Mass Timber Productivity- the Significance of Reduction in Non-Value Add Activities during On-Site Installation Sequence.

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ABSTRACT

The recent uptake of Mass Timber (M.T.), a prefabricated timber panelised form of construction, provides a potential sustainable resource to facilitate improved productivity outcomes to the construction industry. However, in Australia as well as U.S. and Canada, M.T. is in its infancy and there is a lack of empirical information available to industry. This consequently has resulted in reluctance by contractors and professionals to uptake this new innovative system. The aim of this paper is to undertake a comprehensive review of the on-site productivity outcomes. A quantitative Case Study approach was implemented by way of time-lapse digital video recording of three M.T. multi-storey buildings located in NSW, Australia. Crane cycles of the installation of the M.T. prefabricated panels were found to be the most representative and repeatable process and as a consequence were used to measure the M.T. productivity. Discussion is provided on potential areas of process and consequential productivity improvement. The M.T. crane cycles productivity at an Activity Level compared to M.T. productivity at Project Level revealed large differential between the two levels. The quantum of *Non-Value Add* activities was found to be a significant factor in the overall Project Level productivity outcome. This review paper undertakes a review of the outcomes of the case studies on the M.T. installation on three multi-storey buildings, the factors found that affected the resultant on-site construction productivity and its resultant beneficial implications to the construction industry.

KEYWORDS

Mass-Timber; Cross Laminated Timber (CLT); Construction; Productivity; "Non-Value Add" Activities; Pre-construction Planning

INTRODUCTION

The construction industry is regarded as an enabling sector of the economy and a leading key indicator of the general economic activity for the developed and developing world (Yi and Chan, 2014, Kenley, 2014). Construction industries value added between 5 to 8% to the Gross Domestic Product (GDP) (Drewer, 1990). However, construction productivity has been an on-going issue in the construction industry for the past three decades. Statistical evidence indicated that although using more sophisticated technologies its productivity was actually falling from a macro-economic perspective (Yi & Chan, 2014). Construction productivity is also important at company and project level due to its relationship to profitability of organisations.

If the construction industry holistically adopts this new engineering technology of prefabricated M.T. to construct buildings, this decline may, in future, be reversed subject to its claimed improved productivity being empirically supported. (Lehmann, 2012b, Shahzad and Mbachu, 2013, Shahzad et al., 2014)

Media releases and papers of recent M.T. projects have qualitatively claimed that M.T. achieved greater productivity with less labour compared to that of similar projects with traditional form of construction. They indicate that it may be possible that M.T. structures can be built between 30-50% faster with less labour compared to traditional form of construction. One examples of recent project that illustrate these claims is the10-storey M.T. structure of the “Forte” building, Melbourne, Australia constructed in 10 weeks with installation crew of 5 men (Wheeldon, 2012, d'Errico, 2016). Another example is the 18 storey Brock Common M.T. structure, British Columbia University, Canada constructed in 9.5 weeks with a installation crew of 9 men (Kasbar, 2017)

M.T. provides many additional benefits, one of which being environmentally sustainability. Wood is the only self-renewing material used in building construction, therefore a sustainable material and is beneficial to the planet during its growth. Wood provides oxygen during its growth and is storage of carbon dioxide (CO_2 Sequestration) during and after construction (d'Errico, 2016, Lehmann, 2012a, Lehmann, 2012b, Lehmann and Crocker, 2012, Bowyer, 2016, Falk, 2010, Dovetail, 2013).

Even though there has been considerable interest in the clear benefits and advantages in the use of M.T. systems it is apparent that there is a general reluctance in its adoption by industry. This problematic issue facing multi-storey M.T. construction appears to stem, simply, from lack of available empirical productivity data to assist contractors, estimators and quantity surveyors in predicting costs, scheduling and resourcing requirements for such projects. (Shahzad and Mbachu, 2013, Mahapatra and Gustavsson, 2008, Xia et al., 2014) (Lehmann, 2012b).

This provided the impetus for this research and to carry out a quantitative review of on-site productivity output of multi-storey M.T. construction.

A case study approach was used by site observational studies to catalogue multi-storey M.T. construction work processes. This included the breakdown of sub-activities, repetitive work cycles and dependencies with other construction activities. As a result, attention was concentrated on crane cycle times, crane and labour resources and work flow of elements on installation speed.

Discussion is provided on case study findings and identified areas of potential process improvement.

The outcomes of this research will enable to identify factors in M.T. construction for productivity improvement and provide valuable information in relation to the on-site installation sequencing of this innovated timber methodology. The outcomes may also assist in the future facilitation of benchmarking against traditional methods of construction. The contribution of the work is to provide quantitative productivity information to industry and a mechanism for maximizing efficiency of M.T. workflow and reduction of process waste in onsite construction.

METHODS

The data collection methodology for the study was selected by means of a pilot study on various prefabricated timber projects on the Eastern seaboard of Australia. Data collection by way of time-lapse digital video recording camera was found to be the most appropriate.

The selected research case study was from a residential project consisting of three separate M.T. multi-storey tower buildings located on a relatively restricted site area in the state of New South Wales, Australia. The three Towers buildings were constructed consecutively and are identified in this study as Towers A, B and C. From Ground Floor level each Tower was constructed in M.T. using Cross Laminated Timber (CLT) panels. The Towers provided a variety of conditions for comparison as each had a different floor area, layout and number of floor levels to each other.

A “time and motion” approach was adopted to measure the data, generally as per Drewin’s “Memomotion” technique (Drewin, 1982). Crane cycle times of each M.T. panel (the selected repeatable workflow cycle) were measured, identified and documented with time, panel ID and area onto daily worksheets. A total of 24 weeks of M.T. installation activity video footage was collected from this study.

The method of measurement used for the M.T. on-site productivity, as per Park et al and Yi & Chan (Park, 2005) (Yi and Chan, 2014), was by way of the definition/ formula: -

$$P\ (\textit{Productivity}) = \frac{\text{Output } (\textit{units of work quantity completed i.e. surface area of panel})}{\text{Input } (\textit{units in resource hours i.e. labour or equipment})}$$

The advantage that the format of the formula provides is that as productivity increases, the measured productivity increases, which is in line with that generally used in the Australian Construction Industry (Forsythe et al., 2016).

Each crane cycle was broken down and logged into two (2) time elements, which were: -
a) Commencement time: -when the crane was ready to hook and lift the panel.
b) Completion time: -when crane had slewed back and was ready to lift next panel or next activity after installation.

It was observed that, as per the trial studies, that the installation cycle for each CLT panel was either in one or two crane cycle lifts. It was observed that the panel was either a) lifted from the site storage location (or delivery truck) and installed directly in one crane cycle (i.e. in one stage) or b) in two crane cycle (2-stages). The “2-stage” process (*Stage 1* & *Stage 2*) observed to be more frequent at the higher floors.
“*Stage 1*”: the packs of panels were hoisted to the installation deck from the Ground Floor store or delivery truck.
“*Stage 2”:* the CLT panel is lifted from the deck to the panel’s installation location.

The CLT crane cycles measured included both *Value Add* (Productive/ “Net CLT Time”) and *Non-Value Add* (Non-Productive cycles). For this study the terminology of *Value Add* and *Non-Value Add* CLT crane cycle is categorical broken down into 3 headings as listed below: -

1. *Value Add* (V.A) CLT Crane Cycles activities included: *Stage 1* Crane Cycle to Lift Panel or Pack of Panels from Ground Floor storage area or delivery truck to installation deck and *Stage 2* Crane Cycle to lift panel from deck or from Ground Floor Store or Delivery truck and install in designated location.

2. *Non-Value Add* (NVA) CLT crane cycles activities generally consisted of delivery logistics items. These included Double Handling activities (such as identifying, sorting and moving panels in the storage area but excluded *Stage 1* crane cycle), Unloading and Rework.
3. Other NVA -Non-CLT crane activities that contributed to unproductive CLT process due to the principal input resource (crane) being unavailable for CLT. These included activities such as crane working for other trades, stoppages and delays and crane idle/waiting time.

Separating crane cycle activities into *Value-Add* and *Non-Value Add* enabled closer examination of resource wastage and work activities to highlight potential improvement strategies to workflow and overall productivity.

RESULTS AND DISCUSSION

The Project Management team, prior to the commencement of the CLT installation, advised that their planned installation method was to be by Lean construction's "Just in Time" approach (Pheng and Chuan, 2001, Ballard et al., 2003). It was planned that the designated crane would install the M.T. components directly from the delivery trucks and therefore the need for storage was not a prerequisite. Directing this approach was the fact that there was limited on-site storage available.

The crane cycle times for each panel were measured and documented from the video recordings, as outlined previously.

The initial "High Level" review of the video recorded footage of the CLT installation process of the three Tower buildings provided the ability to calculate the overall elementary ("first cut") review of CLT productivity of each of the three M.T. structures. Table 1, below, provides the calculated overall productivity from the observed total number of workdays between the calendar day of start and finish installation, total input (workday hours) and output (the panel areas length x width). Table 1, also, provides the average number of panels installed per workday. It can be seen that the overall productivity for each Tower at first review is relatively low as the calculations include stoppages, delays, unproductive days, etc.. As noted below (**), Tower C indicates a reduced overall productivity compared to the other Towers. Management decision to engage a Mobile Crane, which suspended work twice for several weeks at a time, effected the overall time and consequently the overall productivity.

Table 1. High Level Productivity Summary

Tower I.D.	**M.T. Installation Calendar dates**	**Work Days (5.5 days/ wk.))**	**% of Building Levels Recorded**	**# Fl. Levels Recorded**	**Ave Days /floor**	**Gross Production (M2/Hr) (based on 7.5 hr workday)**	**Ave # Panels installed/ workday**
A	4 Jul.-31 Aug	46	100%	6	7.67	14.82	20.07
B	29 Aug- 4 Nov	54.5	100%	7	7.79	12.26	19.6
C	20 Sept-9 Dec.	63.5**	38% (G.F to level 3)	3*	21.17**	8.9	9.69

Total Workdays = (No of weeks =(Finish date) minus (Commencement Date of CLT installation)) x 5.5 days
Total Hours= Total Workdays x 7.5
**only 3 levels were able to be recorded due to camera location on Tower C*

***Ave number of workdays extended as management commenced Tower C with Mobile Crane (prior to completion of preceding Structure but had to cease work several times as mobile crane selected could only install 50% of floor area*

From observation it found that the documented low overall (*High Level*) productivity was due, generally, to management decisions and delays, which is discussed later.

Using the documented crane cycle times of the V.A. CLT activities (*Stage 1* and *Stage 2*) an activity level productivity output was calculated for the CLT installation of each Tower as shown Table 2. Once CLT NVA and Other NVA activities were removed the productivity outcome was greatly improved, as can be observed by comparing Table 1 to Table 2 below.

Table 2. "Level 2" Productivity Summary

Tower I.D.	TOTAL AREA INSTALLED (M2)	TOTAL "VALUE ADD" INSTALLATION HOURS	AVE. PRODUCTIVITY (M2/HR.)
A	4,223.22	86.979	48.55
B	3826.86	119.806	31.94
C	2792.896	62.73	44.52

By considering the productive V.A. installation activities of M.T. installation this translated to a productivity output improvement to Tower A of 327.6%, to Tower B of 260.5% and Tower C of 459.4%, resulting in an overall mean improvement of 347.4%.

The observed factors contributing to the quantum of NVA activities appeared to result from Management decisions. In regard to CLT activities it was observed from the recorded footage that the first floor and part of second floor levels of Tower A were installed generally as the planned "Just in Time" methodology. However, the delivery logistics third party organisation in the second week of M.T. installation was unable to abide to the planned delivery schedule resulting in the early termination in the use of the planned "Just in Time" installation approach. The panels commenced to be delivered out of sequence with panels arriving for future floors and even future Towers. This delivery logistics issue was compounded, as these unplanned delivered panels required storage for future installation and nominated M.T. storage areas did not exist, presumably due to the planned "Just in time" approach. Consequently, packs of panels were unloaded onto any available free area, stacked on top of other packs and not in sequence.

Due to above, additional NVA CLT activities were required for the M.T. crew such as unloading and double handling in storage areas (e.g. locating panels, moving CLT panels & packs to find required, relocating packs to new storage areas) and re-work.

In regard to overall NVA, the allocation of the sole permanent Tower crane serving the project did not appear to be scheduled in advance for specific activities at dedicated times. It was observed that generally each workday the crane endeavoured to serve all trades as they demanded. This resulted in regular disruptions and stoppages to the CLT installation process with consequential increased NVA CLT activities.

This regular disruption of the CLT installation process by the crane ceasing operation to serve other trades on the site, had an observable effect to the "rhythm" created in the installation of panels. There was observed increased crane cycle time for the first two or three crane cycles following the crane's return to recommence the CLT installation. This was not considered in the productivity calculations in Table 2 above. These disruptions reduced the opportunity to create a "learning curve" advantage to the installation process and created additional crane idle time (for CLT crews to return to deck).

The consequence of the above delivery logistics issues, the non-predetermined allocation of the tower crane and consequential disruptions are illustrated in Table 3 below in form of "Pie-Charts" for each Tower building.

From Table 3 below it can be clearly seen that on Tower A less than 39% of total crane time per day was allocated for productive V.A. CLT activities. This allocation was significantly reduced to 33% on the later two Towers (B & C) partly due to increased overall NVA i.e. delivery logistics consequences and increased crane time serving other trades. This played a significant role in the resultant poor *High-Level* productivity for each Tower building as illustrated in Table 1.

Table 3. Pie Charts of the Logged Activity Break up for each Tower (A, B & C)

GROSS CRANE TIME ACTIVITY USEAGE ANALYSIS

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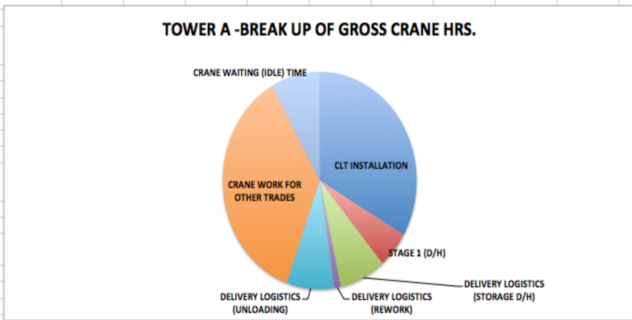
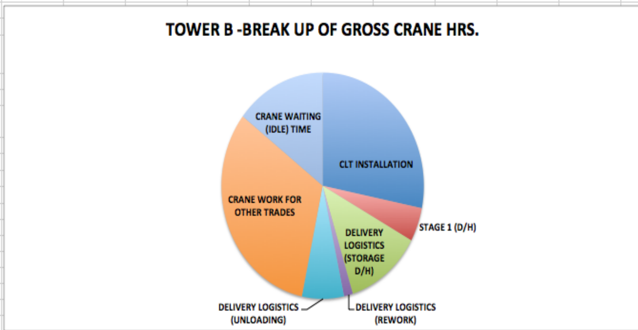
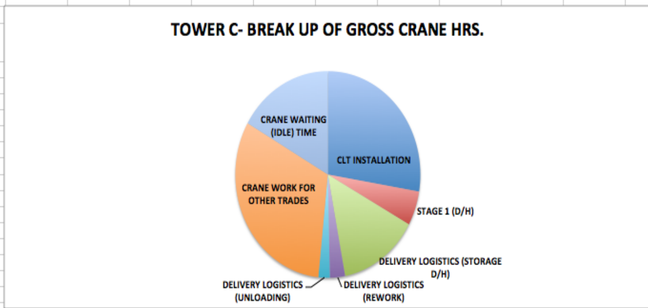
TOWER A - GROSS CRANE ACTIVITIES	BREAK UP OF GROSS CRANE HRS.	%
CLT INSTALLATION	97.8	33.36%
STAGE 1 (D/H)	16.06	5.48%
DELIVERY LOGISTICS (STORAGE D/H)	22.49	7.67%
DELIVERY LOGISTICS (REWORK)	3.23	1.10%
DELIVERY LOGISTICS (UNLOADING)	23.18	7.91%
CRANE WORK FOR OTHER TRADES	106.56	36.35%
CRANE WAITING (IDLE) TIME	23.86	8.14%



TOWER B - GROSS CRANE ACTIVITIES	BREAK UP OF GROSS CRANE HRS.	%
CLT INSTALLATION	98.17	28.19%
STAGE 1 (D/H)	16.86	4.84%
DELIVERY LOGISTICS (STORAGE D/H)	42.31	12.15%
DELIVERY LOGISTICS (REWORK)	4.96	1.42%
DELIVERY LOGISTICS (UNLOADING)	23.32	6.70%
CRANE WORK FOR OTHER TRADES	112.15	32.21%
CRANE WAITING (IDLE) TIME	50.46	14.49%



TOWER C - GROSS CRANE ACTIVITIES	BREAK UP OF GROSS CRANE HRS.	%
CLT INSTALLATION	52.29	27.65%
STAGE 1 (D/H)	10.15	5.37%
DELIVERY LOGISTICS (STORAGE D/H)	26.44	13.98%
DELIVERY LOGISTICS (REWORK)	5.03	2.66%
DELIVERY LOGISTICS (UNLOADING)	3.75	1.98%
CRANE WORK FOR OTHER TRADES	59.81	31.63%
CRANE WAITING (IDLE) TIME	31.62	16.72%



The allocation ratio of productive V.A. CLT activities to that of unproductive N.V.A. CLT activities (excluding stoppages, disruptions and crane working for other trades) is provided in

Table 4 below which indicate that almost 40% of all allocated crane cycles for CLT activities were attributed to non-productive N.V.A. activities.

Table 4. CLT Crane Cycles logged for Towers A, B & C

Description	TOWER A	TOWER B	TOWER C	TOTAL
Number of CLT "Value Add" Crane Cycle	764	780	450	2,444
Number of CLT "Non-Value Add" Crane Cycle	438 (36.4%)	564 (42%)	293 (39.4%)	1,295 (39.4%)
Total Number of CLT Crane Cycles recorded	1202	1344	743	3289

It is logical, using the findings from Tables 3 and 4, that if the unproductive CLT NVA activities were reduced by 50%, the overall M.T. productivity would have resulted in an approximate 26% improved project level output.

Even more significant was the finding, from the comparison of productivity output of Tables 1 and 2, which indicated that over a 300% improvement was possible. This was the case if there was a dedicated crane 100% allocated to the M.T. installation to ensure minimal overall NVA activities.

To achieve such an outcome detailed pre-construction planning with on-site workshops are essential with the involvement of project management, supervision team, selected associated subcontract trades and installation crews. Such a process would ensure that all actors were totally conversant prior to commencement of construction activities with the pre-planned M.T. installation methodology, sequence and deadlines. This may entail field trials and/or prototypes to test sequence of activities, jointing details, installation methods and options, as occurred on Brock Common project (Kasbar, 2017). Detailed pre-planning would ensure the most appropriate method is selected, minimise NVA activities and provide the best possible productivity outcome. As was observed from this case study, to avoid abandonment of the selected pre-construction installation methodology (in the case of unexpected events), it is also recommended for the establishment of a "Plan B" strategy.

CONCLUSION

This paper aimed to outline the findings from the on-site M.T. case studies on its construction productivity and identifying factors contributing to M.T. productivity improvements. The study indicates that prefabricated construction requires in depth pre-construction planning ensuring maximum productivity outcomes are achieved during construction.

The findings show that the quantum of crane and crew time allocated to NVA activities had a negative affect to the overall project M.T. productivity outcome. It is shown that a 346% mean improvement in productivity was achieved when the crane was focused solely on VA CLT activities. It was also observed that productivity could be further improved if M.T. crane workflow was not regularly and randomly interrupted to service other trades. It is shown that minimisation of NVA activities can be achieved by detailed pre-construction planning.

It is recommended that further research be carried out by way of quantitative case studies of various M.T. projects to verify the significance of detailed pre-planning (focused on the minimization of NVA) on the M.T. productivity at a Project Level.

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