UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Mass timber: Improving on-site productivity for multi-storey construction.

by Richard E. Brisland

Thesis submitted in fulfilment of the requirements for the degree of

Masters by Research

under the supervision of
Dr. Alireza Ahmadian Fard Fini
Professor Perry Forsythe.

University of Technology Sydney,
School of Built Environment,
Faculty of Design, Architecture and Building.

March 2021

Certificate of Original Authorship

I, Richard Brisland, declare that this thesis is submitted in fulfilment of the requirements for the award of Masters by Research degree in the School of Built Environment, Faculty of Design, Architecture and Building at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualification at any other academic institution.

This research is supported by the Australian Government Research Training Program.

Production Note:
Signature removed prior to publication.

Signed
Date: 30 May 2021

Acknowledgments

I would like to thank both my supervisors Professor Perry Forsythe and Dr Alireza Ahmadian Fard Fini for their support, assistance, guidance and valuable suggestions and input during my thesis research. I will always be exceedingly grateful to them both.

I wish to thank all those within the School of Built Environment, the Faculty of Design, Architecture and Building and the Library staff at the University of Technology Sydney, for their support and assistance.

I thank my late father, Denis Brisland, for inspiring my interest and guiding me. He was an electrical contractor who introduced me to the commercial construction sector and organised for me to work on building sites during school summer holidays for extra pocket money. I hope this dissertation would make him proud.

I thank the colleagues, staff and clients of my previous construction companies who shared my concerns in the current waste of resources, poor quality control of products and ever-increasing labour pools to meet clients' ever-reducing time demands. I thank Richard Hough and Ron Green, who first introduced me to prefabricated mass timber construction in 2010. This led me to investigate the use of this then relatively new European material in Australia. I soon realised it should be the future construction material of choice.

As my research commenced at an early stage in the introduction of the new form of timber prefabrication in Australia, my progress was hampered by the availability of suitable timber projects. I would like to thank those contractors who agreed to participate in the pilot studies and case study namely: A-Tech Carpentry Services, BDM Construction, Drouin West Timber & Truss, Fraser Property, Pyrda Australia and Strongbuild. I thank them for providing their staff and their time to help capture the prefabricated timber data, to benefit this research and the construction industry.

I thank Rhonda Daniels for her editing assistance in the earlier version.

Most importantly, I would like to thank my wife, Antonette, for her editing assistance, patience, support and the extra load inherited by my absence from home duties over the years while I was studying.

List of Publications

1. Forsythe, P., **Brisland, R.** and Sepasgozar, S. (2016) “Measuring Installation Productivity on Panelised and Long Span Timber Construction”, published by Forest and Wood Products Australia.
The author captured prefabricated timber panel installation of four projects by time-based digital video camera and manual sampling. From the video files the author recorded and analysed each of the four project’s panel crane cycles and productivity, included in the paper.

2. **Brisland, R.,** Forsythe, P. and Fini, A.A.F (2019) “Mass timber productivity: the significance of the reduction in non-value-add activities during on-site installation sequence”, presented at and published by Modular and Offsite Construction Conference, Banff, Canada May 2019.

Table of Contents

List of Figures

List of Tables

Abstract

Mass timber is a prefabricated, panelised form of building with many benefits such as faster construction and a reduction in both process waste and environmental impact. With worldwide population forecast to increase to 10 billion by 2055 and buildings using 40% of global energy and contributing over 33% of greenhouse gas emissions, mass timber can improve construction and increase industry's productivity.

However, the uptake of mass timber by Australia's general construction industry has been slow, partly because insufficient quantitative productivity data is available to help contractors and developers forecast cost, time or resources for timber projects. The knowledge gap results in risk-averse pricing by contractors and clients and increased contingency pricing behaviour, which penalises mass timber's uptake.

This study focuses on mass timber on-site productivity in multi-storey construction to develop a method to forecast and identify the significant factors affecting its on-site productivity.

A quantitative research case study approach was adopted. A method to measure installation data in multi-storey construction was designed to develop an indicative baseline productivity matrix and identify significant determinants, including materials handling and resourcing.

Mass timber installation time and motion studies using a time-lapse digital video recording camera were conducted on three multi-storey residential buildings to understand on-site mass timber installation processes. This study included an analysis of repetitive work cycles and productivity factors, including crane cycle times and installation crew sizes.

A mass timber productivity baseline matrix was established to categorise panel type and size for productivity improvement potential and identify a leading input resource.

Five potential areas of process improvement, both in construction and design, were assessed. Larger size panels were found to provide significantly improved productivity over smaller panels. The crane, not labour, was found to be the primary input resource. Wind had the most significant adverse inclement weather effect on productivity. Floor level height did not statistically significantly affect productivity. Mass timber productivity models were developed from the above factors to forecast CLT panels' and mean daily productivity. A merged model is presented with the relevant steps in the design and pre-construction stages to provide maximum efficiencies in mass timber projects. The model identifies the critical factors to address during the design and pre-construction stages.

The findings and the empirical and quantitative models presented extend current theoretical knowledge. It provides tools to improve and forecast on-site productivity for mass timber multi-storey construction and enhance overall productivity for the construction industry.

Key Definitions

Component is a product, which is produced for a specified place or function, in a building or a building system that dictates its design.

Context is the surrounding physical or theoretical conditions of something, through which an object or issue can be understood, by which it can be influenced and on which it can have influence.

Cross-laminated timber (CLT) is a component built up by layers of boards glued together in two or more directions.

Glulam is a composite of timber and glue. It denotes laminated timber of four or more boards/lamellas glued together. The most common elements are columns and beams.

High rise building refers to a building comprising over seven stories above ground level

Light timber construction denotes stud-framed timber structures, commonly in the range of the widespread "two by four" system. The structure then minimises material volume and is built up by several layers with specific functions.

*Mass timber (*or "*massive timber,*" i.e. *massive timber construction)* is broadly defined as layers of wood that have been joined together to create more significant timber elements that are both stronger and more behaviourally predictable than sawn timber (rethink Wood 2014). Mass timber has several meanings and definitions, depending on trademark-registered principles of production. Other terms are "solid wood", "heavy timber" and "laminated timber". "Massivträ" is the proposed Swedish term. In German the term "Massivholz" is common, but "Brettsperrholz" is also used for plate-like elements.

Medium-rise building refers to a building from three to seven stories above ground level.

Module is an independent part or unit, which can be combined with others to form a structure or building.

Multi-storey building is a building with three or more stories.

Non-value-added is an activity carried out that is not critical or is superfluous to the productivity of the product installed.

Prefabrication (construction) is "a process involving the fabrication or assembly of systems and components off-site, which, when complete, are transported to the job site for installation at the required time. It is an innovative process aiming to minimise on-site fabrication activities more efficiently, in a controlled environment, to achieve gains in quality, costs and time on-site" (Committee on Advancing the Competitiveness and Productivity of U.S. Construction Industry CACPUCI (2009).

Productivity is the effectiveness of productive effort, especially in industry, as measured in terms of the rate of output per unit of input (*Oxford English Dictionary).*

Sub-system is a group of parts related to each other on a specific level. The group is related to other groups as well as to governing systems on a higher level.

Surface element is an element with its main extension in two dimensions.

System is a group of related parts, which work together as a whole. System effect can be noted when relations between different parts of a group get developed to work well.

Value-added is an activity critical to the productivity of the product installed.

Webcam is a video camera connected to a computer, allowing its images to be seen by authorised internet users.

Key Abbreviations

ANOVA = Analysis of Variance

CLT = Cross Laminated Timber.

CD = completion date

CL = Centre Line.

DfMA = Designed for Manufacture and Assembly

Glulam = Glued laminated (bonded) timber

HLP = High Level Productivity

IBS = Industrialised Building Systems.

LCL = Lower Control Line.

LVL: Laminated Veneered Lumber

OSM = Off-site Manufacture

SD = start date

TQC = Total Quality Control

UCL = Upper Control Line.

U.K. = United Kingdom