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PREFAB CONTENT VERSUS COST AND TIME SAVINGS IN CONSTRUCTION PROJECTS: A REGRESSION ANALYSIS

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ABSTRACT

Prefabrication technology (prefab) has various benefits, which have been widely researched and reported. Of all the documented benefits; cost and time savings are the most compelling incentives for adopting the technology. However in spite of these and numerous other benefits of the technology, its use in the construction industry has not gained the level of prominence it deserves. This is largely because the reported benefits have been anecdotal. Only few instances of quantifiable benefits have been reported; and these were mostly based on information derived from one or few isolated case studies. There is a general lack of quantifiable benefits that are based on sufficient empirical data and that are backed by statistical tests of significance. This research aimed to fill this knowledge gap by investigating whether or not prefab contents as percentages of the final contract sums could correlate significantly with the time and cost performance achieved on the projects. Using a case study research approach, 30 light to medium commercial buildings completed during the last 12 months in Auckland, New Zealand, were investigated. The project details acquired included initial cost estimate, final completion cost, estimated duration, actual duration, gross floor area and the value of prefab content as percentage of the final contract sum. Correlation and regression analyses were used to analyse the data. Results showed that cost and time performance improved with the increase in the building prefab content in the buildings within certain limits. Prefab contents ranged from 30 – 90 percents of the final contract sums for all prefab types involved in the projects, while the time and cost performance ranged from 50-130% and 40-120%, respectively. An exponential regression model of the form $y = 0.263e^{1.738x}$ was found as the best fitting curve to the cost performance versus prefab content (pc) plots based on its highest R^2 value of 0.87. The best fitting regression curve for the time performance versus pc plots, was a 2nd order polynomial of the form $y = 1.675x^2 - 0.715x + 0.601$ ($R^2 = 0.92$). Using these best fitting regression models, it was found that to achieve 100% or more in time performance, the prefab content should be at least 74%, while that of cost performance requires 77% or more prefab content. A Student T test of significance confirmed the reliability of these models within 5% significance level used in the tests. Thus, by increasing the offsite proportion of the building component up to 77%, there is 95% chance of achieving the cost and time targets, not withstanding the influence of other

extraneous factors such as weather, contract strategy, site and project characteristics. This result is expected to provide the empirical evidence that decision makers need to employ more of the technology in the industry, and hence contribute to improving its wider up-take.

KEYWORDS: Building systems, cost-saving, off-site manufacturing, prefabrication, time-saving.

INTRODUCTION

Prefabrication (Prefab), also commonly known as offsite manufacturing (OSM) of building components is relatively a modern and innovative construction approach in which bulk of building components are manufactured in remote offsite locations. Manufacturing of building components takes place under controlled environment in specialized factory setting for their subsequent transportation and installation at project site. Prefab is a very beneficial construction approach and numerous benefits of using prefab technology have been reported. Many industry driven panels recognize prefab as an effective solution to cut down some of the prevailing problems encountered by the construction industry including: cost over runs and delay in project completion (CACPUCI, 2009, Shahzad and Mbachu, 2012, BlismasPasquire and Gibb, 2006), poor quality of craftsmanship (DBH, 2009, Gibb and Isack, 2003) inferior environmental performance and risky health and safety conditions (CRC, 2007). Tam *et al.* (2007) reports that uptake of prefab technology is likely to address all the productivity and performance related issues of construction industry.

Despite all the acknowledged benefits of prefab, its application is generally low in construction industry. The observed uptake trend of prefab application is not as widespread as the benefits of this technology. Low uptake of prefab technology in construction process is attributed to the fact that most of the documented benefits of prefab technology are either not quantified or based on investigations of isolated case studies (Davis, 2007, CRC, 2007). Shahzad and Mbachu (2012) also report that existence of fewer evidence based benefits of prefab pivots the low uptake of this beneficial construction approach. This study is focused on filling this knowledge gap by quantifying the correlation between the percentage content of prefab employed in construction process and resulting savings of cost and time. It is important to relate proportion of prefab content in building construction with the cost and time performance that can be achieved with the application of prefab to encourage the uptake of prefab. Goodier and Gibb (2007) record that prefab is mostly adopted for its cost benefits. However, the most valued benefit of prefab over conventional construction methods is the fact that it shrinks the project completion time.

Now a days there is increasingly little differentiation between the prefab buildings and conventional buildings (Shahzad and Mbachu, 2012). Practically there is no building which is either completely prefab or completely conventional. All the conventional buildings involve some form of ‘componentised’ and ‘panelised’ prefab units or the other and similarly even

completely prefab buildings involve some form of site work. Foregoing in view, having the information about the proportion of prefab which can result in 100% or more cost and time performance will not only encourage the use of prefab but it will also facilitate the project management team to have better control on project outcomes.

STUDY OBJECTIVES

The specific objectives of this study include following investigations:

1. To determine whether or not a significant relationship exists between the prefab contents of projects and the cost performance achieved on completion.

2. To also determine whether or not a significant relationship exists between the prefab contents and the time performance achieved on completion.

3. If a significant relationship is found to exist, to establish the percentage prefab contents that could result in 100% or more performance in both cost and time dimensions.

SCOPE OF STUDY

The scope of this study is limited to the case studies of 30 building projects, which were completed during the last 12 months in Auckland region. The projects investigated were light to medium commercial buildings with gross floor area range from 400m^2 to 1400m^{2,} and number of upper floors 1 to 3.

The initial and final project costs considered in this study are only construction costs; excluding other costs such as professional fees, consenting fees, land and land development costs etc. All the projects involved lump sum fixed price and traditional procurement system.

PREFAB IN PERSPECTIVE

The Modular Building Institute (MBI, 2010) defines prefabrication as the process of manufacturing and assembling the major building components at remote offsite locations for their subsequent onsite installation. Operationally, prefabrication is a construction innovation, which aims to take as much as possible the construction activities away from the project site to the factory settings to ensure better quality and safer production under controlled working conditions (Haas and O'Coner, 2000). Prefabrication is also recognized as industrialized

building construction approach (Kamar et al., 2011). This construction approach is seen as being more productive than the conventional construction approach (Arif and Egbu, 2010). Azman et al. (2010) see prefabrication as an evolution of onsite conventional construction techniques into more productive and innovative industrialized approach.

This technique readily supports standardisation and rapid prototyping (including 3D printing/ additive manufacturing technologies), which are expected to re-engineer the future of the construction industry (CACPUCI, 2009).

Types of Prefab

Several taxonomies exist for the classification of prefab technology. Davis Langdon and Everest (2007) classified prefab based on interfaces and connections as open-ended prefab and close-ended prefab. Where open-ended prefab is defined as simple panels or components which are fabricated at off-site locations using single or composite materials and brought to construction site for their assembly. Contrary to this close-ended prefab system is very complex and can only be manufactured in specialized factory settings. Examples of close ended prefab include modules, pods and whole buildings. From a geometric perspective, Bell (2009) categorized prefabrication into volumetric (i.e. modular and ready to install buildings), non-volumetric types (i.e. pre-nailed frames and panels) and the hybrid (i.e. combination of volumetric and non-volumetric). Shahzad and Mbachu (2012) extended Bell's (2009) three classes of prefab system to four: componentised prefab (i.e. prefabricated building components and units such as precast columns and beams), panelised prefab (such as pre-nailed trusses, and the precast wall and floor panels), modular prefab (i.e. modules or pods), and whole building prefab (i.e. complete building short of foundations and onsite service connections).

Areas of Application of the Prefab Types

Davis Langdon and Everest (2004) observe that panelised or componentised prefab is best suitable for residential construction and similarly modular prefab is ideally suited to highly serviced areas, although other studies (Gibb, 1999, Bell, 2009) did not limit the application of this type of prefabrication to any area. Jailon and Poon (2010) note that the whole building prefabrication is mostly suited to portable or temporary applications such as out-door structures, holiday homes and site accommodations, or for any construction project where speed of erection is a necessity like post disaster management etc. Shahzad and Mbachu (2012) observe that there is increasingly little differentiation between the conventional building types and the 'componentised' and the 'panelised' prefabrication types. This is because conventional buildings involve some form of 'componentised' and 'panelised' prefab units or the other prefabricated units.

Why Prefab?

Several studies have explored the advantages of prefab technology. One of the major benefit of this technology is; it reduces the project cost and compresses the time period required to complete the project (Lusby-TaylorAinger and Ogden, 2004, MBI, 2010). Prefab technology helps on time delivery of project (Bell, 2009). Gibb (1999) reports that quality of construction improves with the application of prefab. Further to this, prefab enables improved onsite health and safety conditions (Lu, 2009), reduced onsite material wastage and environmental impacts. Prefabricated construction reduces whole life cycle costs of buildings (Shahzad and Mbachu, 2012). Tam and Hao (2014) explains use of prefab components as the most effective approach to minimize waste generation during construction activity.

Due to the industrialized nature of this technique, shortage of skilled labour to meet market demands is not an issue anymore (Nadim and Goulding, 2009). Prefab method of construction is totally independent of inclement weather and hence there is no delay in project completion due to unpredictable weather conditions (Bell, 2009). Factory setting facilitates easy and close supervision of materials and craftsmanship. As most of the work is carried out in factory, there is less need of material handling at project site and hence the management of construction site becomes a lot easier (Gibb, 1999).

Prefab buildings can be tested by prototyping their models, this facilitates the forecasting of building's response to natural disasters especially the earthquakes (Gibb, 1999). Ngowi et al., (2005) believe that prefab is a resource-efficient technology and it is equally beneficial for all types of building construction as well as infrastructure projects.

Issues with Prefab System

In spite of various recognized benefits of prefab technology, it is observed that uptake of this technology is low in many countries or the use of prefab is not as wide spread as its benefits (Shahzad, 2011). This low uptake is generally associated with the high cost of transportation and requirement of carnage for lifting large size prefab components and modules (Gibb, 2003, MBIE, 2013). Longer project lead time required for ordering and manufacturing of prefab components before the construction activity starts also hinders the likeliness of adopting prefab construction approach (Shahzad and Mbachu, 2011). Another reason that makes prefab unpopular for residential purpose is standardisation of design and lack of flexibility to make any changes in design after the project commencement (Goodier, 2007).

Bell (2009) investigated the socio-cultural perspective of prefab uptake and documented that misperceptions exits about this technology based on cultural issues and the social stigma attached to it, due to bad experiences in the past. These bad experiences are mainly related to the quality of prefabricated buildings, especially the poor quality housing construction of post-world war reconstruction process, labelled prefab as of poor quality and temporary

nature.

Major benefits of prefab like cost savings, time savings and high quality of components are associated with the repetitive nature of manufacturing process and standardization of components, which is in contrast with the requirement of a large number of clients. Shahzad and Mbachu (2012) observe that building owners doesn't like standardization of design, they rather prefer bespoke designs which allows them to make changes to suite their lifestyle throughout the design and initial construction stages. The conventional building approach offers this flexibility and also allows room for more proactive change management, whereas the prefab approach usually limits the extent of the owner's changes to the standard designs; else, the outcomes in terms of costs, speed and wastage will be less desirable when compared to the corresponding outcomes for the conventional system (Scofield and Potangaroa, 2009).

In some cases contractors and sub-contractors are reluctant to adopt this method of construction as they will have to change the way they have been doing their job. In addition to this the requirement of upfront capital to establish specialized prefab factories also hinder the adoption of this technology (Szwarc, 2013). Page (2012) observes that construction industry is inclining towards the use prefab and the use of this technology is likely to grow in future with more understanding of its benefits.

Prefab vs Conventional Construction

Prefab technology has many benefits over and above the conventional construction methods. Gibb (1999) explains how the manufacturing process taking place in factory makes prefab superior over other construction methods. Building panels, components and pods are manufactured in factories, with the use of high tech manufacturing machines making the process quick. The overall duration of project also reduces due to the parallel construction activities taking place at site and off-site. In addition to this, the components manufactured in factories are ready to be installed at project site and this further shortens the duration of site works.

The optimised use of construction material in factories reduces the project cost and also minimizes the waste generation (MBI, 2010). As most of the manufacturing takes place in factories and material is stored in storage, there is less likelihood of material being damaged. Prefab technology is environment friendly because less dust, noise and waste is generated during the construction works (Luo, 2008). Construction workers at project sites are vulnerable to health and safety hazard as they are exposed to extreme weather conditions; temperature, rain and winds. There is also a potential of being injured due to falls and other site risks. Whereas, prefab factories provide a safe workplace (BlismasPasquire and Gibb, 2006).

Challenges for Prefab Uptake

To improve the uptake of prefab technology, there is a need to encourage its application by addressing the barriers which are hindering the adoption of this construction technique. This is not possible until the benefits of prefab technology are fully appreciated by the construction industry and clients (Shahzad, 2011). In this regard, one of the most challenging task would be to create awareness of prefab benefits among the project stakeholders to create an environment where prefab is accepted as a useful construction technique (Bell, 2009). Ian Page and Norman (2014) suggest that builders can perform this task by gradually introducing parts of prefab in conventional construction process and celebrating the performance efficiency gains of prefab application. Builders can also play a role by instructing the sub-contractors to use prefab technology (Szwarc, 2013).

Requirement of training is also recognised as an important challenge by Ian Page and Norman (2014). They highlighted the need of skilled labour required to manufacture high tech prefab components with complex interfaces. Coming up with design options which can ease the transportation of prefab components is also very critical to cut down the cost of transportation, as in some cases high cost involved in transportation of large sized prefab components neutralises the cost savings achievable with the use of prefab (Kelly, 2009).

RESEARCH METHODOLOGY

Case study research method is adopted for this research, this method is recognized to be useful when data samples and participants are selected based on their relevance to the subject issue and how well they represent the target population (Cooper, 1995). Information about cost, time and prefab content of completed commercial building projects provided the data for this study. Where some of the information was missing or incomplete for a specific building, the project manager for that building was contacted for the missing information. This is another reason of selecting case study research method, as it allows the flexibility of extracting required information from project records, making direct observations on the project and interviewing the project stakeholders (Cooper and Schindler, 2006).

Investigations were focused on exploring the performance efficiency of projects in terms of cost and time savings that could be achieved by the use of prefab components and panels in a building. 30 light to medium commercial buildings were randomly selected to be investigated. These buildings are located in Auckland region and have been completed in last 12 months.

With no pre-defined sampling frame for the study, information on the prefab buildings was obtained by online keyword searches by convenience sampling (Cooper and Emory, 1995) for the study. The construction companies were randomly accessed to request the cost and time

data of recently completed commercial buildings. The key information acquired for all the buildings included: Initial cost estimates, final cost of project on completion, estimated project duration, actual duration of project, percentage cost of prefab components, gross floor area (GFA) and number of floors etc.

Data Analysis

The proportion of prefab content for a building was computed by finding out the percentage cost of prefab components out of total project cost, hence the percentage prefab cost reflects the percentage prefab content in a particular building. Cost performance for each building was computed as quotient of initial cost estimate and final project cost (Eq. 1).

$$CP = \left(\frac{ICE}{AC}\right)\% \qquad \text{(Eq. 1)}$$

Where:

CP = Cost Performance
ICE = Initial Cost Estimate
AC = Actual Cost

Similarly, the time performance for each building was computed as quotient of initial time estimate and actual completion time (Eq. 2).

$$TP = \left(\frac{ITE}{AT}\right) \qquad \text{(Eq. 2)}$$

Where:

TP = Time Performance
ITE = Initial Time Estimate
AT = Actual Time

Hypothesis Testing

It is recommended to ascribe some level of confidence in the formulation of hypothesis or theory generated from the limited samples (Cooper and Schindler, 2006, Mbachu, 2006). This is done by reliability tests or statistical tests of significance. The statistical tests of significance, which informed the third objective of the study, therefore proceeded with a null hypothesis which assumed that there is no significant relationship between estimated and actual cost and time performance for the range of prefab content. The alternative hypothesis assumed that significant correlation exists between estimated and actual cost performance data for the range of prefab content data. The hypothesis testing was conducted separately for the observed cost and time performance. Typical procedure for the cost performance is defined as follows:

H_0: There is no significant correlation between estimated and actual cost performance data for the range of prefab content data.

The alternative hypothesis was formulated as follows:

H_a: Significant correlation exists between estimated and actual cost performance data for the range of prefab content data

Acceptance condition: Accept H_0 if t-value is less than the value of t-crtitical.

Rejection condition: Reject H_0 if the t-value is equal or lower than the value of t-critical; accept the alternative hypothesis instead.

The above hypothesis tests were replicated for time performance.

RESULTS AND DISCUSSION

First two objectives of this study pivots on determining whether or not a relationship exists between prefab content and performance of project in terms of cost and time. For this purpose cost performance and time performance of each of the building included in the study was computed against the percentage prefab content. Cost performance of building projects was measured by comparing the difference between initial cost estimates and actual project cost (Eq. 1).

Similarly time performance of case study building projects was computed by comparing the difference between the initial estimate of project duration and actual project duration (Eq. 2).

Of all the buildings investigated in this study, fourteen buildings were constructed mainly using panelised prefab with complementary onsite construction, six buildings were constructed using a mix of modular and panelised prefab with complementary onsite construction, Another six buildings were constructed using conventional construction methods with a small proportion of prefab frames and components and only four buildings were fully modular with complementary onsite construction.

Table 1. Shows the percentage cost performance and percentage time performance for each of the investigated building.

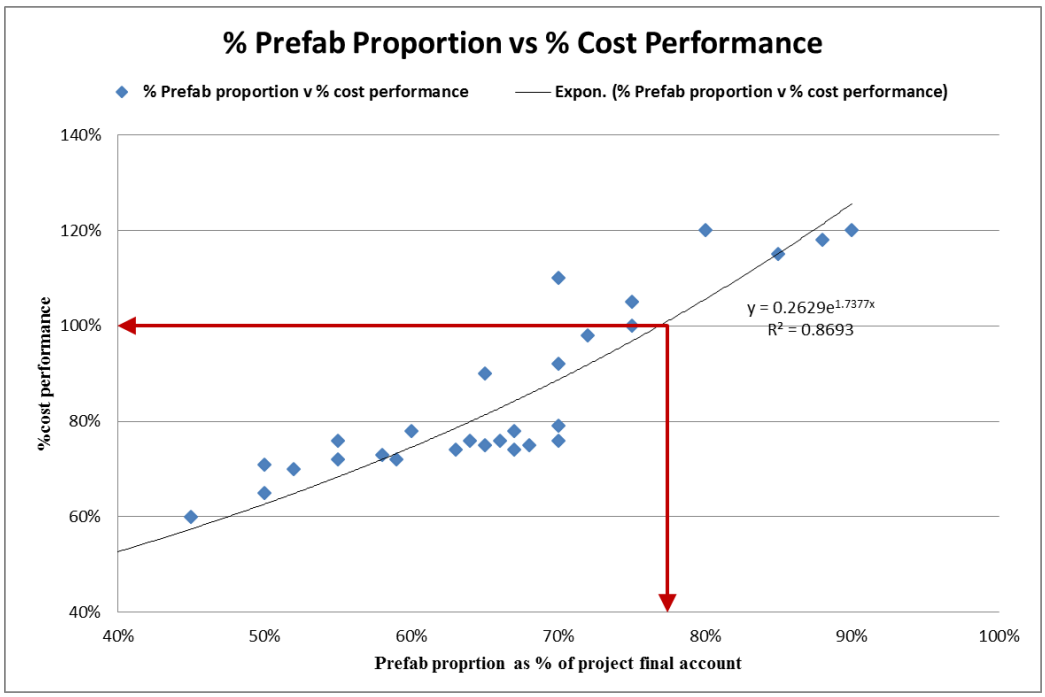
Data analysis yield that significant relationship exist between the proportion of prefab content in commercial buildings and their computed cost performance. Cost performance of all the case study projects was analysed against the proportion of prefab content for each building (Figure 1). Analysis reveal an increasing trend i.e. cost performance of commercial building

projects improves with the increase in percentage content of prefab employed in the construction process. The breakdown of this relationship shown 40% - 70% improvement in cost performance with the application of 30% - 50% prefab content, 70% - 80% cost performance is observed when content of prefab is between 50% - 70% of the total project and 100% or more cost performance is achieved with the application of prefab in the range of 70% - 90%. The exponential trend between the prefab content and cost performance suggest that 77% prefab content in commercial buildings can result in 100% or more cost performance.

Table 1: Cost and Time Performance of Commercial Buildings

Project No.	% Prefab Content	Time performance			Cost performance		
		Estimated Duration (Weeks)	Actual Duration (Weeks)	%age Time Performance	Estimated Cost ($)	Actual Cost ($)	%age Cost Performance
1	30%	24	48	50%	315000	750000	42%
2	38%	28	52	54%	303750	675000	45%
3	45%	32	48	67%	533400	889000	60%
4	50%	24	35	69%	513500	790000	65%
5	52%	32	46	70%	902300	1289000	70%
6	50%	40	57	70%	1101175	1550950	71%
7	55%	37	52	70%	1264201	1755835	72%
8	59%	28	38	75%	1213758	1685775	72%
9	58%	36	52	70%	1137231	1557850	73%
10	67%	24	31	77%	925558.7	1250755	74%
11	63%	24	27	89%	610500	825000	74%
12	65%	40	47	85%	1463126	1950835	75%
13	68%	40	46	88%	1886250	2515000	75%
14	55%	48	67	72%	2090000	2750000	76%
15	66%	36	40	90%	1862592	2450779	76%
16	70%	32	37	86%	1178566	1550745	76%
17	64%	48	64	75%	1710646	2250850	76%
18	60%	40	46	88%	1689305	2165775	78%
19	67%	36	42	86%	1443441	1850565	78%
20	70%	48	60	80%	2176975	2755665	79%
21	70%	48	54	90%	3450511	3750555	92%
22	65%	36	45	80%	2751750	3057500	90%
23	75%	40	42	95%	2850950	2850950	100%
24	72%	40	42	95%	2891760	2950775	98%
25	75%	24	22	109%	918750	875000	105%
26	70%	56	57	98%	3053435	2775850	110%
27	85%	40	32	125%	3631470	3157800	115%
28	88%	24	19	126%	1121000	950000	118%
29	80%	40	34	119%	2588796	2157330	120%
30	90%	36	28	129%	4200924	3500770	120%

Figure 2:Prefab Content vs Cost Performance of Commercial Buildings



The time performance computed for all the buildings was analysed against their prefab content (Figure 2). The analysis of performance show that a significant relationship exists between the percentage prefab content and resulting time performance. 30% - 50% application of prefab content has shown an improvement of time performance between 50% - 70%, whereas 50% - 70% prefab content has shown time performance improvement between 70% - 100% and with the application of 70% - 90% prefab content 100% or more cost performance has been noticed. With the application of 74% prefab content in commercial buildings, 100% or more time efficiency can be achieved.

The findings of this study are in agreement with the previous studies, that use of prefab has many beneficial aspects including saving in building completion cost and the duration required to complete the building project (Egan, 1998, BlismasPasquire and Gibb, 2006, Page and Norman, 2014).

Figure 2:Prefab Content vs Timet Performance of Commercial Buildings

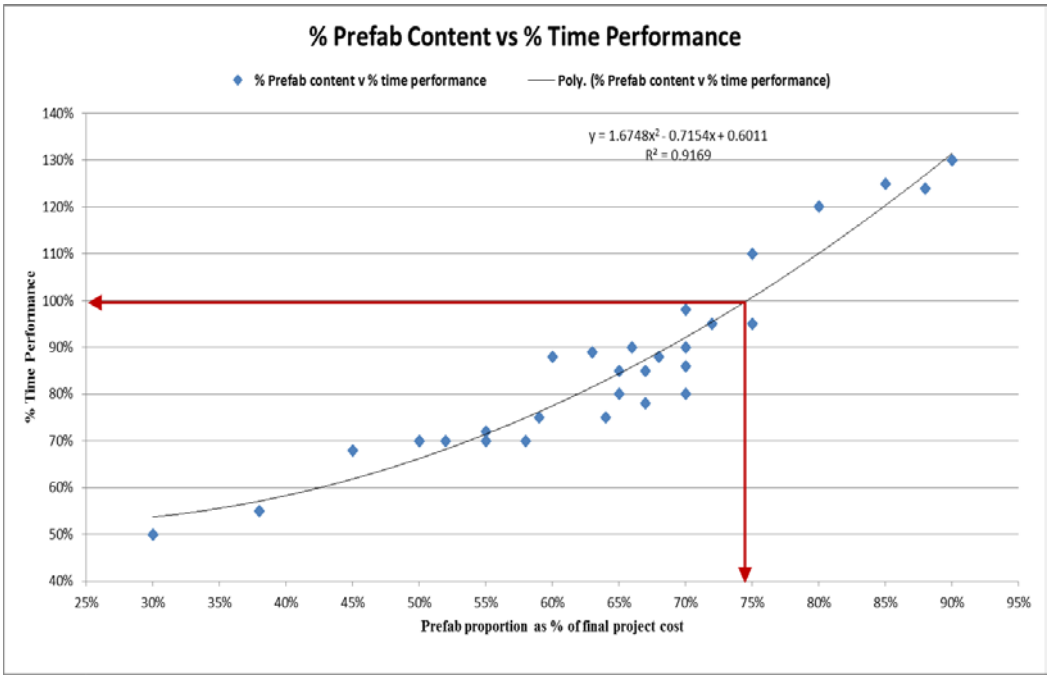


Figure 3:Relationship between Actual and Estimated Cost Performance

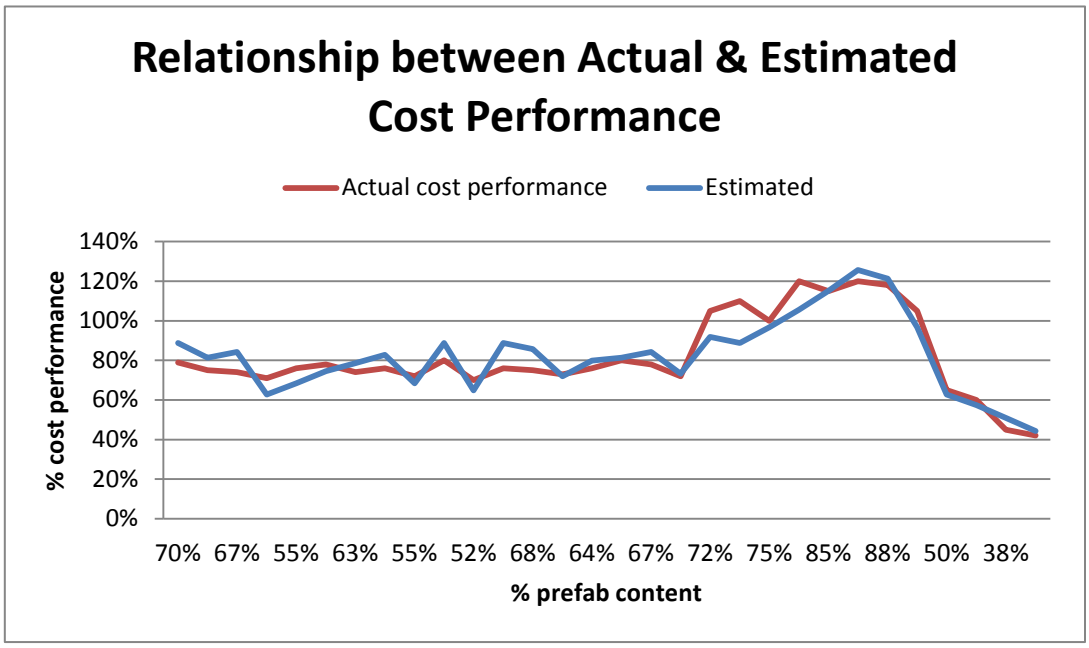


Figure 3 shows the relationship between the estimated and actual cost performance. The observed relationship was analysed to test the null hypothesis using t-value test. As the observed 't-value' (7.755) was greater than the value of 't-critical' (2.04522). Therefore null hypothesis stating that there is no significant correlation between estimated and actual cost performance data for the range of prefab content was rejected and alternate hypothesis stating that significant correlation exists between estimated and actual cost performance data for the range of prefab content data was accepted.

Similar test was replicated for time performance, which also resulted in rejection of null hypothesis and acceptance of alternate hypothesis

CONCLUSION

The study has successfully established the fact that proportion of prefab content has a significant relationship with the cost performance and time performance of the project. The study has quantified the benefits of employing prefab technology in light to medium commercial building projects by concluding that 77% prefab content in light to medium commercial buildings can result in 100% or more cost performance and similarly 74% prefab content can result in 100% or more time performance.

Findings of this study are likely to encourage the uptake of prefab technology in construction process. However, factors other than prefab content might be responsible for the cost and time

performance such as quality of project management, site characteristics, procurement strategies etc. are recommended for further investigations.

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