with similar building materials and technologies
Number of Successfully completed Projects with Similar Technology	This attribute also measures experience of the subcontractor in implementing similar building systems. It takes into account the number of projects completed by the subcontractor which involve implementation of similar technologies.
Adequacy of Skilled Labor	This attribute measures the strength of skilled labors (for implementing the concerned building system) available with the subcontractor.
Adequacy of Technically Experienced Staffs	This attribute measures whether the subcontractor can deploy sufficient supervision to ensure proper implementation of the concerned building system
Adequacy of Required Plant & Machinery	This attribute should be considered especially when provision of tools and tackles or the equipment needed for the implementation of the concerned building system is in the scope of the subcontractor.
On-site Repair and Maintenance Facilities for the P&M	When provision of P&M is included in the subcontractor's scope it should also be assessed whether the subcontractor has the required repair & maintenance facilities for the equipment.
Standard of Workmanship	This is a subjective attribute which can be assessed from the previous works done by the subcontractor.
Training Facilities for the Laborers	This attribute measures if the subcontractor provides sufficient training to its work crew and if any additional training is required to be provided by the employer.
Provisions for QA/QC	This attribute takes into account if the subcontractor has a documented QA/QC Policy.
Provisions for Work-Safety	This attribute measures whether the subcontractor is aware of and implements the safety norms available for the concerned work. If the subcontractor provides adequate Personal Protective Equipment to the laborers and is generally aware of the environmental and safety hazards involved in the work are also taken into account.
Subcontractor's Safety Statistics from Previous Projects	This attributes take account the expected level of work-safety for the subcontractor by scrutinizing its safety statistics from previous projects.
Provisions for Construction Waste Management	This attribute considers if house-keeping is included in the quotations provided by the subcontractor and whether the subcontractor has an effective site waste management plan.
Reputation	Reputation is a subjective parameter which can be used as a measure of the reliability of the subcontractor and its relationship with other project stakeholders.
Willingness to Tender	This is a subjective parameter which is a measure of the reliability of the subcontractor and the probability that the subcontractor will complete the project work once awarded with the contract.
On-going Work Commitment	The ongoing work commitments of the subcontract has to be assessed also with respect to the financial and resource capacities of the subcontractor.
Awareness of Local Laws and Regulations	Awareness of local laws and regulation is always an added advantage for the subcontractors. This attribute should also be taken into account for evaluation and selection of subcontractors.

Compliance with Legislative Requirements	This is a mandatory parameter which must be taken into consideration before selecting any subcontractor. This attribute measures whether the subcontractor fulfills all the legislative requirements for doing the work.

Many of the identified attributes are generic in nature. Apparently they are applicable to any type of subcontractor evaluation. However the assessment and relative importance of these apparently "generic attributes" change when they are considered in the specific context of residential building construction with alternate building systems in India. For example, "*years of experience*" can be called a generic attribute which is usually considered in most of the subcontractor selection models. But in this specific context, one has to assess "*years of experience*" of the subcontractor in using the non-conventional building system in question and not the overall experience of the subcontractor in the building construction industry. Similarly, while assessing "*on-going work commitment*" of the subcontractor, apart from the financial aspects, it should also be considered whether the subcontractor is currently working on any other project which involves implementation of similar technologies. And then again, some of these "generic attributes" like "*adequacy of skilled work force and technically experienced staff* " become more relevant in our context as implementation of emerging building systems require unique skills and proficiencies which are often not found in abundance in countries like India. However, there are also some attributes which are required to be considered specifically for evaluation of subcontractors for non-conventional building systems. For example, the attribute "*number of successfully completed project with similar technologies"*, measures experience of the subcontractor in implementing similar building systems and thus ultimately indicates technical competency of the subcontractor. And as it has been already stated earlier, the type of technical knowledge and competencies required for implementation of the emerging building, is not abundant in India where still most the residential buildings are constructed with conventional building systems.

However, after an extensive discussion with the advisory committee, the identified attributes were grouped into five major categories, *Technical Experience, Financial Competency, Resource Adequacy, Job Quality and Safety and Local and Other Factors (see figure 2.).* Out of these five primary factors*, Job Quality and Safety, Resource Adequacy* and *Technical Experience* define the technical competency of the subcontractor for implementing the concerned emerging system. These five categories represent the five primary factors that are to be considered for evaluation of subcontractors. The evaluation of subcontractors on each primary factor is governed by the attributes underlying that factor.

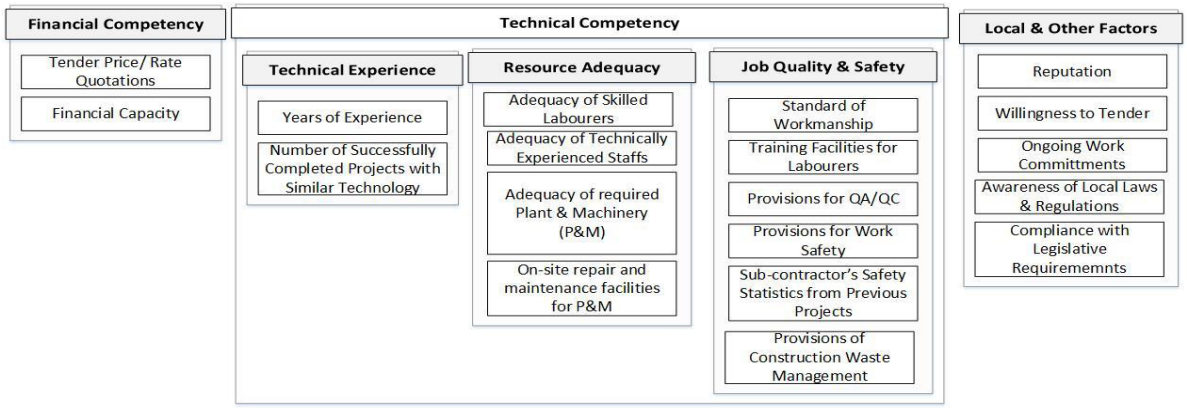

Figure 2. Hierarchy of Subcontractor Evaluation Attributes

5. The proposed Framework for Evaluation of Subcontractors

5.1. Prioritization of the Primary Factors

Before designing the framework it was needed to determine the relative importance of the primary factors for evaluation of subcontractors in the particular context of residential building construction with non-conventional and emerging building systems. Data required for prioritization of the primary factors are collected through questionnaire survey. The survey questionnaire was designed on the principals of Analytical Hierarchy Process (AHP). In the survey questionnaire, the respondents were asked to do pairwise comparison of the primary factors of subcontractor evaluation in the context of residential building construction with non-conventional building systems. For each pair of primary factors the respondents were required to choose the more important factor and indicate its relative level of importance in the nine point scale developed by Saaty [11]. Initially the survey questionnaire was circulated to around one hundred and forty construction professionals from the residential construction Industry of India. However only ninety three responses were received out of the one forty questionnaires sent. The years of experience of the respondents varied between 5 years to 25 years with an average of 10-15 years of experience. But to arrive at a more reliable and consistent conclusion, it was decided that the weightage given to any particular survey response would be decided on the basis of the consistency of the respondent [12]. In addition to this when the consistency of the final pairwise comparison matrix was determined, the consistency ratio came out to be 0.01 only which means as per the principals of AHP the overall findings of the questionnaire survey were extremely consistent.

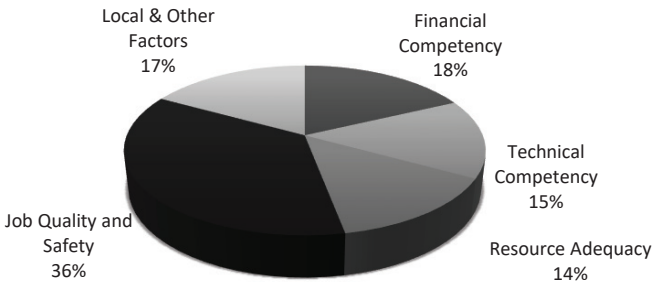

Figure 3. Relative Weightage of Primary Factors

As per survey responses the most important factor for subcontractor evaluation is "*Job Quality and Safety*" with 36% relative importance. Perhaps the reason behind this is that the potential benefits of the emerging housing systems in terms of time and cost savings can only be realized when the quality and safety of work is maintained during their implementation. The next most important factors are "*Financial Competency*" and "*Local and Other Factors*". Relative importance of these factors varies in the range of 17% to 18%. Clearly in India where the present trend of residential building construction focusses most on making the housing units affordable, "*Financial Competency* becomes second most important factor after quality and safety for evaluation of subcontractors. But with the given diversity in the dynamics of Indian real estate sector, "*Local and Other Factors*" like reputation, awareness of the local laws & regulation etc. also become almost as important as "*Financial Competency*" when it comes to selection of subcontractors. "*Technical Experience*" and "*Resource Adequacy*" have got relatively lesser importance (in the range of 14-15%) as per the survey results. It has been already said that often these attributes are not taken into account for subcontractor evaluation in India. Perhaps because most of the employers provide the required training to the subcontractor's labor crews and P&M resources are usually provided by the employer only. However, even then these two aspects cannot be completely ignored during decision making as their relative importance is not significantly less than the other factors.

5.2. Framework Design

The proposed framework for evaluation of subcontractors is designed based upon the principles of Analytical Hierarchy Process as it offers a simplistic yet scientific approach for solving multi-criteria decision making problems. For evaluating competency of a subcontractor for implementing any particular non-conventional residential building system, the subcontractor has to be evaluated on each primary factor. Then the overall competency of the subcontractor (Subcontractor Competency Index) can be determined from the scores obtained by the subcontractor on various primary factors and the relative weightages of the primary factors.

$$SCI = \sum_{i=1}^{n} W_i \times K_i \quad (1)$$

Where,
SCI= Subcontractor Competency Index
n= Number of primary factors = 5
W_i = Relative Weightage of ith primary factor
K_i= Score of the Subcontractor on ith primary factor

The evaluation of the subcontractors on each primary factor depends upon the attributes defined under it. The framework assumes that all the attributes under any particular primary factor are equally important. So the score of the subcontractor on any primary factor can be calculated from the average score obtained by the subcontractor on the attributes under the primary factor.

6. Framework Validation

The proposed framework was implemented at an affordable and mass housing construction project located in the eastern region of India. The project involved construction of twenty three residential building towers using monolithic concrete construction with aluminum formwork. Aluminum formwork (aluform) was a critical resource for the project and the project was already delayed by approximately seven months when the main contractor of the project was approached by the research team for implementation of the proposed framework.

One of the primary causes of delay in aforesaid project was poor productivity of the formwork crew. The main contractor of the project also revealed that the project performance had greatly suffered due to frequent change of the aluform subcontractor. It was found that the root cause behind the frequent need of changing aluform subcontractor was that the productivity of the formwork crew remained very low in spite of providing several onsite trainings and mock-ups. The cost of mock-up and trainings was entirely borne by the main contractor which further impacted the project profitability from the perspective of main contractor.

Analysis of the existing practice of subcontractor selection in the project revealed that the selection of subcontractors were primarily done on basis of the financial quotes provided by various competing subcontractors. In order to get the project, often the subcontractors were indulged to provide unfeasibly low rates which allowed them to engage only semi-skilled laborers for the work. So axiomatically both productivity and quality of workmanship degraded leading to an increased need of onsite trainings and mock-ups.

When the existing aluform subcontractor was evaluated using the proposed framework, it was found that even though the subcontractor had quoted the least rate for work, it did not have the technical competency and resources required for the job. So ultimately the effective cost of formwork increased owing to the lack of labor productivity, increased floor to floor cycle time and requirement of extensive trainings. Therefore, it was decided that the existing subcontractor should be changed for improving the formwork productivity. The proposed framework was used for

selection of new subcontractor. Initial job-training and safety induction was provided to the new subcontractor also. However the productivity of formwork increased considerably. Over a span of only one and a half months the project team was able to reduce the floor to floor cycle time from 12 days to 7-8 days.

The project team was then asked to evaluate performance of the proposed framework on following performance criteria, *Ease of Use, Relevance of Inputs, Accuracy of Results, Usefulness, and Overall Performance*. The evaluation was done on a five point Likert scale and the proposed framework obtained an average score of 4.6 on the performance test.

Table 2. Performance Analysis Results of the Framework

Performance Criteria	Score
Ease of Use	4
Relevance of Inputs	5
Accuracy of Results	4
Usefulness	5
Overall Performance	5

7. Conclusion

The proposed framework posits a rational and quantitative approach for evaluation of subcontractors. The validation case-study for this framework revealed that the frame-work provides a holistic yet simplistic approach for subcontractor evaluation which is likely to support a better decision making process when it comes to selection of subcontractors for residential building construction using non-conventional and alternative housing systems. The relative weightages of the primary factors used in this framework are purely subjective and determined on the basis of the survey responses collected during the course of this research. However based upon the project dynamics these weightages might be adjusted by the decision makers.

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