

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.



MASSEY UNIVERSITY
COLLEGE OF SCIENCES

**OFF-SITE MANUFACTURING AS A MEANS OF IMPROVING PRODUCTIVITY IN
NEW ZEALAND CONSTRUCTION INDUSTRY: KEY BARRIERS TO ADOPTION
AND IMPROVEMENT MEASURES**

Wajiha Mohsin Shahzad

June 2011

OFFSITE MANUFACTURING AS A MEANS OF IMPROVING PRODUCTIVITY
IN NEW ZEALAND CONSTRUCTION INDUSTRY: KEY BARRIERS TO
ADOPTION AND IMPROVEMENT MEASURES

A research thesis submitted in fulfilment of the requirements for the

Degree of

Masters of Construction Management

School of Engineering and Advanced Technology

Massey University

Albany

New Zealand

Wajiha Mohsin Shahzad

June 2011

STATEMENT OF ORIGINALITY

I declare that this thesis is my own work, except where due acknowledgement is made, and that it has not been previously included in a thesis, dissertation or report submitted to this University or to any other institution for degree or any other qualification.

Wajiha Mohsin Shahzad

ABSTRACT

Off-site manufacturing (OSM) of building components could be leveraged to improve the reported low productivity trend in the New Zealand (NZ) construction industry. Despite the numerous known benefits of OSM, the uptake of the technology in the industry has been discouragingly low. Previous studies offer little help in terms of prioritising identified barriers to the uptake of OSM. As a result, improvement efforts have been daunted by numerous barriers in the face of limited resources. This study aims to contribute to bridging the gap in the extant literature by identifying and prioritising the key constraints to the industry-wide uptake of prefabrication and the improvement measures. Through a nation-wide survey of consultants, contractors, employers and manufacturers, feedback was received and analysed using the multi-attribute analytical technique. Results show that the broad categories of constraints to the adoption of prefabrication in NZ are (in order of decreasing impact and relative contributions): industry and market culture (16.2%), skills and knowledge (15.5%), logistics and site operations (14.8%), cost/value/productivity (14%), supply chain and procurement (13.7%), process and programme (13.6%), and regulatory (12.2%). The subcomponents of the broad constraint categories and their relative levels of impact on the uptake of the technology were reported. In addition to addressing the key barriers identified in the study, further measures for improving the uptake of the technology in New Zealand include promotion by client through specifying OSM in the design briefs, improved education and training on the use of OSM, more marketing/ awareness campaign on the benefits of the technology and better supply chain management and transportation logistics.

To enable a methodical evaluation of the marginal value achievable by the use of a variant of OSM over and above that of the traditional stick-built system at the design and life-cycle phases of the procurement process, a decision support model was developed. The model incorporates the key performance indicators (KPIs) underlying clients' value system at the development and operational phases and compares the extent to which each variant of OSM delivers each value criterion relative to the conventional system. The sum of the marginal values at each phase of the procurement

system provides the rationale basis for choosing either the OSM variant or the conventional system based on the approach that delivers the highest marginal value.

The model application to real life project was demonstrated using the modular variant of the OSM compared to the conventional stick-built system. Results of the model application at the development phase shows that the OSM was more beneficial to the client than the conventional system with an overall marginal value of 34% relative to the conventional construction approach. Individual results showed 22% improvement in the completion time for the project, 9% improvement in quality and 3% reduction in the carbon footprint at the development phase. However, the technology was found to be 2.4% more expensive than the traditional stick-built system.

Results of the model application at the operation and life-cycle phases also show that the technology achieved superior value compared to the conventional stick-built system. The overall marginal value achieved by the modular OSM application at the operation phase was 49% compared to the traditional stick-built system; this comprised 23% reduction in the running and maintenance costs, 18% reduction in the maintenance frequency of the structure and fabric, and an annual 8% reduction in the carbon footprint.

Overall, the use of modular variant of the OSM was found to deliver superior value to clients compared to the conventional system at the development, operational and life-cycle phases of the procurement process.

Keywords: Modularization, New Zealand construction industry, Off-site manufacture, Prefabrication, Productivity improvement.

ACKNOWLEDGMENT

First of all, I would like to express my deep gratitude for my supervisor, Dr. Jasper Mbachu, for his expert advice, outstanding support and unfailing patience. This thesis would not have been possible without his enthusiasm and guidance. Dr. Mbachu remained a source of support and encouragement for me during a crucial time when I had to bear the loss of my beloved father, for which I am greatly indebted.

I would like to thank my co-supervisor, Dr. Robyn Phipps and the Academic Director, Prof. Ian Maddox, for their guidance and encouragement.

I am grateful to the Building Research Association of New Zealand (BRANZ) for providing funding for this research. I feel extremely grateful to Dr. John Duncan, for showing confidence in my research and providing continuous support.

I also wish to express thanks to Massey University Human Ethics Committee (MUHEC) for granting approval to undertake the stakeholder consultations.

I am grateful to the organizations and individuals who participated in this research. I would like to thank Dr. Wayne Sharman, John Granville, Martin Fahey, Gregory Chawynski, Rosemary Scofield, Pamela Bell and many others who extended their support, dedicated their time and shared with me their valuable experiences. Their support and knowledge greatly contributed to the quality of this research.

I would like to acknowledge the support of my entire family including my four year old son, Muhriz, who cooperated with me and allowed me to complete the research without minding the reduced motherly attention he was receiving. In the end, my fondest thanks for my husband, Mohsin for his never ending love, support, encouragement and for much needed cups of coffee.

DEDICATION

I dedicate this thesis to my father, Gulzar Ahmed (Rest in Peace), who departed for the eternal world on 20th August 2010.

I wish to tell him that he will always be in my heart and I can never stop missing him.

Daddy, you are truly missed!

Table of Contents

STATEMENT OF ORIGINALITY	i
ABSTRACT	ii
ACKNOWLEDGMENT	iv
DEDICATION	v
List of Figures	x
List of Tables	xi
List of Appendices	i
Chapter 1. Introduction	1
1.1. Background	1
1.2. Statement of Research Problem	3
1.3. Research Objectives	3
1.4. Propositions	4
1.5. Scope and Limitations	4
1.6. Importance of Research Findings	5
1.7. Structure of the Thesis	5
Chapter 2. Literature Review	7
2.1. Overview	7
2.2. Off-site Manufacturing	7
2.3. OSM and Related Terms	8
2.4. Types of OSM	8
2.4.1. Panelised Building System	8
2.4.2. Modular/Volumetric OSM	9
2.4.3. Non-Volumetric OSM	9
2.4.4. Whole Buildings	10
2.4.5. Hybrid systems	10
2.5. Benefits of OSM	11

2.6. Comparison of OSM and Traditional Construction Methods	14
2.7. Global Trends of OSM.....	16
2.7.1. OSM in the UK Construction Industry	16
2.7.2. OSM in the US Construction Industry	17
2.7.3. OSM in the Australian Construction Industry.....	17
2.7.4. OSM in the Hong Kong Construction Industry	18
2.8. OSM in the New Zealand Construction Industry.....	19
2.9. Barriers Constraining the uptake of OSM.....	20
2.9.1. Barriers Pertaining to Process and Programme.....	21
2.9.2. Barriers Pertaining to Cost, Value and Productivity	22
2.9.3. Barriers Pertaining to Regulations	23
2.9.4. Barriers Pertaining to Industry and Market Culture.....	24
2.9.5. Barriers Pertaining to Supply Chain and Procurement	25
2.9.6. Barriers Pertaining to Skill and Knowledge.....	25
2.9.7. Barriers Pertaining to Logistics and Site Operations	26
2.9.8. Further Challenges Facing OSM.....	27
2.10. Conceptual Framework of the Study.....	28
2.11. Summary	29
Chapter 3. Research Methodology	31
3.1. Research Method.....	31
3.2. Research Strategy.....	31
3.2.1. Secondary Data Sources.....	31
3.2.2. Primary Data Collection.....	32
3.2.3. Sampling Frames.....	32
3.2.4. Sampling Method	33
3.2.5. Survey Questionnaire	33
3.2.6. Ethical Approval	35
3.2.7. Pre-testing of Survey Questionnaire	35
3.2.8. Industry Survey	36

3.2.9. Data Analysis	37
3.2.10. Rank Correlation Analyses	38
3.2.11. Triangulation of the Survey Results.....	40
3.2.12. Research Model.....	41
Chapter 4. Data Presentation, Analysis and Discussion of Results.....	42
4.1. Survey Responses	42
4.2. Demographic Profile of Survey Participants.....	42
4.3. Relative Levels of Impact of the Constraints to the OSM Uptake.....	45
4.3.1. Constraints Related to Construction and Design Process and Programme	46
4.3.2. Constraints Related to Cost, Value and Productivity	47
4.3.3. Regulatory Constraints.....	49
4.3.4. Constraints Related to Industry and Market Culture.....	49
4.3.5. Constraints Related to Supply Chain and Procurement	52
4.3.6. Constraints Related to Skills and Knowledge	53
4.3.7. Constraints Related to Logistics and Site Operations	55
4.4. Relative Levels of Impact of the Broad Constraints Groups to the Uptake of OSM	56
4.5. OSM Application	57
4.6. Improvement Measures.....	59
4.6.1. Measures for Addressing Constraints Related to Construction and Design Process and Programme	60
4.6.2. Measures for Addressing Barriers Related to Cost, Value and Productivity	60
4.6.3. Measures for Addressing Barriers Related to Regulatory Constraints.....	61
4.6.4. Measures for Addressing Barriers Related to Industry and Market Culture.....	61
4.6.5. Measures for Addressing Barriers Related to Supply Chain and Procurement.....	62
4.6.6. Measures to Improve OSM Skills and Knowledge.....	62
4.6.7. Measures for Addressing the Barriers Related to Logistics and Site Operations.....	63
Chapter 5. Proposition Testing and the Research Model	64
5.1. Test of Proposition 1	64
5.2. Test of Proposition 2	67

5.3. Need for the Research Model.....	68
5.4. Structure of the Research Model.....	69
5.5. Phases of the Model Application	70
5.5.1. Development Phase Model	71
5.5.2. Model for Life Cycle Application.....	73
5.6. Model Application	75
5.6.1. Development Phase Application of the Model	78
5.6.2. Operation Phase and Life Cycle Application of the Model	81
5.6.3. Conclusion of Model.....	82
5.7. Summary	84
Chapter 6. Conclusions and Recommendations	85
6.1. Conclusion	85
6.2. Contributions to Knowledge	87
6.3. Recommendations for Future Research	88
References	90

List of Figures

FIGURE 1: TYPES OF OSM, DEFINITIONS, SUBCATEGORIES, EXAMPLES AND MAIN MATERIALS [SOURCE: (GIBB AND ISACK, 2003)]..... 10

FIGURE 2: BENEFITS OF OSM [SOURCE: ADAPTED FROM CRC (2007)]..... 12

FIGURE 3: DRIVER OF OSM [SOURCE: (BECKER, 2005)]..... 13

FIGURE 4: BROAD CATEGORIES OF CONSTRAINTS TO THE UPTAKE OF OSM IN THE NEW ZEALAND CONSTRUCTION INDUSTRY. [SOURCE: ADAPTED FROM CRC (2007, p.19)] 29

FIGURE 5: FLOW CHART OF THE RESEARCH ACTIVITIES FROM CONCEPTION TO COMPLETION..... 34

FIGURE 6: PROFESSIONAL AFFILIATION OF SURVEY PARTICIPANTS 43

FIGURE 7: PARTICIPANTS DEMOGRAPHIC INFORMATION 44

FIGURE 8: EXPERIENCE OF SURVEY PARTICIPANTS..... 45

FIGURE 9: STRUCTURE OF THE RESEARCH MODEL 69

FIGURE 10: STRUCTURE OF THE MODEL FOR DEVELOPMENT PHASE APPLICATION..... 71

FIGURE 11: STRUCTURE OF THE MODEL FOR LIFE CYCLE APPLICATION 74

FIGURE 12: EVALUATION OF THE OSM MODULAR SYSTEM’S MARGINAL VALUES RELATIVE TO THE CONVENTIONAL SYSTEM AT THE DEVELOPMENT PHASE 80

FIGURE 13: PLOTS OF THE OSM MODULAR SYSTEM’S MARGINAL VALUES FOR THE KPIS AT THE DEVELOPMENT PHASE..... 80

FIGURE 14: EVALUATION OF THE OSM MODULAR SYSTEM’S MARGINAL VALUES RELATIVE TO THE CONVENTIONAL SYSTEM FOR THE OPERATION PHASE/ LIFE CYCLE 82

FIGURE 15: PLOTS OF THE OSM MODULAR SYSTEM’S MARGINAL VALUES FOR THE LIFE CYCLE KPIS..... 82

FIGURE 16: PLOTS OF THE MARGINAL VALUES OF THE OSM VARIANTS FOR THE KPIS AT THE DEVELOPMENT PHASE..... 89

List of Tables

TABLE 1: CONSTRAINTS TO UPTAKE OF OSM RELATED TO CONSTRUCTION AND DESIGN PROCESS AND PROGRAMME	46
TABLE 2: CONSTRAINTS TO UPTAKE OF OSM RELATED TO COST/VALUE/PRODUCTIVITY	48
TABLE 3: REGULATORY CONSTRAINTS TO THE UPTAKE OF OSM	50
TABLE 4: CONSTRAINTS TO UPTAKE OF OSM RELATED TO INDUSTRY AND MARKET CULTURE	51
TABLE 5: CONSTRAINTS TO UPTAKE OF OSM RELATED TO SUPPLY CHAIN AND PROCUREMENT	52
TABLE 6: CONSTRAINTS TO UPTAKE OF OSM RELATED TO SKILLS AND KNOWLEDGE ISSUES	55
TABLE 7: CONSTRAINTS OF UPTAKE OF OSM RELATED TO LOGISTICS AND SITE OPERATIONS	56
TABLE 8: RELATIVE IMPACT LEVELS OF THE BROAD CATEGORIES OF CONSTRAINTS TO THE UPTAKE OF OSM	57
TABLE 9: SUITABILITY OF BUILDING TYPES USING OSM.....	58
TABLE 10: SUITABILITY OF BUILDING ELEMENTS/COMPONENTS USING OSM	59
TABLE 11: TEST OF PROPOSITION 1 (CORRELATING THE OPINIONS OF THE EMPLOYER AND SERVICE PROVIDER GROUPS ON THE RELATIVE LEVELS OF IMPACT OF THE BROAD CONSTRAINT CATEGORIES)	66
TABLE 12: RELATIVE LEVELS OF CONTRIBUTION OF THE BROAD CONSTRAINT CATEGORIES AS KEY BARRIERS TO OSM	67
TABLE 13: RELATIVE WEIGHTS OF THE KEY PERFORMANCE INDICATORS.....	78

List of Appendices

Appendix A: Low Risk Notification	99
Appendix B: Survey Questionnaire	100
Appendix C: Sample Cover Letter	104
Appendix D: Survey Notification in the Newsletter of Property Council of New Zealand	105
Appendix E: Survey Notification in Newsletter of PrefabNZ	106
Appendix F: Survey Notification in the Newsletter of IPENZ	108
Appendix G: Sample Interview	109
Appendix H: Cost Estimation for Research Model	112
Appendix I: Abstract of Paper Accepted for Publication in the Proceedings of the PAQS Conference 2011	113
Appendix J: Abstract of Journal Article Submitted for Publication in the International Journal of Project Organization and Management	114