Prefab content versus cost and time savings in construction projects: A regression analysis

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ABSTRACT

In spite of the numerous benefits of prefabrication technology (prefab) 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. There is a general lack of quantifiable benefits that are based on empirical data. This research aimed to fill this knowledge gap by investigating whether or not significant relationships exist between prefab contents as percentages of the final contract sums and the time and cost performance achieved in the projects. 30 light to medium commercial buildings completed within the period January 2013 and December 2014 in Auckland were investigated. The project data 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. Regression analyses and t tests of significance were used to analyse the data. Results showed that cost and time performance improved with increase in the building prefab content in the buildings within certain limits. Prefab contents ranged from 30 – 90% 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 was found as the best fitting curve to the cost performance versus prefab content (pc). The best fitting regression curve for the time performance versus pc plots was a 2nd order polynomial. Using the 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. T tests of significance confirmed the reliability of these models within 5% significance level used in the tests. These results are expected to provide the empirical evidence that construction clients need to specify more of the technology use 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 the bulk of building components are manufactured in remote offsite locations. Manufacturing of building components takes place under controlled environment in specialized factory setting. The components are subsequently transported to and assembled on project sites.

Despite the numerous acknowledged benefits of prefab, its application is generally low in construction industry (Davis, 2007). The low uptake of the technology in the 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). This study was aimed at contributing to bridging the gap in the evidence-based and quantifiable benefits of the technology in the industry. The focus was on examining the relationships between the prefab contents of case study buildings and the cost and time performance achieved.

Research objectives: The specific objectives of the study were as follows.
1. To determine whether or not a significant relationship existed between the prefab contents of projects and the cost performance achieved on completion.

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

3. To establish the percentage prefab contents that could result in 100% or more performance in both cost and time dimensions, should a significant relationship be found to exist between the prefab contents and the cost and time performance achieved on the projects.

Scope: The scope of the study was limited to case study commercial building projects completed during the period January 2013 to December 2014 in Auckland, and for which the project owners and contractors were willing to grant access to the project records. The projects investigated were light to medium commercial buildings with gross floor areas ranging from 400m2 to 1400m2, and number of upper floors ranging from 1 to 3. This project scope was selected because it occupies the middle range of complexity, scale and size of building projects from residential to industrial building types (Kamar et al., 2006; Mbachu and Nkado, 2006).

The initial and final project costs evaluated in the study were only construction costs; these excluded other costs such as professional fees, consenting fees, land and land development costs. The entire projects were procured using the lump sum fixed price contracts and traditional procurement system. The choice of scope was aimed at limiting the distorting influences of variables such as project size, location, complexity and procurement system on the results.
PREFABRICATION BUILDING SYSTEM

Contextual definition: 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).

Types of prefab systems: Several taxonomies exist for the classification of prefab technology. Davis Langdon and Everest (2007) classified prefab based on interfaces and connections as ‘open-ended’ and ‘close-ended’ prefab. ‘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 to be assembled. On the other hand, ‘close-ended’ prefab system is a complex system which can only be manufactured in specialized factory settings; examples include modules, pods and whole buildings.

From a geometric perspective, Bell (2009) categorized prefabrication into volumetric (i.e. modular systems and ready-to-install buildings), non-volumetric types (i.e. pre-nailed frames and panels) and the hybrid (i.e. a combination of volumetric and non-volumetric systems). 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 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).

Prefab versus conventional construction system: Prefab technology has many benefits over and above the conventional construction method. Gibb (2003) argued that because prefab is a manufacturing process that takes place in a factory-controlled environment, it is superior to the conventional site-based construction system. In the prefab process, building panels, components and pods are manufactured in factories, with the use of high-end technologies that ensure speed and quality of construction. The overall duration of a project can be reduced due to the parallel construction activities taking place on-site and off-site, especially when the just-in-time (JIT) logistic and supply approach is combined with the prefab system (Mbachu, 2012).

The optimised use of construction materials and components in factory controlled conditions could substantially reduce the project cost and also minimizes waste generation (MBI, 2010). Luo (2008) argued that prefab technology is environment friendly because lesser amount of dust, noise and waste is generated during the construction works compared to the onsite conventional methods. Construction workers at project sites are vulnerable to health and safety hazards in the conventional approach due to exposure to extreme and dangerous weather conditions; whereas
prefab factory controlled conditions provide a safer and healthier workplace (Blismas et al., 2006). In addition, prefab system minimises the number of onsite labour required to complete a project and brings with it a significant reduction in labour-related mistakes, accidents, poor workmanship and overall costs.

**Challenges facing industry-wide uptake of prefab:** To improve the uptake of prefab technology, there is the need to ensure that the benefits of the technology are fully appreciated by the construction industry and clients (Page, 2012). Unfortunately, reports on the benefits of the technology 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 (Scofield, R. et al., 2009; Page and Norman, 2014). There is a general lack of quantifiable benefits that are based on empirical data and that are backed by statistical tests of significance (Shahzad and Mbachu, 2012). Parke (2014) argued that to persuade clients and key decision makers to adopt or invest in a particular technology requires evidence-based quantifiable benefits rather than rhetoric. Perhaps, the prevailing reports of the benefits of the technology – being anecdotal - have failed to make compelling cases for improved adoption of the technology by clients and industry operators. A crucial challenge is therefore providing evidence-based quantifiable benefits that are reliable and that backed by statistical tests of significance.

**RESEARCH METHOD**

**Units of analysis and data gathering:** Case study and archival research methods were adopted for this research, since the empirical data gathering required in-depth probing of isolated cases of completed project records (Cooper and Schindler, 2006). The units of analysis comprised information about cost, time and prefab contents of some recently completed commercial building projects.

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 building system in place of the conventional method. The key information acquired for all the buildings included the 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. The building consent database maintained by the Auckland Council provided the records of commercial building projects completed recently within the period January 2013 and December 2014, which matched the scope delineated for the study. The database therefore provided the sampling frame for the study. However, rather than undertaking representative sampling, access to all the projects were negotiated to ensure that the units of analysis – i.e. the project records - had equal chance of being sampled. This also helped to minimise bias in the research design.

**Data analysis:** The proportion of prefab content for a building was computed by evaluating the cost of prefab components as a percentage of the total final project
cost. The elemental cost reporting structure adopted in the case study projects provided useful basis for the computation.

Cost performance for each building was computed by expressing the initial cost estimate as a percentage of the actual final project cost. This is shown in Equation 1 (Eq. 1).

\[
CP = \left( \frac{ICE}{AC} \right) \%
\]  
(Eq. 1)

*Where:*

- CP = Cost Performance achieved in a project.
- ICE = Initial Cost Estimate.
- AC = Actual Cost on completion.

Similarly, the time performance for each building was computed by expressing the initial duration estimate as a percentage of the actual final duration for the project as shown in Equation 2 (Eq. 2).

\[
TP = \left( \frac{ITE}{AT} \right)
\]  
(Eq. 2)

*Where:*

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

**Hypothesis testing:** To accord some level of confidence in the outcome of investigations involving limited data samples which might not be representative of a target population, Cooper and Schindler (2006) recommended reliability tests via statistical tests of significance. This informed the first and second objectives of the study, which focused on determining whether or not significant relationships existed between the prefab contents and the cost and time performance achieved on completion of the case study projects. The test was preceded with a null hypotheses which assumed that there were no significant relationships between the prefab contents and the cost and time performance. The alternative hypotheses assumed that significant relationships would exist.

The hypothesis testing was conducted separately for the observed cost and time performance. The test statistics for the significance tests were the t-values computed by the SPSS from the standard error of estimate (SE) and the constants and
coefficients of the predictor variables in the regression lines/curves that modelled the relationship in each case. The p-values associated with the t-values formed the basis for accepting a null hypothesis if greater than the alpha value of the right tailed test (i.e. 5%), or rejected otherwise; in which case the alternative hypothesis would be accepted, which assumed that significant relationship would exist between the response variables (i.e. the cost or time performance achieved) and the predictor variables (i.e. the prefab contents). In addition, the coefficient of determination ($R^2$) was used to examine how changes in the predictor values (i.e. the prefab contents) were associated with changes in the response values (i.e. the time or cost performance achieved) (Cooper and Schindler, 2006).

RESULTS AND DISCUSSIONS

**Units of analysis and survey results:** As indicated in the Research Method section, information about cost, time and prefab content of recently completed light to medium commercial building projects comprised the data for this study. The building consent database maintained by the Auckland Council provided records of 350 light to commercial building projects completed within the period January 2013 to December 2014 as delineated in the study scope. However, the Council records did not contain all the information required. Access for the full project records were negotiated with the building contractors involved. Out of the 350 projects which matched the scope of investigations, access was granted to only 30 projects. The access was granted on the proviso that details about the clients and stakeholders should be kept in strict confidence. Access to the remaining projects was denied on the basis of confidential agreement entered into with the clients.

Out of the 30 buildings investigated in this study, 14 were constructed using panelised prefab with complementary onsite construction, 6 were constructed using a mix of modular and panelised prefab with complementary onsite construction, another set of 6 buildings were constructed using conventional construction methods with a small proportion of prefab frames and components. Only 4 buildings were constructed using modular system with complementary onsite construction. The majority of the projects therefore comprised panelised prefab system.

**Prefab content, and cost and time performance achieved in the case study projects:** The first two objectives of this study focused on determining whether or not a relationship exists between prefab contents and the time and cost performance achieved in the case study projects. The cost performance and time performance achieved in each of the case study buildings were computed using Equations 1 and 2, respectively. Table 1 shows the results.
Table 1. Cost and Time Performance of Commercial Buildings

<table>
<thead>
<tr>
<th>Project No.</th>
<th>% Prefab Content</th>
<th>Estimated Duration (Weeks)</th>
<th>Actual Duration (Weeks)</th>
<th>%age Time Performance</th>
<th>Estimated Cost ($'000)</th>
<th>Actual Cost ($'000)</th>
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<td>4201</td>
<td>3501</td>
<td>120</td>
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Plots of cost and time performance against prefab contents: Figure 2 shows the plots of the percentage cost performance against the percentage prefab contents of the case study buildings. Similar plots for the time/schedule performance are shown in Figure 3.

Figure 1. Prefab Content vs Cost Performance of Commercial Buildings.

Figure 2. Prefab Content vs Time Performance of Commercial Buildings.
Results in Figures 1 and 2 show that cost and time performance improved with increase in the building prefab contents in the case study buildings. These results are in agreement with the conclusions reached in a number of studies such as Tam et al. (2007) and Szwarc (2013) which confirm that offsite prefabrication offers significant time and cost savings. It should be noted that the increases in the cost and time performance with corresponding increases in the prefab contents were within certain limits. This could be explained from the fact that no building can be built entirely of prefab or conventional system. The figures show that prefab contents ranged from 30 – 90% of the final contract sums for all prefab types involved in the case study projects, while the time and cost performance ranged from 50-130% and 40-120%, respectively.

The figures also indicate that increasing the prefab content in the light to medium commercial buildings up to 77% can result in 100% achievement of the cost performance target. To achieve 100% of the time performance target, the prefab content should be increased to 74%.

**Regression analyses – cost and time performance against prefab contents:**
The analysed cost and time performance achieved in the case study projects (as presented in Table 1) were regressed against the corresponding prefab contents using the SPSS. Results of the cost performance versus prefab content regression as plotted in Figure 1 show exponential model best-fit curve of the form indicated in Equation 3

\[ y = 0.263e^{0.738x} + \varepsilon \quad /0.5 < x < 1.3/[R^2 = 0.87] \quad (Eq.3) \]

(Where \( y \) is the % cost performance corresponding to % prefab content, \( x \), within the range 50 – 130%); \( \varepsilon \) is the residual or error term which indicates the difference between the observed and predicted performance values (i.e. \( \varepsilon = I - R^2 \)); \( R^2 \) is the coefficient of determination – a measure of how well the model fits the data or the percentage of the response variable variation that is explained by the curvilinear regression model (Hollander et al., 2013).

Results of the regression analysis for the time performance versus prefab content in Figure 2 show a 2nd order polynomial model best-fit curve of the form expressed by Equation 4.

\[ y = 1.675x^2 - 0.715x + 0.6011 + \varepsilon \quad /0.5 < x < 1.3/[R^2 = 0.92] \quad (Eq.4) \]

(Where \( y \) is the % time performance corresponding to % prefab content, \( x \), within the range 40 – 120%); the coefficient of determination (\( R^2 \)) value of 0.92 shows a better model fit with the data than was obtained for the cost performance.

**Hypothesis testing results:** The objectives of the study included determining whether or not significant relationships existed between the prefab contents of the case study projects and the cost and time performance achieved on completion. As indicated before, statistical tests of significance were carried out using the t-values of the constants and regression coefficients of the developed models. Cooper and
Schindler (2006) advised that significant relationship exists between the predictor and response variables where the p-value associated with each model coefficient’s t-value is less than the alpha level of the test (i.e. 5%). This was a test condition that rejected the null hypothesis, which assumed that no significant relationship existed between the variables. The SPSS t test results for both regression models in Tables 2 and 3 show that the p-values of the model terms are less than 5% in each case. The null hypotheses were therefore rejected. At 95% level of confidence within which the tests were conducted, it could therefore be concluded that significant relationships existed between the changes in the prefab contents of the case study projects and the observed cost and time performance achieved in the projects.

Table 2. Test of significance of the established relationship between cost performance and prefab contents of the case study projects

<table>
<thead>
<tr>
<th>Model term</th>
<th>Coefficient</th>
<th>Standard Error (SE)</th>
<th>abs t value</th>
<th>P-value</th>
<th>Remarks</th>
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</thead>
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<td>Constant, a</td>
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<td>0.032</td>
<td>8.321</td>
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<td>Significant</td>
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<tr>
<td>Constant, b</td>
<td>1.738</td>
<td>0.534</td>
<td>3.254</td>
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Table 3. Test of significance of the established relationship between time performance and prefab contents of the case study projects

<table>
<thead>
<tr>
<th>Model term</th>
<th>Coefficient</th>
<th>Standard Error (SE)</th>
<th>abs t value</th>
<th>P-value</th>
<th>Remarks</th>
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<td>x2</td>
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<td>0.303</td>
<td>5.523</td>
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<tr>
<td>x</td>
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<td>0.055</td>
<td>12.915</td>
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<td>Constant</td>
<td>0.6011</td>
<td>0.102</td>
<td>5.888</td>
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CONCLUSION

This research has investigated whether or not significant relationship existed between prefab contents as percentages of the final contract sums and the time and cost performance achieved in the case study building projects. Results of t-tests of
significance showed that significant relationship existed in each case. Cost and time performance was observed to increase with corresponding increase in the building prefab content in the buildings within certain limits.Prefab contents ranged from 30 – 90% 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, \( y = 0.263e^{0.738x} + \epsilon \), was found as the best fitting curve to the cost performance versus prefab content plots (pc). The best fitting regression curve for the time performance versus pc plots was a 2nd order polynomial of the form, \( y = 1.675x^2 - 0.715x + 0.6011 + \epsilon \). Using the 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 t-test of significance confirmed the reliability of these models within 5% significance level used in the tests.

These results are expected to provide the empirical evidence that decision makers need to specify more of the technology use in the industry, and hence contribute to improving its wider up-take. It should be noted that factors other than prefab content could influence the cost and time performance on a project. These factors may include quality of project management, site characteristics and procurement strategies (Jallon and Poon, 2010). Further investigations are recommended to examine the influence of these other variables on the observed relationships.

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