CRC Construction Innovation
BUILDING OUR FUTURE

Final Report
Offsite Manufacture in Australia

Research Project No: 2005-004-C-03

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Research Program: C
Delivery and Management of Built Assets

Project: 2005-004-C
Off-site Manufacture in Australia

Leaders in Construction and Property Research

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PREFACE

The project team would like to thank all persons and companies that offered their time for workshops, interviews and case studies. Our particular thanks to those who offered valuable information for the examples in this report.

EXECUTIVE SUMMARY

Off-site Manufacture (OSM) offers numerous benefits to all parties in the construction process. The uptake of OSM in Australia has however been limited. This research is a 'scoping study' to determine the 'state-of-the-art' of OSM in Australia. Specific objectives of the study are to:

- review work already done in the area, particularly from the UK and US, to provide a context against which Australia can be compared;
- provide a definition and basic theoretical framework for future work in OSM, whilst also ensuring a common nomenclature is established in the industry;
- determine key economic, social and environmental benefits of OSM within the Australian context, whilst also identifying real and perceived barriers to the use of OSM;
- ascertain key suppliers and sectors of the industry engaged in OSM within Australia;
- recommend how OSM can be driven through the industry, and where future research efforts should be concentrated, particularly noting the role of technology in OSM.

These objectives were addressed by a literature review, three workshops, seven case studies and eighteen interviews. These revealed that skills shortages and lack of adequate OSM knowledge are generally the greatest issues facing OSM in Australia.

This study identified numerous drivers and constraints of OSM. OSM was seen to:

- reduce construction time;
- simplify construction processes;
- provide higher quality and better control;
- provide high levels of consistency;
- produce products that are factory tried and tested;
- reduce costs when resources are scarce;
- reduce costs where work is in remote areas;
- result in improved working conditions;
- reduce onsite risks;
- alleviate skills shortages in certain centres;
- revitalise 'traditional' manufacturing regions;
- provide fewer trades and interfaces to manage and coordinate on site;
- reduce waste on and off site;
- improve housekeeping on site;
- facilitate the incorporation of sustainable solutions; and
- achieve better energy performance.

However, OSM was also seen to: result in

- longer lead-times;
- require designs to be fixed at an early stage;
- need to be designed for;
- be hindered by low IT integration in the industry;
- be impeded by the high fragmentation in the industry;
- be expensive when compared to traditional methods;
- have high set-up costs; possibly increase the consequences of incidents;
- have to cope with restrictive, fragmented, excessive, onerous and costly regulations especially between geographic jurisdictions;
- have to cope with a lack of codes and standards;
- have a negative stigma and attract pessimism based on past failures;
- meet resistance by unions;
- be restrictive and unable to deliver customer desires;
- be difficult to finance;
- result in loss of control on site and into the supply-chain;
- be limited by capacity of suppliers;
- be subject to inter-manufacturer rivalry and protection;
- attract low quality imports;
- be restricted by a lack professionals skilled in OSM;
- be restricted by manufacturers / suppliers lacking skills to enhance OSM efficiency;
- have sufficient industry investment in R&D;
- lack a knowledge portal;
- be subject to difficulties in inventory control;
- be constrained by site conditions;
- need to cope with difficult and expensive long distance transport for large, heavy loads; and
- be restricted by interface problems on site due to low tolerances.

Opportunities to exploit OSM exist within Australia. These include its application in high-density multi-residential complexes as well as the public sector (including hospitals, schools, prisons etc). Promotion of OSM was seen to come primarily from constructors, but also designers and clients.

Technical areas for research and development into OSM were identified as walling systems, modularised housing, lightweight concrete wall panels and internal ceilings. Furthermore, risk identification and mitigation strategies for OSM also need investigation.

Finally, this report presents an action-plan for driving OSM through the industry. Initiatives largely revolve around skills training, education and knowledge provision.

1 INTRODUCTION

1.1 Context

Off-site Manufacture (OSM) has long been recognised, both in Australia and internationally, as offering numerous benefits to all parties in the construction process. More importantly, it is recognised as a key vehicle for driving improvement within the construction industry. The uptake of OSM in construction is however limited, despite well documented benefits. The research aims to determine the 'state-of-the-art' of OSM in Australia. It confirms the benefits and identifies the real and perceived barriers to the widespread adoption of OSM. Further the project identifies opportunities for future investment and research. Although numerous reports have been produced in the UK on the state of OSM adoption within that region, no prominent studies exist for the Australian context. This scoping study is an essential component upon which to build any initiatives that can take advantage of the benefits of OSM in construction. The Construction 2020 report predicted that OSM is set to increase in use over the next 5-15 years, further justifying the need for such a study. The long-term goal of this study is to contribute to the improvement of the Australian construction industry through a realisation of the potential benefits of OSM.

1.2 Project objectives

The objective of the study is to produce a report on the current state and future opportunities of OSM in Australian construction. The report will;

Objective 1 - Review work already done in the area, particularly from the UK, US and Japan, providing a context against which Australia can be compared;

Objective 2 - Provide a definition and basic theoretical framework for future work in OSM, whilst also ensuring a common nomenclature is established in the industry;

Objective 3 - Determine the key economic, social and environmental benefits of OSM within the Australian context, whilst also identifying the real and perceived barriers to the use of OSM;

Objective 4 - Ascertain the key suppliers and sectors of the industry engaged in OSM within Australia;

Objective 5 - Recommend how OSM can be driven through the industry, and where future research efforts should be concentrated, particularly noting the role of technology in OSM.

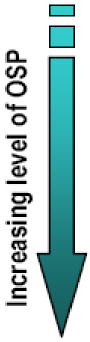
1.3 Definitions and types of off-site manufacture

Many terms have been used to describe the manufacture of building components in places other than the construction site. These have changed over time, with a tendency for terms to vary as the emphasis of the industry changes. Some have fallen from favour simply due to a poor reputation inherited from the past. Terms still in use today include Off-Site Fabrication (OSF), Off-Site Manufacturing (OSM), Off-Site Construction (OSC), pre-assembly and prefabrication (Goodier & Gibb, 2004a). In order to maintain consistency with the Construction 2020 Report (Hampson & Brandon, 2004) the term Off-Site Manufacture (OSM) will be used throughout this report to encompass all the terms mentioned above.

For this report, Off-Site Manufacture (OSM) is defined as the manufacture and preassembly of components, elements or modules before installation into their final location (Goodier & Gibb, 2004a). The degree to which such preassembly takes place can however vary greatly, ranging from basic sub-assemblies, which are largely taken for granted, to entire modules.

A useful categorisation system for OSM is provided by Gibb (1999). The system groups OSM products into 4 levels generally associated with the degree of off-site work undertaken (Figure 1.1). Whilst the levels, as such, are not readily adopted terms by industry, they are useful as each level has a different effect on the project process and may require different management strategies. This study only covers OSM levels 2-4.

Figure 1.1: Levels of OSM



Level	Category	Definition
1	Component manufacture & sub-assembly	Items always made in a factory and never considered for on-site production.
2	Non-volumetric pre-assembly	Pre-assembled units which do not enclose usable space (e.g. timber roof trusses).
3	Volumetric pre-assembly	Pre-assembled units which enclose usable space and are typically fully factory finished internally, but do not form the buildings structure (e.g. toilet and bathroom pods).
4	Modular building	Pre-assembled volumetric units which also form the actual structure and fabric of the building (e.g. prison cell units or hotel/motel rooms).

Source: Gibb (1999) as adapted in Goodier & Gibb (2004a)

1.4 Methodology

The scoping study employed a variety of methods to collect the appropriate data for the report. Data gathering was deliberate and extensive across Australia, ensuring that a variety of perspectives were included in the study. The methods employed for the study are briefly noted below:

1.4.1 Literature review

A comprehensive review of literature and research reports was undertaken to establish the extent of previous work undertaken in OSM, particularly concentrating on the United Kingdom and United States. The main findings of this aspect of the study are reported in chapter two.

1.4.2 Industry workshops

A series of three industry workshops was conducted in Melbourne, Perth and Brisbane to gather the views of a variety of stakeholders in the industry about the drivers and constraints of OSM use in Australia. Potential participants were contacted by e-mail or telephone to invite them to the workshops. A breakdown of workshop attendees is provided in Table 1.1 below.

The programme (example provided in the appendices) for each workshop consisted of a series of presentations on various OSM systems and solutions encountered in the United Kingdom and United States, in both the commercial and residential sectors. An open discussion among delegates followed that documented the drivers, benefits, constraints and barriers to the adoption of OSM in Australia. The main points of the discussion were recorded through notes and, in Perth, by digital video recording. The data was amalgamated with the interviews and analysed for common themes.

Table 1.1: Details of industry workshops

Details	Melbourne [VIC]	Perth [WA]	Brisbane [QLD]	TOTALS
Date workshop conducted	12th December 2006	22nd February 2007	23rd February 2007	-
Venue	State Library Conf. Centre	Dept of Housing & Works	Qld Dept. of Works	-
Number attended	12	8	29	45*
Researchers	*3*	*4*	*6*	*9**
Client (Public)	*1*	*0*	*5*	*6*
Designer	*0*	*1*	*2*	*3*
Constructor	*4*	*3*	*1*	*8*
Supplier	*3*	*0*	*10*	*13*
Other	*1*	*0*	*5*	*6*

** Adjusted so as to account for attendance of multiple workshops*

1.4.3 Case studies and interviews

Seven case examples of the use or manufacture of OSM products were studied. The case studies involved site visits by the researchers, coupled with interviews of key persons in the relevant organisations and project teams. Participants were invited from workshop attendees and those identified by the research/project team. Apart from ascertaining the details and particular factors on the case projects and organisations, additional, broader questions were also raised regarding OSM. This provided depth to the factors emanating from the industry workshops. They further highlight the various challenges that different types of OSM encounter within the industry. A summary of the case studies is provided in Table 1.2 below.

A number of interviews were also conducted with persons not involved in the case studies to provide further breadth to the study. The responses from these, more general, interviews were analysed together with the workshop data. Details of the interviews are listed in Table 1.3.

Table 1.2: Summary of cases documented in the study

Case number	1	2	3	4	5	6	7	Total
State	WA	VIC	NSW	QLD	QLD	VIC	QLD	-
Type (see Ch. 2)	2	2	3	4	2	2	2,4	-
Number interviewed	1	4	3	6	3	2	2	21
Client	-	-	-	*2*	-	-	-	*2*
Designer	-	-	*1*	-	-	-	-	*1*
Constructor	*1*	*4*	*1*	*1*	-	-	-	*7*
Supplier	-	*(4)*	-	*3*	*3*	*2*	*2*	*10*
Other	-	-	*1*	-	-	-	-	*1*

Table 1.3: Details of interviews

Details	Victoria	NSW	WA	TOTALS
Number interviewed	1	2	15	18
Client (Public)	-	-	-	*0*
Designer	-	-	*7*	*7*
Constructor	*1*	-	*6*	*6*
Supplier	-	*2*	*1*	*3*
Other	-	-	*1*	*1*

1.5 Delimitations

The Off-site Manufacture in Australia project was a short six-month scoping study and therefore its findings are limited. Data gathering and consequent applicability of findings is restricted to Australia, and specifically to four main centres, namely Brisbane, Melbourne, Perth and Newcastle. Nevertheless, the factors should be broadly applicable to all major urban settings in Australia.

Within the scope of this project, the definition of 'off-site manufacture' has been left broad to incorporate a wide range of issues.

1.6 Structure of the report

The report consists of five chapters. The first outlines the objectives of the study, and provides a brief overview of the methods employed for data collection and analysis. Chapter two provides a brief introduction to research undertaken in off-site manufacture, distilling the main benefits and constraints found in non-Australian studies. Chapter three presents the main drivers and constraints found through the Australian workshops, case studies and interviews. These are compared with those of chapter two, providing an indication of the factors particular to Australia. The seven cases studied are presented in chapter four highlighting the benefits and barriers of OSM in each. The concluding chapter (five) suggests opportunities for extending the use of OSM in the future.

The following chapter provides the context for the study by briefly outlining previous research in OSM.

2 BACKGROUND

2.1 Introduction

Chapter one introduced the project, outlining the objectives of the study and offering a definition for OSM. This chapter provides an overview of research initiatives undertaken in other countries, particularly the UK and United States. The chapter distils and discusses the drivers, benefits, barriers and constraints of OSM emanating from UK and US research. These form the basis for analysing and comparing the findings from Australia, which are presented in the next chapter.

2.2 Overview of research from the UK and US

The Australian construction industry has recently identified off-site manufacture (OSM) as a key vision for improving the industry over the next decade (Hampson & Brandon, 2004). This echoes sentiments in other parts of the world, specifically the United Kingdom. However, no notable research or industry initiatives have been undertaken in Australia. This study serves to scope the drivers and constraints of OSM in Australia, enabling an informed strategy to be derived for facilitating the adoption of OSM towards 2020.

Australian construction has been characterised as adversarial and inefficient; and in need of structural and cultural reform (Cole, 2003). Several UK Government reports have likewise called for significant improvement of the construction industry, which is likewise described as fragmented, adversarial and inefficient, requiring significant improvement (e.g. Latham, 1994; Egan, 1998). Significant similarities exist between these two construction industries. The reasons for the problems in the respective industries are complex, and require multiple, complimentary initiatives to ensure improvement. However, this call for efficiency and productivity improvements across these industries suggests that OSM has a major role to play. Indeed, the more recent UK government commissioned reports have proposed OSM as an important contributor to progress in the construction industry (e.g. Egan, 1998; Barker, 2004).

Given the high profile offered to OSM in the UK, activities to encourage the adoption of OSM in that industry is considerable, involving several research initiatives, communities of practice and government sponsored forums (e.g. Accelerating Change). Approximately £5 million had been invested by the UK government in research projects that included construction OSM between 1997 and 2001. This figure growing to £10 million when industry funding is taken into account (Gibb, 2001). Notwithstanding the consensus that OSM use will become significant in Australia (Hampson & Brandon, 2004), little coordinated effort has been made with almost no government investment. The review of literature is consequently concentrated on the UK, where the government's demonstrated interest over the past decade has stimulated extensive research in OSM.

Research in the UK has generally concentrated on case studies and anecdotal evidence, with a limited number of industry surveys or applied process mapping and improvement studies. These largely industry-level studies have produced an abundant array of benefits and barriers to OSM, with the hope that these would spur activity. Despite these well documented benefits (Neale *et al.*, 1993; Bottom *et al.*, 1994; CIRIA, 1999, 2000; BSRIA, 1999; Housing Forum, 2002; Gibb & Isack, 2003), uptake is limited. Goodier and Gibb (2004b) suggested that OSM accounted for approximately 2% of the £106.8bn UK construction sector in 2004. Initiatives are nevertheless ongoing, with Modern Methods of

Construction (MMC) seen as an avenue for OSM adoption in sectors such as housebuilding (Barker, 2004; Goodier, Dainty & Gibb, 2004; Pan, Gibb & Dainty, 2005).

A major reason posited for the reluctance among clients and contractors to adopt OSM is that they have difficulty ascertaining the benefits that such an approach would add to a project (Pasquire & Gibb, 2002). The use of OSM, by many of those involved in the construction process, is poorly understood and based on anecdotal rather that data supported intelligence (CIRIA 2000). Given this, the UK industry's ability to appreciate the opportunities presented by OSM is hindered (Blismas *et al* 2005a). Some view the approach as too expensive to justify its use, whilst others view OSM as the panacea to the ills of the construction industry's manifold problems (Groak, 1992; Gibb, 2001).

To address this poor understanding of OSM, several different streams of research have emerged – two in particular are the 'case study' and 'added-value' approaches.

A large effort has focussed on presenting (positive) case studies of OSM within the construction environment. For instance BSRIA (1999) concentrated on mechanical and electrical services cases. Gibb (2001) included a series of case studies with some historical and contemporary examples of OSM ranging across all building types, from military installations, civils structures, airports through to modular office buildings. Most recently this case study approach of demonstrating successful uses of OSM has been further supplemented with a government-sponsored publication of 150 cameo case studies across all sectors of construction from residential through to civil and commercial (Buildoffsite, 2006).

The second stream of research has attempted to identify the value-adding aspects of OSM, so that the benefits could be better assessed and realised within projects considering adopting OSM. The Construction Industry Research & Information Association (CIRIA) conducted a research project entitled "Adding value to construction projects through Standardisation and Pre-Assembly" in 1999 in which the value gained from the application of OSM was reviewed. The reports concluded that a deliberate and systematic use of OSM, which commenced early in the process of the project, would increase predictability and efficiency, and ultimately add value to the process (Gibb 2001).

Further associated studies developed interactive tools for ascertaining the benefits of OSM. Blismas *et al* (2003) developed a tool enabling a comparison between traditional methods and OSM options, highlighting that a holistic evaluation would provide a more accurate and realistic assessment than is commonly used in the industry. A sample of the costing approaches used in six cases considering OSM demonstrated that most costing exercises simply take material, labour and transportation costs into account when comparing various options, often disregarding other cost-related items such as site facilities, crane use and rectification of works. (Blismas *et al*, 2006). These cost factors are usually buried within the nebulous preliminaries figure, with little reference to the building approach taken. Further, softer issues such as health and safety, effects on management and process benefits are either implicit or disregarded within these comparison exercises. Yet it is demonstrated that these issues are some of the most significant benefits of OSM. With this entrenched reductionist approach to costing, OSM will invariably appear more expensive than traditional methods. Other studies (Gibb *et al*, 2003) have looked at the health and safety risks associated with OSM. The issues in these UK studies are unlikely to be applicable to developing countries (Polat *et al* 2006), although highly relevant to the Australian industry.

The benefits and barriers identified in the studies above form the basis for the review in sections 2.4 and 2.5. Apart from the two streams described above, a third area that has not received significant attention is the application of manufacturing principles to construction. There have been some comparative studies undertaken with other industries; including steel, chemical material and manufacturing, where the latter's principles have been successfully used to produce attractive, customised and affordable homes in Japan (Gann 1996, Gibb 2001). However, many argue that these principles could be further applied to construction, particularly relevant to OSM. The following section briefly explores some aspects of manufacture.

2.3 Manufacturing principles

Offsite manufacture is used for several different reasons. At times it may be forced on a construction project due to restricted site access or time constraints, however OSM is largely seen as offering the ability to produce high volume, high quality products based on the efficiencies of general manufacturing principles common to many industries. These perceptions are supported by US research (unpublished research under review) showing that offsite production consistently shows higher productivity growth than onsite production. Despite this evidence of greater efficiency and productivity, it appears the principles are generally poorly understood.

Basic manufacturing concepts

The industrialisation aspects of OSM are often implicit in the research or discussion of the topic, giving the impression that these principles are applied and universally understood, however construction OSM is still largely immature in manufacturing terms. Industrialisation, the broader term that incorporates manufacture, encompasses many different concepts and initiatives. The PATH project (2002) summarised some examples of industrialisation concepts that have been successful in other industries and that may have application in construction. Briefly these include (but are not limited to):

- Just-in-time (JIT) manufacturing that includes effective supply chain management;
- Flexible, agile, lean production systems;
- Concurrent engineering and design for manufacturers that use various techniques and processes to enhance the manufacturability of the product;
- Manufacturing requirements planning (MRP), manufacturing resource planning (MRP II), and enterprise resource planning systems (ERP), which are processes that are enabled by information technology;
- Concurrent design, where communication among designers and the producers (construction foremen, site supervisors, trade contractors) can significantly improve the efficiency of production;
- Time- and space-based scheduling that facilitates keeping track of who is where, doing what, and when. This type of scheduling is especially appropriate for construction activities, as crews move among sites.

Some aspects of all of these have been adopted to some extent in construction. JIT and concurrent engineering have received notable attention in construction although mainly regarding on-site works. Two other areas where manufacture and construction have converged regard product modelling and lean construction.

The first is ***Building Information Modelling*** (BIM) which describes the virtual modelling of products, with all associated information within a single model. BIMs can contain numerous dimensions including spatial, geographic, material, component, lifecycle performance and workflow information. The American Institute of Architects simply define BIM as "a model-based technology linked with a database of project information". Essentially it allows information to be linked into the building model. This can take the form of geometrical, non-graphical and other information. The wealth of information contained within or linked to BIMs allows the possibility for direct interfacing between designers, suppliers, manufacturers and users. This offers future CAD/CAM-type possibilities for the construction industry that can interface directly with OSM.

The second area of convergence is ***Lean construction*** (LC) which seeks to adopt lean production methods into construction. It has established itself in certain sectors of construction, although is not yet widespread. The manufacturing principles underpinning LC lend themselves well to OSM (see for example Ballard & Arbulu, 2004, for lean concepts and OSM). Its core concepts are encapsulated by Roy *et al* (2003) and are:

- specify work value in the eyes of the customer;
- identify the value stream and eliminate waste;
- make value flow at the pull of the customer;
- involve and empower employees;
- continuously improve in the pursuit of perfection.

These five core concepts can be articulated into two simpler principles, namely 'efficiency' and 'flexibility'. 'Efficiency' describes an understanding of value, the elimination of process and material waste, the synchronisation of supply-chains, and the continuous improvement of process and product. 'Flexibility' alludes to delivering customer-controlled solutions – both now and in the future. The rigidity of production processes is increasingly seen as a hindrance, and is stimulating further development for flexible delivery in manufacture. Further, flexibility in the use of the product into the future is equally drawing attention (sometimes referred to as 'open buildings'). Future OSM solutions will need to embrace both of these aspects.

Efficiency and flexibility

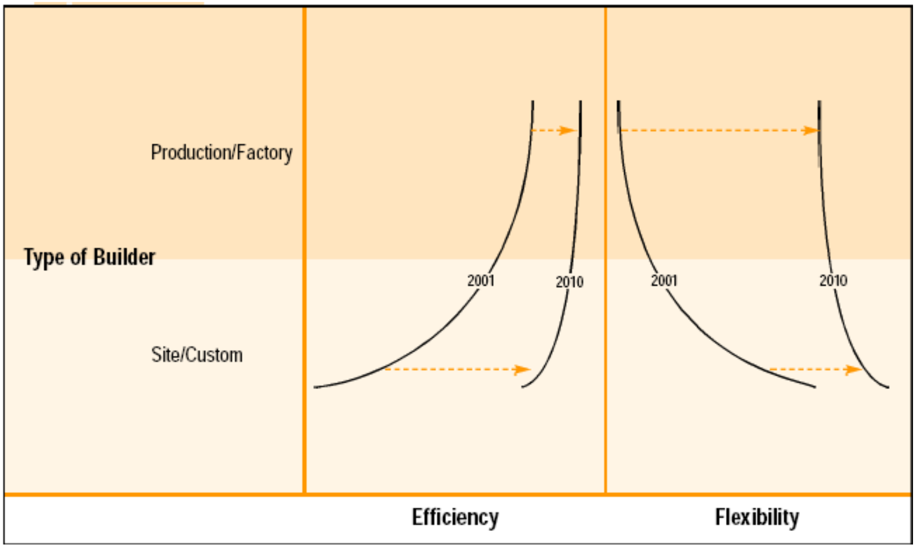
The tension that has naturally existed in manufacturing is that between volume and choice. High volumes and therefore economies of scale have naturally precluded variance amongst products, limiting customer choice. Manufacturers in construction have long argued that large volumes of the same product are needed to ensure viability. Standardisation has therefore been put forward as an enabler of construction OSM. However, to ensure there is a stable demand for standardisation, either choice needs to be limited or demand needs to be increased. Both options have inherent problems as viable strategies.

The drive to combine standardisation with systematic building practice has grown alongside the development of the off-site fabrication shops and the factory-based building component industry (Groak 1992). However the struggle to resolve the conflict between uniformity and variation, and between maximum standardisation and flexibility still continues to be a source of tension. The requirement for standardisation to include interchangeability of components highlights that it is the interfaces between the components that is important, rather than the components themselves (Gibb 2001). Future developments in non-construction manufacturing and OSM will be the replacement of mass production with mass customisation. Customer's needs and desires will be important drivers for such customisation, however a reliable and responsive supply chain with short lead times will be essential for an efficient customised solution (Roy *et al* 2003).

The future

This view has been adopted by PATH (2002), in which they called for increasing industrialisation in US house building towards the year 2010, mainly targeting an increase in flexibility. Figure 2.1 below illustrates this concept, showing the shift required in the decade to 2010, calling for manufactured housing to improve in efficiency, but most importantly to make marked strides in offering flexibility that is currently enjoyed by site-based construction. OSM needs to deal with this trend if it hopes to make inroads into the construction industry.

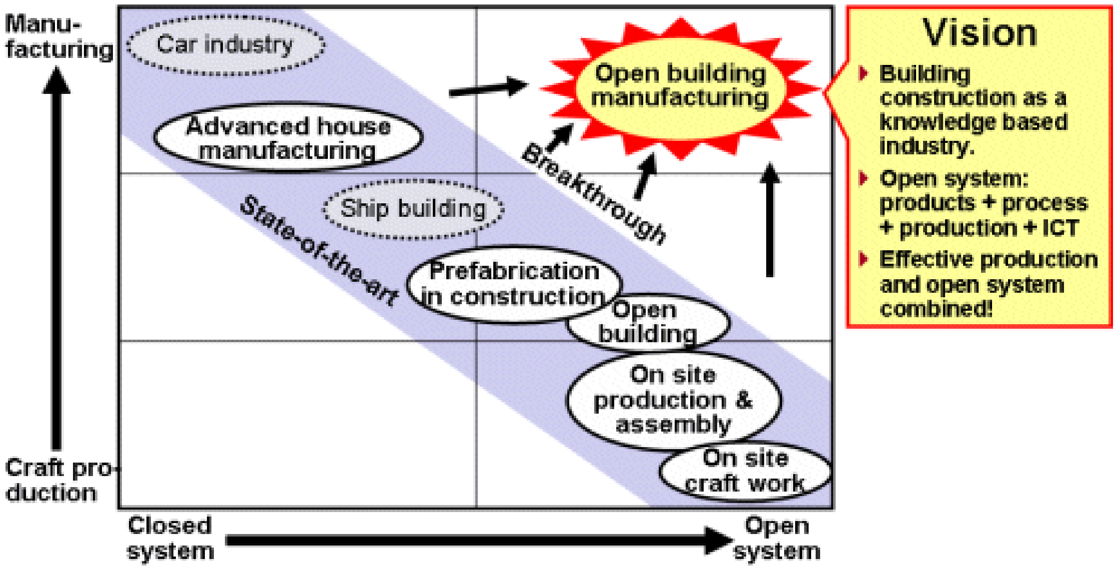
Figure 2.1: Industrialising the house building process (PATH, 2002)



Source: Technology Roadmap: Whole house and Building Process Redesign, PATH (2002)

Another representation of this idea is communicated by Manubuild (2007) in Figure 2.2, who illustrate the state-of-the-art in construction manufacture showing the array of sophistication across all types of construction delivery. Whilst manufacturing (i.e. efficiency) aspects are well understood by some sectors, such as advanced house manufacturing, the systems are closed (i.e. inflexible). Generally the more traditional methods of construction are open and flexible yet are bespoke and inefficient. The challenge facing the advance of construction is to break through to 'open building manufacturing' that combines highly efficient manufacturing in factories and on sites, with an open system for products and components offering diversity of supply in the market (Manubuild, 2007). These views echo those mentioned above, essentially efficiency combined with flexibility. OSM therefore must embrace this view if it has any hope of succeeding in the future.

Figure 2.2: Open building manufacturing (Manubuild, 2007)



Source: www.manubuild.net, 2007

The next section extracts the drivers/benefits and constraints/barriers to OSM that have been documented in previous research. These lists informed the study and are used to compare the findings from this study.

2.4 Drivers and benefits

The successful completion of a construction project whether using OSM or traditional approaches, depends on the clear identification of the key factors driving the project, as well as an appreciation of the constraints affecting its efficient completion (Gibb & Isack 2001). The study of OSM is simplified by initially identifying the drivers and constraints for their use – an approach consistent with a scoping study. Initially the drivers and benefits will be listed, before moving to the barriers and constraints in the next section. The split between these positive and negative aspects can be arbitrary at times. A driver stated negatively can be a construed as a barrier, and *vice versa*. In this study the terms drivers and barriers are used interchangeably, although it is appreciated that their meanings differ.

The broader benefits of mass production essentially centre on increased control of the total construction process (Gibb 2001). The Building Research Establishment (BRE, 2004) believes that offsite construction offers the following advantages:

- the development of a controlled environment which leads to benefits in OH&S, handling and storage of materials;
- ability to manufacture in shapes and styles impossible to achieve on site;
- reduction of waste;
- an associated reduction in unit cost as production increases.

Apart from these broad benefits of industrialisation, more specific client benefits have been articulated in various forms by CIRIA (2000), PATH (2002); Gibb and Isack (2003); Roy *et al* (2003); Goodier and Gibb (2004a); PATH (2004) and Blismas *et al* (2006). These have been distilled and recast in Table 2.1 below.

Table 2.1: Drivers of OSM identified in the literature

Drivers	Description
Process & Programme	Less time on-site—speed of construction
	Speed of delivery of product
	Less time spent on commissioning
	Guaranteed delivery, more certainty over the programme, reduced management time
	Programme driven centrally
	Simplifies construction process - pragmatism
Quality	Higher quality—on-site and from factory
	Product tried and tested in factory
	Greater consistency—more reproducible
	More control of quality, consistent standards, reduced snagging and defects
	Products work first time
Cost/Value/ Productivity	Lower cost
	Lower preliminary costs
	Increased certainty, less risk
	Increases added value
	Lower overheads, less on-site damage, less wastage
	Reduced whole-life cost
	Allows systems to be measured
People & OHS	Fewer people on-site – possibly reducing OHS risks
Skills & Knowledge	Site skills/knowledge - People know how to use products - Limited or very expensive available skilled on-site labour
Logistics & Site Operations	More success at interfaces
	Less site disruption
	Reducing the use of wet trades
	Removing difficult operations off-site
	Work continues on-site independent of off-site production and *vice versa*
	Restricted site layout or space
	Multi-trade interfaces in restricted work areas eliminated
	Live working environment limits site operations – overcome by OSM
	Site restricted by external parties alleviated
	Security onsite or high levels of theft mitigated
Environmental Sustainability	Reducing environmental impact during construction
	Maximising environmental performance throughout the lifecycle

2.5 Constraints and barriers

The constraints to OSM are highly varied, with a consequent variation in emphasis between authors. Table 2.2 condenses the views of numerous authors into eight themes (Blismas *et al*, 2005a; Ballard & Arbulu 2004; PATH, 2004; Goodier & Gibb, 2004a; Gibb & Isack, 2003; PATH, 2002; Pasquire & Gibb, 2002; BSRIA, 1999; CIRIA, 1999; Groak, 1992).

Table 2.2: Constraints to OSM identified in the literature

Constraints	Description
Process & Programme	Longer lead-times
	Inability to freeze design & specification early, including a constant stream of variations cannot be easily accommodated in OSM
	Key decisions early in the process preclude OSM as there is a poor fit between design and OSM processes
	Continuation of the fragmented 'cottage industries' approach that prevails in some sector
Cost/Value/ Productivity	Seen as expensive when compared to traditional methods
	High initial cost for some solutions
	Obliged to accept lowest cost rather than best value
	Obliged to accept element-specific costing
	Commercial sell for OSM can be high, or over-stimulation in OSM
	Clients having difficulties understanding the benefits
Regulatory	Restrictive, fragmented, excessive, onerous, costly regulations especially between jurisdictions
	Few codes and standards available
Industry & Market Culture	Deep rooted pessimism over past mistakes rather than a determination to learn from history. Client resistance, often due to negative image.
	Clients view OSM as standardised and lacking any customisation
	Strong client perception that OSM, quick-built products are of lower quality
	Resistance by labour (especially unionised) to change
	Resistance to change by builders – due to desire for independence, lack of training by suppliers
	General construction industry fragmentation
	Difficult to obtain finance from institutions not familiar with OSM
Leadership	Lack of visionaries committed to change in the industry
Supply-chain & Procurement	Unwilling to commit to single point supplier (increased risk)
	Limited choice of supply-chain for the project
	Limited capacity of supplier(s) or supply not available locally
	Inter-manufacturer rivalry preventing the development of a common framework and interchangeability of products, rather than encouraging increased competition and supplier capability. Lack of standardisation especially at interfaces

Constraints	Description
Skills & Knowledge	Professional skills/knowledge: - General lack of systems engineering and systems analysis, so that durability and buildability are developed concurrently with aesthetics - Early advice unavailable - Limited previous OSM experience within the team, especially a lack of in-depth manufacturing and engineering skills concentrating on construction, including the provision of training and equipment to trades - Limited expertise in off-site inspection, often resulting in poor quality assurance on products
	Site skills/knowledge: - Lack of familiarity with OSM systems and use, including lack of new trades and training schemes for their use - Lack of IT knowledge and tools by small builders to improve process
	Offsite skills/knowledge: - Product or component repeatability not feasible due to low volumes and bespoke nature of products - Difficult to re-use process on new projects - Concerns over intellectual property rights
	Industry knowledge: - Lack of investment in the effective research and development, including innovation - Absence of a common pool of industry knowledge
Logistics & Site Operations	Problem transporting large, heavy manufactured products to site
	Limitations to movement of OSM units around site
Technological	Reticulation of services though panelised systems is problematic

2.6 Summary

The review of literature on OSM drivers and constraints provides a basis for understanding and comparing the findings of this study. The previous chapter listed the objectives of the study, informing the focus of the literature review. The next chapter (Ch. 3) summarises the results from the industry workshops and interviews undertaken in some of the major centres across Australia. Together with the outcomes of this chapter a brief comparison is made, highlighting where issues regarding OSM in Australia differ. Chapter four presents seven case examples of OSM in Australia, before the concluding chapter suggests the way forward for OSM in Australia.

3 OFF-SITE MANUFACTURE IN AUSTRALIA

3.1 Introduction

The review of drivers and constraints in the previous chapter (Ch. 2) provides a useful basis for analysing, presenting and comparing the results from the industry workshops and interviews undertaken across Australia. The chapter begins by presenting the general findings from the industry responses, before condensing these into two sections – drivers and constraints. The discussions from the Melbourne, Perth and Brisbane workshops together with the several interviews conducted form the source for the findings in this chapter. Chapter one outlined the methodology and participant numbers for the workshops and interviews. Following the derivation of drivers and constraints for OSM in Australia, a brief comparison is made with those found in other countries. The next chapter (Ch. 4) follows with seven examples from Australian industry that illustrate some of the issues discussed in this chapter.

3.2 General observations of OSM in Australia

In general, all participants in the interviews, workshops and case studies expressed a keen willingness to explore OSM implementation on future projects, and noted that there was an increasing use of OSM products in the industry. However, a lack of knowledge and information emerged as one of the key barriers in the industry. These will be explored individually later in the chapter.

3.2.1 Level of OSM in Australia

Ascertaining the degree to which OSM is undertaken in a country is very difficult, as evidenced by the work of Goodier and Gibb (2004b). Part of the difficulty is the vague boundary that exists between the construction and manufacturing industries. In the US for instance much of OSM census data will be captured under manufacturing and not construction. These vagaries are not easily overcome, and a number of assumptions are needed to make any reasonable estimate.

Gibb and Goodier (2004b) in trying to ascertain the size of the UK OSM market had to make several approximations and assumptions to derive their figures, and also found it 'extremely difficult' to obtain or calculate the true proportion of offsite which is imported or exported. In order to obtain meaningful industry volume data a combined top-down and bottom-up approach is required, which is both costly and time consuming – and may not produce accurate data. Such a study is beyond the scope of this project. Nevertheless, in order to gain some indication of the types and volume of OSM occurring in Australia a comprehensive key word web search was initiated.

This soon showed that it was difficult to gain information about all the individual companies practicing OSM. This was related to a number of factors, including:

- Many companies, particularly the smaller ones, do not have websites;
- Many companies do not specifically advertise the fact that they make OSM items;
- Perceived uncertainties about what actually is OSM;

- No trade association providing a portal for publicising OSM;
- Some OSM items are of a transient nature – in that the manufacturing facility is set up and used for a particular construction project. Once finished this facility is removed.

The only way to determine the extent of OSM in Australia would be to conduct a comprehensive industry survey, which was outside the scope of this study.

However the result of the web searches produced a total of 50 manufacturers, whose information showed a direct involvement with OSM (this sample excluded roof truss manufacturers). The following table shows the number of manufacturers in that sample producing items from the different levels of OSM, and could be considered to suggest the current balance of manufacturing across all aspects of OSM within Australia.

It should again be noted that this is in no way a representative sample of the industry, but merely a crude indicator.

Table 3.1: Activity in the different levels of OSM

Level	Category	Typical items	No. of organisations
2	Non Volumetric pre-assembly	- Pre-cast concrete – beams, floors, wall panels, columns, pipes; - Steel fabrication; - Timber and steel wall panels	41
3	Volumetric pre-assembly	- Wet room modules	5
4	Modular building	- Homes; - Schools; - Shelters	8

NOTE: a number of manufacturers produce items across the three levels of OSM.

During interviews, respondents in WA indicated that the two most commonly used OSM products are framing systems and cladding systems. Structural Insulated Panel Systems (SIPS), foundations and building services were related as the least commonly used. This concurs with the indications in Table 3.1.

3.2.2 Terminology

There appeared to be a general understanding of the term 'Offsite Manufacture', although some participants noted that they were more familiar with terms including 'pre-cast', 'pre-fabrication' and 'pre-assembly'. These terms are still the predominant terms, although their meanings can be restrictive.

Some however pointed to ambiguity surrounding OSM terminology, suggesting that it could be applied to standard construction components including bricks, structural steel, and even joinery. This did not manifest during the workshops, but only the interviews. The general use of OSM however did not appear to be problematic and could continue to be used.

3.3 Drivers and benefits of off-site manufacture

The drivers and benefits of OSM as described by respondents were distilled into Table 3.2 below. The table correlates results with the literature, and suggests how these can be enhanced. The correlation notation indicates the strength and direction of agreement with the drivers found in the literature.

Table 3.2: Drivers of OSM as identified by the Australian workshops and interviews (comparison is made with drivers identified in the literature)

Drivers	Description of drivers	Comments and notes	Correlation	Action
Process & Programme	- Reduces construction time - Simplifies construction process	Significant contributor to reducing whole cost of construction, e.g. - lower site-related costs for constructors, - earlier income generation for clients Quicker completion reduces site disruptions and hazards, e.g. - decreased road closures etc.	AUS < LIT Less emphasis on process drivers and speed of delivery	Benefits of speed of construction need to be emphasised
Quality	- Higher quality and better control in the factory - High levels of consistency - Product tried and tested in the factory	Product testing allows for better control of safety factors/margins Can deliver better product quality, consistency, component life, reduced whole-life cost and defects through QA in controlled factory environment. e.g. - level of accuracy for steel fabrication better offsite - better surface finish achievable for precast concrete which is not being covered - some products offer 100 year design life unlike in-situ - Can achieve better surface finish Design can be refined in manufacture to improve quality Enables new/different materials and processes to be used, e.g. - elaborate surface definitions/colours/textures can be easily specified and precast	**AUS = LIT** Degree of agreement between literature and AUS very high	Use this to mitigate negative sentiments about OSM (see constraints)
Cost/Value/ Productivity	- Lower costs where work is under resource pressure - Lower costs of workforce in remote areas - Lower whole cost of construction	Costs related to material and labour force pressures drives OSM, e.g. - trade skills shortages such as bricklayers - reduced supply of formwork in Queensland - brick shortage in WA Allows for more efficient designs that reduce need for high safety margins and specifications Reduced labour/trade living expenses in remote areas Significant contributor to reducing whole cost of construction, e.g. - lower site-related costs for constructors, - earlier income generation for clients	**AUS < LIT** Some apparent lack of awareness of possible costs savings over whole-life	Whole-life cost needs to be emphasised with understanding of value rather than purely direct material/labour costs
People & OHS	- Improved working conditions for labour - Reduced onsite risks due to lower likelihood and exposure	Improved working conditions for workers, controlled environments to protect workers from elements such as rain, high temperatures etc. Reduces OHS risks onsite due to - reduced time on-site - reduced likelihood due to lower hazard exposure, e.g. open hole in sewage pipe-laying reduced - fewer trades and people on-site OHS risks can be better controlled in factory environment - OSM could be driven if increased responsibility is put on designers for OHS OSM gives sense of job security, not reliant on variable subcontractor work with a more stable workforce an better loyalty - Work ethic reported as very low in SE Qld due to high volume of work. High staff turnover, absenteeism and low loyalty	**AUS >> LIT** Higher emphasis by Australian respondents to labour working conditions, perhaps due to climate and IR considerations	Take advantage of positive work benefits OSM can provide to a workforce to promote OSM

Drivers	Description of drivers	Comments and notes	Correlation	Action

Skills & Knowledge	- Significant shortage of skilled trades in construction, being acute in certain centres
	- Revitalisation of 'traditional' manufacturing regions with high unemployment
		Site skills/knowledge:
		- Low skills bases in remote areas of the larger states
		- Shortage of trade skills a major driver for OSM
		  o fewer trades needed in OSM environment
		  o reduce risk in 'boom' times with shortages
		  o during shortage, it is difficult to find good tradesman and exposes poor tradesman
		  o systems that require lower skills may be favoured (e.g. steel frames), likening to 'mecano-set' mentality
		Skills shortages identified in WA include:
		- bricklayers;
		- form workers;
		- plasterers;
		- carpenters; and
		- shop detailers
		Offsite skills/knowledge:
		- Can revitalise manufacturing sectors in 'traditional manufacturing' areas that have lost their industries
		  o benefits especially in areas of low skills where labour costs are low
		  o improves local skills base
			AUS > LIT
			Awareness of the ability to utilise OSM to revitalise regions (see Case 2 for example of this)
				Importation of 'cheaper' labour suggested by respondents as possible with new IR laws; but hesitance expressed due to problems from Unions
				
				Skills training

Logistics & Site Operations	- Fewer trades and interfaces to manage and coordinate onsite - Ability to transport large loads easily	Fewer trades on site aid coordination and reduce interfaces Ability to build and transport increasingly large components for delivery to (remote) areas without trade base, skills or facilities, e.g. - 100 tonne bridge beams for remote areas Enables better trade coordination	AUS<LIT Slightly fewer details on the particular benefits, perhaps due to low levels of OSM use	Demonstrate process improvements and interface reductions
Environmental sustainability	- Waste reduced on and off site - Better housekeeping due to removal of trades - Sustainable solutions better incorporated through design - Can achieve better energy performance	Building and especially on-site waste (up to 40% of landfill) can be reduced by OSM, e.g. - one case used waste from manufacture to fuel site - one pre-caster claims all steel and concrete recycled with no waste The Building Codes of Australia Section J – Energy Efficiency (ANCN 2007b) expected to drive greater OSM use due to better ability to design performance of panels Cleaner sites due to decreased on-site wet-trades OSM is innovative in material and design and therefore can incorporate sustainable solutions including easier re-use and recycling after useful life	**AUS=LIT** Although the literature was not as explicit, its drivers encompass those mentioned for Australia	Demonstrate that better efficiency ratings due to better dimensional tolerances are possible Demonstrate sustainability benefits
Other	- Quick response housing for emergency/natural disasters	OSM items such as homes/cabins can be stored as stock. This would give an improved response in times of need - to get the products onto site and in use in as short time as possible etc.	AUS<<LIT Not mentioned in the literature	Requires government policy for this driver to be operational

3.4 Constraints and barriers of off-site manufacture

The constraints and barriers of OSM as described by respondents were distilled into Table 3.3 below. The table correlates results with the literature, and suggests how these constraints can be mitigated or addressed. The correlation notation indicates the strength and direction of agreement with the constraints found in the literature.

Table 3.3: Constraints of OSM as identified by the Australian workshops and interviews (comparison is made with constraints identified in the literature)

Constraints	Description of constraints	Comments and recommendations	Correlation	Action
Process & Programme	- Longer lead-times - Inability to fix design without further changes - OSM must be designed in, not retrospectively - Low IT integration in the industry - High fragmentation in the industry	Design process is based on traditional mode and is unsuited to OSM Requires more pre-planning on a project, suggested that lead times required may nullify any overall time advantages Generally low level of IT integration in construction – high levels of integration make OSM efficient Advantage only possible if facility designed for OSM, not fitted retrospectively Does not permit changes, as these are expensive once manufacture has commenced Knock-on effects of problems in the manufacture process can be significant	**AUS=LIT** High degree of correlation between the literature and Australian observations. Industry conditions are generally similar between Australia, UK and parts of US	Disciplines and processes need to be streamlined using integrated IT systems. Including development of IT based project management system to coordinate subcontractors and integrate the process. Need to learn from other industry's systems – from design through order and production, giving - Improved design tools - Better engineering solutions - Easier control and specification - Just in time capabilities - Fully integrated billing and payment – time and materials - More accurate production Information and document distribution and management protocols required in high IT environment, so as not to overload Storage and ownership of digital information should be addressed Client needs to decide with team to design OSM into the project from concept stage, however client may be more interested in functionality rather than method of delivery
Cost/Value/ Productivity	- Seen as expensive when compared to traditional methods - High initial and set-up costs	Seen as expensive when compared to traditional methods High initial set-up costs OSM seen to increase design fees Cranage costs can be high Transport costs interstate or over distance costly and can negate any advantage	**AUS<LIT** Fewer cost/value constraints identified, although implications are that similar issues are relevant	A system or method is required to objectively ascertain the benefits of OSM Demonstrate that OSM systems should reduce design fees as these are 'written-off' within the product
People & OHS	- May increase consequence of incident	Need for crane has safety issues associated with large loads etc.	**AUS>LIT** None identified in literature	Perhaps use screen lifting and self-climbing cranes
Regulatory	- Restrictive, fragmented, excessive, onerous, costly regulations especially between jurisdictions - Few codes and standards available	Australian Building Greenhouse Rating (ABGR) only attributes 20% of the building to energy - Energy ratings not affected by OSM as measured at the design stage on the building rather than the construction process - Section J can be used to encourage more OSM components Legislation and qualifications unclear for pre-casters (versus concreter). Appears concreter needs more qualifications with manufacturing and installing tilt up than a civil engineer with experience in manufacturing and installing pre-cast Inadequate Codes for OSM varieties, e.g. - addresses tilt-up but not other pre-cast products Inconsistency between local and shire legislation and interpretations, e.g. - difficulty getting sign-off on electrical or plumbing systems in different areas not familiar with system	**AUS=LIT** High degree of correlation between the literature and Australian observations. However performance requirements of housing higher in the US and UK due to harsher weather conditions, nevertheless regulatory fragmentation still significant	Energy rating systems to be used to demonstrate that OSM can exceed current standards Regulators (e.g. BCA) need to look at (pre-cast), accreditation for OSM skills Regulators need to look at (pre-cast) introducing separate section to code for pre-cast Changes to fire engineering standards could be re-thought to open the steel market

Constraints	Description of constraints	Comments and recommendations	Correlation	Action
Industry & Market Culture	- Negative stigma and pessimism of OSM due to past failures - Resistance by unions to changes - OSM seen as restrictive and unable to deliver customer desires - Difficulty obtaining finance	Unionised labour market limits flexibility OSM can give. General resistance to offsite work, although this resistance seems to be diminishing Client's desire for particular structures or traditional finishes may inhibit OSM, e.g. - double-brick housing in WA 'The whole industry is conservative' Resistance to change by contractors, suppliers and professions Design options seen as too limited Negative stigma from failures or perceived low-quality products, e.g. - poor pre-cast systems from post-war through to 1960s - 'transportables' for schools, mining and harsh remote climates - bad experiences with 'cowboy' suppliers Difficulty obtaining finance from institutions more familiar with traditional approaches	**AUS=LIT** High degree of correlation between the literature and Australian observations.	Different approaches required to market commercial and residential products Annual OSM products and careers expo to showcase and promote OSM, trade shows and seminars Changes to tertiary education - emphasis on future trends and OSM for engineers, architects and CMs Emphasis should be on mass customisation rather than mass production, includes increased standardisation but not necessarily repetition Improve government standards for civic architecture intended to improve building quality and longevity, thus, showcasing OSM products in operation and dispelling negative perceptions Establish government funded display centres showcasing OSM products in use

Supply-chain & Procurement	- Loss of control onsite and into the supply-chain - Limited supplier capacity - Inter-manufacturer rivalry and protection - Low imported quality	Control of supply-chain, especially interstate and international is high risk Capacity to supply OSM products is limited (severe in places such as WA where industry is small and rely on east with high transport costs) Importation of OSM products prone to low quality and non-compliance to Australian standards Potential loss of project control, especially onsite Different payment terms and cash-flow arrangements required for OSM Market protection from traditional suppliers	**AUS>LIT** Australian respondents appeared to identify more constraints in the supply-chain than those in the literature, perhaps due to the size of Australian market and physical disparity of centres	Assembling project team early in the process (e.g. alliance or D&B) improves relationships and improves OSM success Manage, inspect supply-chain actively

Constraints	Description of constraints	Comments and recommendations	Correlation	Action
Skills & Knowledge	- Lack of skills by professionals in OSM with subsequent effects on the entire process - Lack of skills in manufacturers/ suppliers to enhance OSM efficiency - Lack of industry investment in R&D - Lack of knowledge repository, portal	Professional skills/knowledge: - Limited expertise in the marketplace by designers and constructors - Design philosophy is based on traditional methods that are unsuited to OSM - Finer design skill and understanding is required to ensure interfaces are managed and designed - Education and training still focussed on current practices, not future ideas Site skills/knowledge: - Requires higher onsite skill to deal with low OSM tolerances for interfaces - May necessitate higher levels of IT literacy which is low in SMEs Offsite skills/knowledge: - Pre-casters uncomfortable with new technologies/systems of OSM, qualifications are not adequate or transferable. Reliance is currently on supplier to train contractors to install correctly - Particular OSM specific skills are limited, e.g. o logistics management o coordination of OSM installation o erection skills Industry knowledge: - General lack of guidance and information on OSM available in the market-place. Lack of single information source, rely on experience. Particularly disadvantages SMEs - Lack of R&D in OSM	**AUS=LIT** High degree of correlation between the literature and Australian observations.	Focus on future trends and ideas for CMs, Engineers and Architects, as well as students of these disciplines Funding to attend conferences/meetings needs to be encouraged Improved research incentives to stimulate local innovation and start-ups A whole philosophy change is needed – a paradigm shift. Design research for developing innovative integrated designs Increase appeal for manufacturers to employ apprentices Better skills training to address requirements Locate manufacture plant in areas with suitable labour source Conduct career days at schools to interest people in the OSM market Portal for international trends, products and processes, especially in WA Market research needed to ascertain opportunities
Logistics & Site Operations	- Difficulties in stock/inventory control especially with large heavy products - Site conditions can constrain OSM use - Transport difficult and expensive for long distance and large, heavy loads - Interface problems on site due to low tolerances	Production facility logistics and stock management difficult, especially with large concrete products Site specific constraints include: - limited access on site for manoeuvre - limited or restricted access to site for delivery - access of cranage to site - scale of the facility/structure - size of components Crane use vulnerable to stoppages, that are high risk for OSM, e.g. - crane driver stoppage, - high winds - hook time availability Transport of large components limited due to: - load/mass of item - road widths - bridge load capacities - transport curfews - requirement of escorts at great expense E.g. Road travel restrictions (NSW): - 2.5-3.5m can only travel between the hours of 09:00 and 15:00 - 3.5-4.5m must have an escort vehicle - 4.5m + must have a police escort – which has massive costs High mass of PC concrete products results in higher transport costs Low tolerances increase problems when fitting components onsite	**AUS>>LIT** Constraints appeared greater than those reported in the literature Transport costs due to distances are expected for Australia Crane driver vulnerability is State-based and can be problematic	Bar coding or RFID (radio frequency identification) management is crucial to help identify where parts are all the way along the supply and construction phase. RFID also allows for a 'birth certificate' so any item can be tracked back at any point in the building's construction and life If possible locate manufacturing plant close to the project to reduce transport costs and logistics

3.5 Analysis and Opportunities for OSM

The analysis of drivers and constraints in sections 3.3 and 3.4 illustrated that the issues facing the Australian construction do not differ markedly from those of other developed countries, although issues such as market size, physical distance and skill shortage are prominent problems.

In order to explore the possible opportunities for OSM in Australia a basic analysis of the relative strength of driver and constraint themes was conducted based on the number of incidences that an issue was raised between regions and participants. Table 3.4 illustrates this analysis, indicating the relative strength in brackets.

Table 3.4: Relative importance of drivers and constraints in Australia

Drivers	Relative strength	Constraints	Relative strength
Skills & Knowledge	Very High	Skills & Knowledge	Very High
Process & Programme	Moderate	Process & Programme	Very High
Quality	Moderate	Industry & Market Culture	High
Logistics & Site Operations	Moderate	Supply-chain & Procurement	High
Cost/value	Moderate	Cost/value	Moderate
Environmental sustainability	Moderate	Regulatory	Moderate
People & OHS	Low	Logistics & Site Operations	Moderate
Other	Low	People & OHS	Moderate-low

Clearly constraints, in rudimentary numbers, outweigh the drivers for OSM indicating that sentiment is somewhat against its widespread adoption.

Surprisingly the clear forerunners that drive and constrain OSM are both regarding skills and knowledge. The chief driver or apparent benefit of OSM appears to be the increasing trade skills shortage in the construction industry. This is particularly apparent in the State capitals and in remote areas of Australia. A history of underdevelopment of trade skills, together with restrictions and resistance to importation of trade skills is resulting in shortages of trades such as bricklayers. This is sparking interest in OSM that may be able to overcome the shortages with the use of un- or semi-skilled labour.

Conversely, the greatest constraint to OSM is likewise a lack of skill, knowledge and understanding of OSM among the entire construction supply-chain, from client, through professionals, suppliers to constructors. This paradox is natural given that the market is in transition. Addressing both these aspects simultaneously will be required.

Process and programme constraints are similar to those identified in the literature and are reflective of the industry's traditional fragmented structure. Difficult industry-level transformation is required. To some extent the negative stigma (confirmed by the high Industry & Market Culture constraint) and strong inertia of the industry contributes to the challenges faced by the sector of the industry desiring this transformation. Again the high procurement barriers confirm the paradigm shift required for OSM adoption.

3.5.1 Opportunities

Throughout the interviews participants offered views on where opportunities exist in OSM within Australia. Briefly these are listed below:

Suggested markets for the increased use of OSM in Australia:

- High-density multi-residential complexes due to product standardisation and repetition (interestingly excluded detached housing in WA);
- Public sector, such as hospitals, schools, prisons etc.

Groups seen as drivers of OSM in the market:

- Contractors/constructors seen as key drivers of OSM (this however probably assumes the current process of procuring constructed facilities);
- Designers also perceived as strong drivers of OSM;
- Clients identified as occasional drivers, particularly with regards to commercial projects requiring rapid construction and tenancy.

Research & Development suggestions for OSM include:

- Walling systems, particularly for traditional markets that prefer brickwork, as the continued viability of double-brick residential construction was questioned (WA);
- Modularised housing, particularly in remote areas and those with severe housing shortages;
- Lightweight concrete wall panels;
- Risk identification and mitigation strategies for OSM.

3.6 Summary

A condensed set of drivers and constraints, highlighting those peculiar to Australia have been put forward in this chapter. The analysis revealed that skills shortages and lack of adequate OSM knowledge are generally the greatest issues facing OSM in Australia. The drivers and constraints determined in this chapter are illustrated in a series of seven cases presented in the next chapter. The cases serve to highlight both the drivers and constraints. A further discussion of how OSM will progress into the future is offered in chapter five.

4 CASE EXAMPLES IN AUSTRALIA

4.1 Introduction

Seven cases are presented in this chapter, illustrating some of the drivers and constraints derived from the workshops and interview data in chapter three. The cases were selected to provide a variety of OSM levels and contexts. The first five of the cases relate projects on which OSM products were used. The last two cases are of organisations that manufacture off-site products. Each case begins with a description of the project and product, before listing the benefits, barriers and lessons from the project. The chapter concludes with a summary analysis of the cases. The chapter following discusses the opportunities to extend and facilitate the use of OSM in Australia.

Each case commences on a new page.

4.2 Case 1 – Bull Creek Station Project

4.2.1 Historical Context

The South West Metropolitan Railway in Perth is a large-scale transport infrastructure project. The route extends from Perth CBD to Mandurah and comprises of almost 82 kilometres of track, 15 stations and 20 bridges. This case study focuses on the construction of Bull Creek Station, Leach Highway.

Located at the Kwinana Freeway (north-south) and Leach Highway (east-west) junction it is situated almost 14 kilometres from Perth CBD in an area which is predominantly low density residential land. Categorised as a ‘major transit interchange’, the Station is forecast to cater for more than 3100 weekday daily boardings, peaking at around 1400 passengers during weekday morning periods.

A range of transport alternatives, including bus and rail services, motor vehicles (‘park n’ ride’ and ‘kiss n’ ride’), cycling, and walking will all integrate at the station to allow consumer choice. Car parking for 617 vehicles is located on the west side of the freeway.

Designed by Woodhead International / MPS Architects and constructed by John Holland, the structure is a typical station building. It comprises of an elevated bus concourse that spans the Kwinana Freeway and station platform access for railway-passenger from a concourse via escalator, elevator or stairs.

No OSM innovative products were used on the project, being limited to ‘tried-and-tested’ products, namely:

- Bridge spans;
- Wall abutment systems;
- Lifts;
- Escalators;
- Balustrade.

4.2.2 Products

The various pre-cast products used on the project are briefly described below.

Leach Highway Bridge T-Roffs

Duplicating Leach Highway Bridge, ten pre-cast concrete T-Roffs were used to span the Kwinana Freeway. Supported on four central columns, each 1.5 metres wide, the bridge comprises two spans: the western span being 36.6 metres and the eastern span, 39.5 metres.

Locally manufactured by Delta Corporation, the pre-cast T-Roffs, weigh between 120t and 145t and were transported onto site with police escort outside peak traffic hours. The beams were then offloaded and stored until they were needed on the project. When the T-Roffs were installed it was necessary to close the freeway for a weekend. Two cranes then lifted the beams onto their bearings working to an accuracy of 2 mm.

Figure 4.1: Leach Highway bridge T-Roffs being lifted into position (Source: New Metrorail 2006a)

Bridge Abutment Walls

In order to accommodate station car-parking and the realignment of the Leach Highway on/off ramps, significant earthworks were necessary. These earthworks were retained by using pre-cast concrete abutment walls. Manufactured locally by Paragon Pre-cast, the concrete panels generally measured 7m x 3m x 175mm and were transported onto site without any transport restriction. Standard tilt-up erection techniques were employed to install the panels.

Platform Retaining Wall

To act as a retainer for the station’s platforms, pre-cast concrete panels from Paragon Pre-cast were again used. Measuring 7m x 1.6m x 175mm, these items were transported onto site and craned into position.

Figure 4.2: Leach Highway Bridge: Pre-cast concrete abutment walls

Elevator/Escalator

Manufactured and installed by Schindler Lifts Australia, the elevator at the station was manufactured entirely off-site and lifted into position fully assembled. Otis Elevator Company Pty Ltd, a West Australian supplier, was awarded the contract for escalator supply and installation. Manufactured in China and ordered well before construction of the station started, once onsite the escalators were installed with no problems. They were lifted into place using two mobile cranes, the installation process took around two hours to complete.

Figure 4.3: Bull Creek Station escalator being lifted into position (Source: New MetroRail 2006b)

Structural Steel

The structural steel was supplied pre-fabricated by a local company. The steel was pre-finished with paint before getting delivered to site.

There were a number of design issues which came to light when the steel was on site – the main one being that the internal cavity within the steel components was intended to be a conduit for the electrical wiring/services. However, access points had not been identified at the design process so therefore they were left off during manufacture. The result of this necessitated a consultation with the appropriate electrical services personnel, and significant fabrication delays resulted as a result of having to make changes.

Pedestrian Footbridge Balustrade

The pedestrian footbridge comprises of three spans. The main span is a pre-cast T-Roff beam; the remaining two are Delta Corporation pre-cast concrete slabs. The foundations and support columns were cast in-situ and the Balustrades were OSM items.

The finish of the balustrades was intended to be a hot-dip galvanised finish. However a design specification conflicted with the ability to successfully hot-dip. The hot-dip galvanising process produced a non-uniform finish which was contrary to design specifications. In order to rectify this it was decided to paint the balustrade.

Along the same vein, shop drawings identified the need for 'hit and miss' fillet welds yet the galvanising process required continuous fillet welds. Clearly, confusion existed between drawings and specifications: an issue overlooked by the design team.

Another issue with the balustrades related to both the design and manufacture. It was noted that very detailed design and an inexperienced fabricator combined resulted in a poor product. The fabricator had to carry out many on-site rectifications in order to meet design specifications.

Figure 4.4: Balustrade on footbridge showing installation problems

4.2.3 Benefits

- All of the pre-cast concrete items were successfully integrated on the project.
- The use of pre-cast components saved time and reduced inconveniences on the existing infrastructure, i.e. limited time needed for road closures. Regarding these components, it was felt that the installation process went very well and progressed without hindrance and according to schedule.
- The other OSM items such as the lift and escalators were also successfully integrated within the build process. Even items such as the escalator – fully manufactured in China were incorporated without any problems. This suggests that the suppliers/manufacturers and the main contractor were well acquainted with OSM items and procedures. Identifying the management complexities associated with the co-ordination of multiple OSM suppliers (e.g. steel fabricators, lift manufacturer etc.) and individual contractors (e.g. concreters, electricians), there were no problems with product quality or component integration.

4.2.4 Barriers

- Product handling issues resulted in damage to pre-painted finish on the OSM steel components. However these were rectified by on-site touch-up painting of the damaged areas.
- More importantly, relating to the steel OSM items a design oversight failed to recognise the need for access to electrical conduits running through internal cavities. As a result, significant fabrication delays were encountered while rectifying the design fault.
- Lastly, fabricating the pedestrian footbridge balustrade highlighted differences between design expertise, product knowledge and local workmanship quality. Detailed designs failed to fully comprehend galvanising requirements and processes thus altering the overall finish. Poor workmanship required significant on-site modifications.

4.2.5 Lessons

The problems highlighted by this case study suggest greater communication is required earlier with all stakeholders involved with the steel OSM manufactured items. If design issues had been sorted before manufacture of the OSM components commenced, most of the issues could have been solved or minimised.

4.2.6 Acknowledgements

Malcolm Wilkinson – Project Manager, John Holland J.V.

Peter Bifield – New MetroRail

4.3 Case 2 – Melbourne East Link Project

4.3.1 The project and company

The East Link Freeway project in Melbourne, Victoria was undertaken by the Theiss John Holland Joint Venture. The project was awarded in October 2004 and manufacture of precast commenced in July 2005. Completion of the project is due in mid 2007. Its design necessitated a significant number of pre-cast concrete components, and therefore a manufacture yard was required.

A location was sought that could accommodate manufacture on such a large scale, have readily available labour, with little to no impact on the actual construction site. Morwell was selected as the location. Although the location was approximately 130 kilometres away from the construction site, it had a reasonably high rate of unemployment from which to access labour. Among the reasons for the award of the contract, the joint venture presented to the Government that if successful the project would provide employment to the region.

The pre-cast manufacturing plant was located in a disused steel fabrication plant for the duration of the project. Converting the existing plant into one suitable for pre-cast manufacture presented its own problems. There was significant work around ground consolidation, providing new gantries, and production of assorted casting beds for both internal and external areas.

Prior to award the joint venture elected to appoint a Precast Start-Up Manager for the precast operation to ensure a reasonable level of readiness once the project was awarded. In the first four months after award the work packing of all aspects of precast operation was developed and major contracts for long lead items such of prestressed moulds from China were designed and the procurement process started. As part of the pre-cast operation the joint venture then appointed a senior person as the Precast Facility Manager (PFM). The PFM had little prior knowledge of the pre-cast industry, but exhibited skills in the management of people through his experience as a manager of one of the local power stations in Morwell. The two managers then worked together in an effective handover phase. Initially the PFM employed some seven staff with different skills in pre-cast concrete. These employees spent many months developing the existing plant into a working pre-cast concrete manufacturing plant. The PFM also employed various senior engineers experienced in the manufacture of prestressed concrete. Employment of approximately 200 workers followed. The PFM was advised not to employ those with concrete experience, opting rather to skill them up over a three week period, providing potentially superior quality of product. This reduced the likelihood of bringing potentially bad practices from site to the factory.

Transport

The newly opened rail network through Morewell provided a possible means for delivering components to site. However this proposition was quickly dispelled as the cost of loading and unloading the concrete pre-cast elements would have been prohibitive compared to trucking the elements by road with only one lift onto the carrier, and one lift into the final position. The train option would require four lifts in total. The 130km distance from the factory to site did not pose any problem as pre-cast elements would require loading onto trucks for transport regardless of distance. Consequently, in dollar terms, the extra time involved in actual transport on the road was the only consideration, and in context was deemed minor.

4.3.2 The Process and Products

The system and process allowed manufacture of concrete pre-cast bridge components and assorted sound barriers off-site whilst earthworks were underway at the main East Link site. The components were ready for use when the construction team required them on-site.

Bridge beams

The largest and heaviest components manufactured by the plant were the pre-stressed beams of weights exceeding 90 tonne. Much of the plant's capacity was designed around these products. Manufacture of large pre-stressed beams was fairly standard and consisted of:

- Setting-up steel strands in the moulds;
- Pouring 50 MPa concrete and curing ready for lifting the next morning;
- Curing, carried out by pumping hot water through pipes on the outside of the moulds utilising a new hot water plant specifically designed for the curing process;
- Attaching safety platforms and rails before loading onto the 'jinker'.

Figure 4.5: Boiler system used to accelerate curing of the moulded concrete.

Manoeuvrability of these heavy components required specific attention and necessitated the mobilisation of a 85 tonne Straddle Carrier, 50 tonne rail mounted portal gantry cranes and 70 tonne mobile sling crawler for handling pre-stressed beams from the moulds and various operations leading up to loading and dispatch. Due to this weight the base on which the rubber tyred straddle carrier operated had to be consolidated with approximately half a metre of stabilised crush rock at significant cost.

These heavy pre-stressed beams, forming part of the numerous bridges, were loaded onto 'Jinkers' late in the afternoon. They were then transported, in twos, stopping at Officer (just outside the East Link site) around 10.00pm, recommencing the last section of the trip at 6.00am. The transport often slowed to 20kms per hour on the highway.

Figure 4.6: Safety rails fitted to beam and loaded onto 'jinker' for transportation.

Figure 4.7: 'Jinkers' being loaded with post-tensioned bridge beams

Sound barriers

Apart from the bridge beams, smaller sound barriers were also produced at the plant, using Vertical (battery) moulds. Utilising the gantry, these were easily transported outside for storage. Reusable impression moulds were also used for many of the barriers.

Figure 4.8: Vertical sound barrier moulds (Battery Moulds).

The larger 'rock face' sound barriers were produced horizontally. The 'rock face' mould was made utilising a continuous pour method. The latex moulds had an estimated life of 150 pours although they were able to last beyond 200 pours. The cost of producing these moulds was about one third that of the more traditional supplier with an original $1.5million price tag. Polystyrene was also incorporated into the cast to reduce the overall weight of the panel. Concrete cost savings were not realised through the polystyrene moulds, as these were offset by the increase labour costs associated with laying the styrene.

4.3.3 Lessons

- Use of battery moulds worked exceptionally well. The space occupied by vertical moulds, casting up to 56 panels per day, was greatly reduced by implementing the vertical mould design.

- Coordination between on-site and off-site operations was difficult, particularly regarding the coordination of panel delivery to site. Some large panel and beam sections were made and stored, but were not required as stated on the original production schedules until much later in the project. Further, beams were stored on top of other beams due to storage area shortages. Access to particular beams became problematic. The control of inventory was therefore an area that could be improved, perhaps with the use of electronic tracking devices. The use of radio frequency identification (RFID) technology was investigated during the start up phase and was abandoned due to the high cost. However, in hindsight the RFID system step up costs would have been recovered.

The set-up of the temporary production pant was highly successful, producing components to a very high standard, at a rate exceeding demand, and to a lower cost than anticipated. The case clearly demonstrated that offsite options were not restricted to fixed, long-term facilities, but rather were more about understanding the concepts of production and manufacture.

4.3.4 Acknowledgements

John Reddie – Precast Start-Up Manager, John Holland (Pty) Ltd.

4.4 Case 3 – Newcastle Mercure Apartments Project

4.4.1 Historical context

The Mercure apartments are a new development in Newcastle NSW. It is a mixture of new build and the adaptation of an older structure. The finished building will be 14 floors and consist of a number of Mercure branded hotel apartments.

Originally the client who owned the building looked to find a company which could develop the site into private apartments to a specific budget. Timwin Construction – a Chinese construction company with offices in Sydney - was selected to construct the building. In order to keep to budget Timwin decided to develop the idea for the using a number of different factory made modules for the bathrooms, en-suites and kitchens in the development. Together with another company in China they established a factory in China to build these modules.

After construction of the building had commenced the client decided to brand the building into the Mercure Brand – and therefore its original use as private apartments changed to that of a hotel/serviced apartments. To ensure that the decor and therefore the design and construction of the kitchens and bathrooms fitted in with the Mercure branding the client contacted Duc Associates to assist in altering the design of the modules to fit in with the new branding and use. Duc Associates have a reputation for specialising in the design of large scale hotel projects. Their work ensured that standards are met and the designs to fit in with the Mercure brand.

During the construction of the building Timwin were taken over by the company making the modules.

4.4.2 The Product

The building uses the following modules:

- Bathroom;
- Kitchen;
- Laundry;
- En-suite.

There are many variations in design so they are by no means standard modules. There are approximately 100 modules of each type of room.

4.4.3 Construction

The modules consist of 75mm steel tubular chassis in which a concrete reinforced floor is poured. The finished floors are approximately 80mmm thick. The chassis provides the structural rigidity for the module which allows them to be craned out of the containers, and also provides protection against damage while shipping.

Once the chassis is built the frame is lined internally in a conventional way with plaster boarding and internal finishes.

- All services are plumbed in using Australian standard water pipes which are supplied to China.
- All Kitchen cupboards are pre-fitted.
- Wiring conduits are fitted and some wiring pre-done but most lighting and sockets/switches are fitted once on site.

4.4.4 Transportation

The modules are manufactured in China and loaded into standard shipping containers. They are then shipped to Sydney. The containers are off-loaded at port, placed on a truck and driven to the site. Once on-site the modules are craned out of the containers directly to the floor in which they will be fitted. They are then shifted by hand using rollers to place them into the correct position. Once in place they are levelled and plumbed. Once on site many of the modules have to have an in-situ built ‘extension’ on them to bring them to the size necessary for the room.

4.4.5 On site

Because half the building is in a 50 year old structure, adapting it to its new use and incorporating the modules within has been challenging. In the existing building the floor slabs have a very thick topping on them and this has had to be chiselled out in order to take the thickness of the module floors. Once the modules are in place a new screed is poured. In the new parts of the building the floor slabs have been designed with a set down to incorporate the thickness of the modules.

Once onsite the modules are craned to the desired floor using a static power crane, then manhandled off onto rollers and moved to the required position. At this stage they are then integrated within the building systems. No (minimal) service ducts were constructed in the in-situ floor slabs. Holes to accommodate vertical service pipes were drilled through the slabs at a later date. There was a sizeable space between the top external side of the modules and the underside of the concrete slabs of the ceiling above. This void was used to run horizontal service mains that the modules connected to.

Figure 4.9: Modules in position (note void above for services).

4.4.6 Benefits

- The completed modules are very cheap – a typical completed kitchen module installed on site cost less than a traditional kitchen replacement;
- Materials which are perceived to be of a better quality in Australia actually cost less than conventional materials in China – so its more cost effective to use 'higher quality' materials;
- By making the module off site, it allows the structure of the building to be completed while modules are being manufactured at the same time, which should theoretically reduce the total build time of the project.

4.4.7 Barriers

The main disadvantages of this project have seemingly stemmed from the history of the project and how things have changed during its build history.

The thickness of the module floors has caused considerable construction problems with the existing building and the new build. The requirement for step changes in the floor slab to take the modules has resulted in an inefficient building process and restricted any future changes to the building's use.

One of the current problems is that modules have been supplied and fitted on the site before the building structure is complete. At the time of the site visit there were still a number of floors which were being built on the new build section. As a result of this the structure has no windows and is not yet water tight. The modules are therefore exposed to rain ingress and damage by splashes of concrete and general workers being in the vicinity. This would have been minimised if the modules had been temporarily covered but no attempt had been made to do this. However this was not perceived to be a problem as such items as cabinet doors can easily be replaced at little cost.

Figure 4.10: Kitchen module in place by window (note drop down floor).

4.4.8 Lessons

The project has been earmarked as a learning curve for the various stakeholders – with the plan to use the system on future projects.

One of the key areas that needed improvement was document management. It is considered that any future projects will have a fully established documentation system for recording all aspects of the construction process stage by stage.

Because the modules are being manufactured in China and because the main construction company on site is Chinese there have been many cultural differences between the Chinese and the Australian stakeholders which have had to be overcome in order for the project to succeed. To help drive this process an external consultant has been employed by the client to act as a facilitator on the project. However, as all parties involved wish to get to the same end point - and indeed use the experience as a platform to expand the availability of Chinese-made modules on other projects within Australia - a great deal of effort has resulted in many lessons being learnt.

As a result of a Newspaper article about the project Duc Associates have been contacted by another hotel group and they are currently working with the module manufacturer to refine the design/production/integration process for new projects.

4.4.9 Acknowledgements

Edward Duc – Duc Associates

KK Yeung - Project Manager, Timwin Construction Pty Ltd

John Smolders – Facilitator, Global Developments (Asia Pacific) Pty Ltd

4.5 Case 4 – Prep School Capital Works Project

4.5.1 Historical context

Prep is a new school year which has been introduced into Queensland. Getting ready for Prep has meant that the Queensland State Government has taken on one of the largest ever capital works programs in the education department's history. It involves providing approximately 500 new build classrooms and a similar number of refurbished classrooms together with numerous smaller upgrades of pre-school classrooms and small schools.

The Queensland Department of Public Works managed the project. A government-led review team undertook the original scoping for the project and established the project budget. This was then handed to the Education Queensland for delivery. One of the key suggestions from the review team was to use modular transportable buildings as a means of meeting the tight deadlines set by Government policy. From the go-ahead in mid 2004, the prep facilities were required to be up and running by early 2007 – giving approximately 2.5 years to complete the bulk of the new builds and refurbishments. Another factor favouring OSM was the large geographic spread of the sites, which would have been logistically difficult to manage and challenging to resource given the limited number of contractors available.

As nothing had been done on this scale before it was also seen as a test case, with its concomitant pressure to succeed.

4.5.2 The product

A risk assessment was initially carried out to establish the procurement packages and how to manage the different types of new build and refurbished work, together with how the new classrooms would be integrated into the existing school site. One of the recommendations of this was to reduce the risks of non-supply by using two contractors to produce the classrooms and two contractors to do site ground works. It was also decided to combine the refurbishment projects in the same contract package as the new build works because in many cases both types of work were required at the same site.

The transportable building suppliers were Bendigo Relocatable Buildings (BRB Modular) and Ausco Building Systems (Ausco). The ground works contracts went to Bovis Lend Lease and the Department of Public Works own commercialised business unit, QBuild.

Another key requirement was that it was necessary to provide the new buildings with an appearance of permanence so that they blended well into the existing school infrastructure. The buildings were also briefed not to be moved once in position so all joints could be permanently covered.

Obviously the wide number of different sites and requirements dictated that a number of different options would have to be made available. As this would put the cost up an effort was made to limit the options. Where space was a premium however it was necessary to build two storey in-situ buildings, but this was kept to a minimum. Generally no more than three classroom blocks were installed on each site.

Figure 4.11: Classroom onsite and in use.

4.5.3 Design

The basic design of the classrooms was developed by Project Services, a commercialised business withinthe Department of Public Works. The manufacturers were responsible for the engineering design and resultant production drawings. The design took the form of a rectangular, 7 bay module with a classroom at each end. Kitchen and storage facilities were located in the middle section. A 5-bay offset version of the above was also offered. Originally there had been in the region of 12 different designs to cater for different site requirements but ultimately two designs were sufficient to cover almost all situations.

To further ensure that the products did not have the portable 'temporary classroom look', two specific features were incorporated into the design. Firstly, a sloping roof was designed incorporating vertical windows near the apex; and secondly the external joints between modules were effectively covered by a deliberate design detail that used full cladding sheets. Theses were a combination of compressed fibre cement sheeting and corrugated colorbond cladding.

Figure 4.12: Completed roof sections assembled at ground level.

Internally, the walls were clad with varnished plywood below dado level to protect them from every day classroom activities. Above dado level the walls are painted. Again, the design called for full cladding sheets to hide the joints. A further benefit of wood sheeting is that they provided a high level of flexibility to the modules whilst they were transported to site.

The 'feel' of the interior is very light which is partly due to the light colour scheme and the abundance of windows. Ventilation has been provided by louvers in large wall panels as well as in the high level roof windows. In practice this has been found to keep the classrooms cool in summer.

4.5.4 Manufacture

The two manufacturers had similar approaches to the construction of the modules – but with some differences. The following describes the method in which the classrooms are built.

A mock-up and two prototypes were built to test out the initial designs. After consultation with stakeholders a number of items were changed to generally improve the structure by stiffening the floor beams to give a more permanent feel. It was also found that rain caused excessive noise within the classrooms, which necessitated the inclusion of additional insulation in the roof space and walls.

At the outset a design team inspection was held at each site, with representatives from the individual school, to formulate a design brief. Following agreement, the necessary documentation was developed and submitted for building surveying approval with the respective local authority. On approval, plans were sent to the building supplier for foundations and the specification was sent to the manufacturers. The designer developed a bill of materials including all requirements for each building, enabling a streamlined ordering system. This also ensured better inventory control.

The basic structure consists of a hot rolled steel skeleton with light gauge steel framing in-fills, designed to the appropriate wind resistant category.

Production line methodologies were used in the construction of the roof sections. They were manufactured indoors at ground level to remove any risks of working at heights. The roof structure was manufactured complete with external finishes, wiring, insulation and internal ceilings. At the same time the 7 modules of the floor were bolted together and levelled before the basic skeleton was built. With this in place the roof sections were placed on posts, moved outdoors and attached to the framework. Once the ceiling was attached, the walls and interior were fitted-out onsite. Elements of the building were excluded at the module interfaces to allow the covering of joints onsite using full sheeting. All the necessary components for finishing the module interfaces, down to screws and glue, were supplied attached to the module floors.

Once completed the modules were separated and dispatched to site. By fully assembling the building before delivery, the manufacturer guaranteed that the complete building could be assembled onsite without any interface discrepancies and associated delays.

Figure 4.13: With competed roof in place the framework and fitting out commences.

Figure 4.14: Completed classroom at factory showing cladding left off at module joints.

Figure 4.15: Completed classroom at factory showing cladding left off at module joints and transportation supports (blue steel).

4.5.5 Onsite installation

Two processes take place on installation:

Modules

Once onsite the installers organised the set out of the building on site and supervised installation. Thereafter trades (electricians, plumbers etc) followed to complete the fitting out of the class rooms and removed all evidence of the individual modules. The following main items were finished onsite:

- Battening under the building to hide the foundation stumps (Education Queensland does not normally do this with temporary buildings).
- The roof panels at the joint were left off so that standard roofing could be fixed onsite ensuring no joints could be seen.
- Likewise the exterior walls received a full cladding sheet between windows or doors to hide joints.
- Internally, flooring panels completed onsite to conceal joints.
- Full length guttering was attached onsite.

Ground works

Having completed the logistics for the installation of the modules the ground works teams undertook services connections and integrated the new building with the rest of the school - while also completing refurbishment in other areas of the school.

The main task was to provide walkways, ramps and stairs to the classrooms and fitting these with appropriate hand rails for safety. Rails and balustrades were manufactured beforehand and were adaptable to the differing needs of the site. One of the main reasons for pre-manufacturing these items was the limited amount of galvanising facilities in the area which could have led to a supply shortage.

There had been pressure on the project to address individual requirements for the different sites; however this was restricted due to cost. The only situations where alteration were permitted related to works undertaken on or near historically listed buildings, where more appropriate colour schemes were necessary to meet planning legislation.

4.5.6 Benefits

- Quality - highly consistent product.
- Well received by users.
- Good aesthetic properties – does not look like a ‘prefab’.
- Large scale manufacturing enabled the process to be very efficient.
- Buildings delivered onsite quicker.
- Less time spent onsite which could disrupt the school.
- Easier to access difficult sites.
- Costs in the current market were marginally cheaper than in-situ new build. At the time there was substantial overheating of the local market and significant shortages of skilled trades in Queensland.
- Underwent a learning process during the first few weeks, but times were reduced to a ‘start-to-hand-over’ period of 3 weeks.
- Factory building in controlled environment with dedicated work centres improved efficiency.
- Much safer working environment.
- Provided a stable and static workforce.
- Repetitive manufacturing process reduced the requirement for skilled trade labour.
- Sub-assemblies were also manufactured off-site arriving ready to install and saving time, e.g. doors complete with sills and frames.
- Reduced waste and increased recycling of materials.

4.5.7 Barriers

- Statutory approval process – Approval system of such items as services was mainly a documentation issue. Also different Shire authorities were found to have slightly different requirements.
- Due to the large up-front investment needed by manufacturers to start manufacture, an 80% payment was made on initial installation and retentions released on practical completion.
- Ancillary supply chain supply problems, such as window supply, limited galvanising facilities in regional areas, loss of suppliers.
- There was a concern that the labour market would restrict the project timetable.
- Quality was an initial concern – however the prototypes resulted in significant improvements. One manufacturer continued to have problems until a QA plan was put in place, thereafter quality continued to improve over the life of the project.

4.5.8 Lessons

- Managing logistics, 'lots of people in lots of locations installing lots of buildings'.
- Getting the process right up front – making sure that everyone talked the same language (e.g. contractors and suppliers talk structural dimensions and architects talk external dimensions and they are different).
- Considering the track record of companies involved helped lay the foundations and reduced risk.
- Cost – treasury may have seen some cost savings initially but in reality the costs of the in-situ build classrooms were about the same as the OSM versions.
- Prototyping allowed accurate schedules to be produced, enabling the whole Organisation to be more efficient.
- Continuous improvement and learning allowed improved time cycles and reduced snags.
- The sheer volume of the program made it 'do-able'.
- The products had been designed for a 50 year life; however this is an unknown quantity.
- Confidence to use the model again – one of the key messages from the Government was that they saw it as a trial for further work and they wanted to make sure it would work because they can see lots of advantages to this type of program in the future.

4.5.9 Acknowledgements

Martin Miles – Project Manager, Department of Public Works Queensland

Luis Biaggini – Construction Manager, Bovis Lend Lease

Andy Jacka – Project Director Prep Year Capital Program, Department of Education and the Arts Queensland

Andrew Jones and Glen Goodfruit – Ausco Building Systems Pty Ltd

Justin McNamara – Bendigo Relocatable Buildings Pty. Ltd.

4.6 Case 5 – Robina Stadium Project

4.6.1 Historical context

Robina stadium was constructed by Watpac and successfully utilised OSM products throughout.

Watpac has a history of constructing stadiums in Queensland (Ballymore Stadium extension, Queensland Sport and Athletics Centre extension, Brisbane Cricket Ground and Suncorp Stadium) and therefore has a good knowledge base for this type of construction. Watpac were originally approached to submit a guaranteed construction sum (GCS) based on the initial design documents that had been submitted by a consortium to a government design competition. Initially the organisation aided the consortium until it produced the final documents to which Watpac could submit a guaranteed price. The consortium novated the project to Watpac, which then managed the project to the guaranteed sum.

The design of Robina differed from other stadiums that Watpac had constructed. HHK Architect's, although experienced in stadium design, had not worked with Watpac before. Nevertheless, by being involved early in the project they were able to consider buildability and tailor the design to accommodate OSM. The system of construction was selected based on experience gained during the Brisbane Cricket Ground project. OSM is particularly suited to stadium construction as they tend to have large elements, with large volumes, spaces and heights, all of which introduce particular construction and OHS risk.

At Robina the main driving forces for OSM were the limited time available for construction and the restricted labour market, which encouraged the minimisation of onsite work. The client required the regional stadium to be completed in time for seasonal sports requirements in order to generate income as soon as possible.

Construction was started onsite in August 2006 and it is anticipated be complete in late 2007.

Figure 4.16: Robina Stadium site January 2007 (Source: Watpac Construction).

4.6.2 The product

Structural steel was selected for the main structural frame as it could be constructed quickly and easily offsite in many sections. The company then considered incorporating further off site manufactured items into the development, eventually deciding to undertake the whole production process off-site. The structure consisted of the following components:

- Structural steel for the main structure of the stadium;
- Seating plats, being the main concrete beams that support the stadium seating;
- Precast planks forming the load-bearing floor structure that is placed on the structural steel before a topping is poured in-situ to tie them into the structure;
- All verticals – the stair shafts, lift shafts and vomitories (spectator exit points);
- Roof structure, consisting of a fabric roof manufactured by a German company in Poland.

4.6.3 Steel

The main Steel fabricator, Beenleigh Steel Fabrication (BSF), worked early on in the design process. Once material quantities were established, they were able to start ordering metal from suppliers while simultaneously working-up the detailed drawings for manufacture. This reduced the possibility of been delayed at a later stage. BSF tend to use shop detailing companies who work exclusively for them to ensure good levels of communication. BSF had two main roles on the Robina project: fabrication and erection.

Figure 4.17: Steel fabrication.

Fabrication

The steel was constructed in a controlled environment to eliminate any adverse weather effects. BSF have two factory locations that, among other things, enable them to have a stable workforce of boiler workers. All sections were made-up on the bench and then broken-down into transportable sections. The overhead cranes in the factory make it possible to easily move larger items around when required. Theses were then stored until they were dispatched for protective finishing and painting. From then the items went directly to site. All items were labelled for identification and could be referenced back to the shop drawings if required.

Erection

BSF erected its steelwork together with the precast concrete elements. The company owns its own cranes and supplies crane drivers and riggers onto site.

Erection began once the in-situ foundations had been placed. The erection process had very low tolerances – typically a couple of mm, requiring precision in the onsite and offsite elements. BSF also installed the precast concrete elements as these required installation concurrently with the steel frame, and it was deemed more efficient to have one contractor complete both aspects. This further aided the project programming.

4.6.4 Concrete Plats

Precast concrete plats (long beams to which the seating is attached) have for a long time been used as a standard item for stadium design, as these are both cost and time efficient. Casting these in-situ would take considerable time and also expose a large number of people to high levels of risk during the construction process.

Precast Elements manufactured the seating plats. Previously seating plats were cast where a large surface area had to be steel dowelled. The Plats were 'T' shaped and moulded at 90 degrees to the final orientation to reduce the amount of dowelling required. This gave the maximum amount of off-mould surface, which result in a high quality surface finish – typically a class 1 or 2 surface.

Figure 4.18: Pouring the concrete plats.

The T shape (on its side section) was designed to overcome a perceived problem that was considered by the architects and engineers (normal plats are L-shaped). It was feared that a crowd jumping on the plats simultaneously would induce a natural frequency in the elements, hence the introduction of the T-shape to stiffen the plats.

Precast Elements have four, 60m moulds and can make different length plats by using adjustable end plates. Using these moulds they have the capacity to make up to 24 plats a day. Steel reinforcements were laid and tensioned in the moulds before pouring the concrete. Magnets are used to hold the fully-adjustable mould sides in place.

To speed up the production process quick-curing high strength concrete was used in conjunction with steam curing. The steam increases the temperature of the moulds to around 55-60C and reduces the cure time. The process took around 18 hours from start to finish, with pours commencing at 2pm and finishing by 8pm. By 6am the following morning, the plats could be removed from the moulds and stacked. Generally the plats required no patching or repair. The pre-stressing of the plats necessitated a half inch cut in the steel to tension the concrete on removal from the moulds. Once cut and trimmed the ends of the steel were then painted with an epoxy paint to seal them and prevent corrosion.

The connection systems and fasteners, together with stencils for product identification, were cast into the product allowing easy installation and product identification.

Figure 4.19: Steel structure and concrete plats onsite.

4.6.5 Benefits

- The biggest benefit in this type of stadium construction is reduced overall project time and the associated cost savings.
- Reduced time and labour levels on site.

- Safer site – an in-situ approach would have required a large infrastructure of platforms, scaffolding etc. to be set-up. Using precast items drastically reduced the exposure to risk.
- Better quality control – easy to control and obtain a better finish.
- Coordinated interfaces and reduced trade conflict – allowed different trades to be present at anytime without competing for common workspaces.
- Better environmental performance – reduced amount of wastage and better recycling was achieved both on and off site. All items brought onto site were used in the construction. The OSM providers also minimised waste as they were able to order materials more precisely reducing off-cuts, left-over concrete etc.

4.6.6 Barriers

- Mistakes made at the drawing stage may not have been discovered until the item was installed onsite. The consequences of mistakes were more significant.
- Less control of individual onsite.
- In automated systems, single component break-down has a significant impact on other aspects.
- Even with prefabricated elements appropriate labour and workshop space and access are still challenges.
- In-situ solutions have the flexibility to adjust elements on-site – this ability is largely lost with OSM.
- The number of engineers that are comfortable designing precast components is limited, tending to be conservative in their designs.
- Fastenings are a substantial cost of pre-cast concrete elements – problems arise if the engineer does not understand pre-cast or has limited technical knowledge. Knowledge in connection systems and their capacities is required.

4.6.7 Lessons

- Co-ordination and documentation flow is critical and normally the main contractor's responsibility.
- Spend more time getting the drawings right in the first instance. Delays in finalising engineering and architecture designs for the detailing of the steel and precast concrete elements cause fabrications delays.
- Negotiate and award the contract to a builder early – this allows better co-ordination and earlier commencement of offsite works.
- Allow architects and engineers enough time – they have been surprised at the speed of installation onsite – a basic stand being completed within a week.

- A large amount of trust is required – by using people who have worked together before reduces this risk.
- Ability to discuss options and aspects with clients throughout the project is highly beneficial.

4.6.8 Acknowledgements

Gilbert Gouveia – Design Manager, Watpac Construction

Mark Finney – Beenleigh Steel Fabrication

David Cullen-Ward – Managing Director, Precast Elements Pty Ltd

4.7 Case 6 – Hollow Core Concrete Pty Ltd.

4.7.1 Historical context

Hollow Core Concrete Pty Ltd (HCC) was established in Melbourne in 1987 after the managing director had seen the use of hollowcore floor slabs in the Middle East. Production of hollowcore commenced in 1988 at their specially built manufacturing facility in North Laverton.

Hollowcore slabs are precast prestressed concrete elements that are designed to be used as floor slabs or industrial walling. The manufacturing process was developed in Europe in the 1950's and first used in Australia for industrial walling in the 1960's.

The Company initially just produced hollowcore slabs, but found that their use generated a demand for a prefabricated flooring system including the support structure.

This prompted the company to investigate what options and systems were available for a complete support structure. These investigations identified a potential demand for skeletal frame structures that allowed the whole structure of the building to be prefabricated. Systems being used in USA and Europe were not suitable for the types of buildings and construction methods used in Australia.

Through their in-house design team HCC developed a product range that suited the smaller buildings and low levels of repetition that are common in the Australian market. The result is a precast skeletal frame system of which hollow core planks are an integral part. The remaining elements are precast columns, precast beams and other precast elements that make up the complete building structure.

The degree of precast use depends on the nature of the design, although the elements the company produces can be used in conjunction with other construction processes and techniques.

The current range of products focuses on all the main skeletal framing elements of a building. Their manufactured products include:

- Floor slabs: Hollow Core and solid slabs;
- Columns;
- Beams;
- Stairs and landings;
- Wall panels;
- Stadium seating units;
- Small bridges;
- Balcony units.

HCC markets are principally the commercial and civil engineering sectors, although a recent development has seen increased use of hollowcore planks for the transfer floor in domestic housing where basement car parking facilities are required. This is still considered a small market.

A large percentage of HCC work results from the in-house design team producing precast alternatives to insitu concrete or steel frame designs. This allows the Company to offer a 'design, manufacture and installation' package.

Figure 4.20: Example of a building using Hollowcore system.

4.7.2 Hollow Core production

Hollowcore is essentially an extruded hollow concrete plank that incorporates tensioned steel multi strand reinforcement. It is possible to manufacture the hollow core planks in different widths, depths and lengths.

The company has four under cover casting beds each approximately 120m long. These act as forms for the bottom of the hollow core planks. Steel strands reinforcement is laid out along the length of the bed and then stressed to a pre-determined force. The number of strands and force can be altered depending upon the specification of the hollowcore plank.

Concrete is then fed into an extrusion machine that travels down the bed extruding the hollowcore section. The extrusion machines are fitted with a number of dies, each of which has a cone shaped screw on the front. These screws rotate, compressing the concrete and extruding it as the machine moves along the bed. This also removes all air and most of the water from the concrete mixture. The concrete is fed into the machine by overhead hopper with the whole process being computer controlled. As the machine moves along the bed the area behind the dies become the hollow centres of the extruded section.

The concrete mixture is very dry and keeps its shape after extrusion without having to be tampered or trowel finished (it is quite possible to walk on it shortly after the machine has passed).

Once extruded the planks are left to cure before being cut to pre-determined lengths and removed from the mould. All slabs are manufactured as individual components for specific projects. The planks are stored outdoors for further curing before being delivered to site for erection.

The extrusion machines, cutting saws, concrete conveyor system and lifting clamps are sourced from Finland or manufactured by HCC.

Figure 4.21: Hollowcore in production

4.7.3 Pre-cast skeleton frame system

In order to assemble the precast elements into a structurally stable building a number of solutions have been developed. The basic system consists of precast columns, precast beams and hollowcore floor slabs.

Columns are erected over steel dowels projecting from the foundations or column below and temporarily braced. The column bases incorporate dowel tubes, filled with high strength grout after erection. In a similar manner beams are erected over steel dowels projecting from the top of the supporting column. These dowels project above the top of the beam to provide the dowels into the column above. Dowel tubes through the beams are filled with high strength grout. In order to stop the grout escaping at the edges where the two structural members contact, a flexible foam strip is placed on top of the columns before the beams are erected. Beams are typically inverted Tee sections and are design such that no temporary support is required.

The Hollow core planks sit on the ledge of the inverted Tee beams. On a typical system an 80mm thick screed is used over the top of the hollowcore and beams to tie them the structure together. Once the structure is tied together the temporary braces on the columns can be removed.

The key to the success of this system is to use standard profiles and simple connections that are easy and quick to implement on site. This is critical to the speed of the project.

Figure 4.22: Hollowcore planks, beams and columns (showing support) onsite.

4.7.4 Example in practice – GPO Building Melbourne

A new six-level glass façade building was to be constructed next to a historic building in the centre of Melbourne. The new building, although having connecting foot traffic and services was to be structurally separate from the original building.

Although originally designed to be built in-situ concrete, the builders (St. Hilliers) and the consulting engineers (Arup) in conjunction with HCC decided prior to the commencement of the project to investigate the use of pre-cast concrete components. One of the main drivers of this decision was the difficulty of using insitu construction in the confined central city location with its associated access and time constraints.

Hollow Core was asked to propose a suitable construction technique to overcome the technical difficulties of cantilevered floors on three sides and, due to the glass façade, the lack of shear walls to provide lateral stability.

The HCC solution incorporated the basic precast column, beam and hollowcore skeletal frame solution as well as solid cantilevered planks. Lift-shaft walls, together with stair-shafts and stair flights within the original building were also included as precast concrete.

To provide lateral stability a pre-cast moment resisting frame was incorporated at the West end of the building.

Constructed almost entirely out of pre-cast components the new building has approximately 2300m² of hollow core plank floor area. The cantilevered sections are pre-cast solid slabs and incorporated a small up-stand section on the external edge. This was to act as a 'shuttering' for the screed, which was poured to tie the cantilevered panels in with the rest of the structure. This up-stand also enabled temporary railings to be fitted for the safety of the construction team and following trades and avoided the need for external scaffolding during erection. These up-stand sections also incorporated fixing points for the glass curtain wall, further reducing the time to install the façade.

Figure 4.23: GPO Building Melbourne

4.7.5 Benefits of the project

- Speed of construction and therefore less impact on the surrounding area.
- Rapid access available for following trades.
- Showed that Hollow Core planks and pre-cast construction can be adapted to suit an architecturally complex project.
- Significant formwork and scaffolding systems to handle the large floor to floor heights was required for the original scheme. This was completely eliminated using the precast system.
- Safety concerns were significantly reduced due to the reduction of on-site labour required.

4.7.6 Typical Benefits

- Hollow Core enables spans up to 17m. This reduces the need for beams and columns and is very suitable for car parks or open plan areas.
- No need to have scaffolding or form work so there is a reduced onsite labour cost.
- Speed of construction.
- Early access of following trades.
- The process of hollowcore manufacture is highly mechanised resulting in high quality products.
- Reduced onsite labour.
- Excellent surface finishes.

4.7.7 Barriers

- Over the years precast concrete has been associated with low-cost housing blocks that have affected its image and restricted its uptake – 'Grey Box' mentality.
- The construction industry is traditionally very conservative so the introduction of anything perceived as new or different faces barriers.
- There is need to realise that precast concrete is not suitable for every project. If more people were aware of its capabilities they could identify particular projects that suited the system.
- There is a lack of knowledge and understanding of precast concrete in Australia. Engineers think that precast is a new system. Many in Australia have little understanding of hollowcore, yet it has been used in Europe since the 1920s and is by far the largest flooring system used in Europe.
- It is suitable for domestic project housing, however it cannot compete on costs with traditional light weight wooden joist construction.
- Many building design codes and specifications are not written for precast. They are not restrictive but extra design time is required to ensure systems used are compliant with the codes.

4.7.8 Lessons

- HCC works across all procurement methods but they have found that where they are involved in the project from the conception stage it has proved more beneficial to the whole project.
- Working together with all stakeholders within the project team gives greater efficiency and leads to more economical buildings.
- HCC have products to suit a number of different applications but there are a number of misconceptions in the industry of the limitations of hollow core and pre-cast.

HCC needs to generate greater publicity about the large number projects they have successfully completed.

- More education is required to inform the industry of the advantages of precast concrete and prefabrication. Much is this education relates to understanding precast as a system rather than a combination of a series of individual components.

- Recent industry skills shortages in the standard trades (such as concreters, steel fixers, carpenters, crane operators) have necessitated more training and a shift to greater use of precast component. Internal corporate expertise in the products and OSM, more broadly, are used to train new staff. HCC also run training on other items such as industry standards, OHS, QA requirements and on-the-job training which are specific to precast.

4.7.9 Acknowledgements

Simon Hughes – Hollow Core Concrete Pty Ltd

4.8 Case 7 – Monarch Building Systems

4.8.1 Historical context

Monarch Building Systems (Monarch) has experience involving many hundreds of building modules and panelised buildings including several large projects involving over 100 accommodation units produced within tight production timetables. Monarch position themselves at the top end of the traditional 'pre-fab' market and are able to provide for a market where clients are demanding better quality housing, particularly in the mining sector.

Monarch Building Systems consist of two main organisations which came together to offer a total package:

- Pantex – is a construction company mainly specialising in building housing and multi-residence buildings, and more recently dealing with OSM products.
- Monarch – established in 1979 to manufacture transportable buildings based around a steel frame system.

Both organisations complement each other and are kept separate to maintain independency with regard to standards and building requirements and regulations.

4.8.2 The Product

For the purpose of this case study, the focus will be on Monarch Building Systems and the construction of its different products. Within Monarch itself there are two key areas, namely Monarch Panelisation and Monarch Modular.

4.8.3 Panelisation systems

The panelisation system has been developed to allow whole houses to be built to lock up stage within a few days. The system comprises of a number of whole wall panels which are built in the factory and include all frames and sheeting ready for onsite erection.

The process

The wall panels comprise of a proprietary roll formed steel frame to which an external lightweight concrete panel is attached. When developing the exterior cladding system key considerations were that the panel had sufficient rigidity and long term stability, as well as sound 'solid' when hit by the hand (no 'drumming').

The cement-based panels are 26mm thick and comprise a light weight concrete of proprietary composition and a water proof membrane. The board has been tested for impact, fire, water proofing and insulation. The finished panels meet most QLD insulation requirements without the need for additional bulk insulation. The cladding is screwed to the steel frame. The external surface of the cladding is pre-finished with robotically applied render and paint.

All windows and doors are then installed and sealed before the frame is stacked into a rack for loading onto the truck. Specialised trailer units have been developed by Monarch allowing a single truck to transport an entire typically-sized house in one journey. This includes the wall frames, roof frames, internal frames and all cladding. The modular wet rooms of the houses are loaded onto a separate truck for delivery.

Where wet area modules are included in the house these are generally supplied to site before the panels. They are placed on a prepared base, and tied into the concrete slab, which is poured around them. The installation of panels as described above is then commenced.

Once onsite the frames are craned off the truck and assembled onto the pre laid foundation slab. Within about a day, a typical crew of three carpenters would expect to have completed the construction up to installation of trusses. After this point the crane is no longer required. Subsequently the roof structure and internal wall frames are fitted together, including the anchoring of all wall frames to the slab. The roofing and guttering are fitted together with the facia and soffit linings, achieving lock-up stage.

Figure 4.24: Lifting completed wall panels onto site (Source: Monarch).

Figure 4.25: Construction onsite (Source: Monarch).

Once at lockup stage the follow-on trades can get access. The house is plumbed and wired using pre-stamped holes in the frame system for routing, and then the interior is plaster boarded conventionally. At this stage such items as push-fit pre-finished window/door architraves help to reduce fit out time and painting further.

Figure 4.26: Completed house (Source: Monarch).

4.8.4 Modular

The modular system which has been developed is based on the construction techniques used in the panelised system. They have a steel frame on a pre-cast concrete floor, to which cladding is fixed. As the modules have to be lifted onto trucks for delivery, cranage points, durability for transportation and such issues as balance points all have to be considered at the design stage.

The manufacturing system of the company is based on that of vehicle manufacture and relies heavily on the use of robotics and other process philosophies such as just-in-time supply-chains.

The module systems which have been developed to include:

Whole unit transportable buildings

Modular buildings are typically fully completed in the factory including all plumbing, electrical items, internal and external wall linings and finished floors.

The buildings have a steel frame and are clad depending upon requirements, typically either panelised wall colourbond steel pre-finished weather board or corrugated profile. This gives durability and long life.

There are a number of different types made:

- Single person accommodation facilities for such sites as mining towns, comprising of two, three and four bedroom modules each typically with its own en-suite for privacy;

- Residential homes of conventional architecture;

- C Commercial office buildings. Applications have been in remote area;

- Tourist Accommodation which has been designed to provide tourist park operators with three and four star standard facilities.

Wet room modules

These comprise of bathrooms, toilets, en-suites, laundry rooms and linen cupboards. Depending upon the design requirements of the building, these can be stand alone or fitted back to back within the building.

As with the building modules the wet room modules consist of a concrete floor and steel frame to which an external cladding is attached (if required) and the interior is fitted out with conventional materials. Once again all plumbing and electrical items are pre-fitted. These have been used in single story, as well as, multistorey developments.

Figure 4.27: Bathroom modules in production (Source: Monarch).

4.8.5 Benefits

- The manufacturing process enables the production to be very efficient and cost effective.

- Quality-controlled construction delivering a consistent product.

- Short delivery times and very quick onsite construction time.

- Minimal trades requirement onsite, particularly in remote areas.

- The overall look of a completed house is that of an in-situ built product, eliminating the negative stigma attached with 'pre-fab'.
- Suits low-rise multi-residential applications in remote areas and regional centres where access to trades can be difficult.
- Minimal on-site disturbance therefore giving a tidy work site with minimal waste or pollution.
- Minimal disruption due to weather delays.

4.8.6 Barriers

- Need volume to make OSM competitive.
- The structure has to be stronger than is necessary to survive the transportation with no damage.
- Processes differ from conventional building, requiring all stakeholders to modify site processes and techniques.

4.8.7 Lessons

- Monarch has developed a strong engineering and project management skills base which enables it to operate more efficiently. Aspects such as the IT systems use fully integrated building design programs, which allow for thorough design work, steel roll forming and robotic assembly.
- Trust is required between builder and supplier – a certain degree of confidence is required.
- The nature of OSM requires more accuracy – the builder who installs the product must be able to work within these tight tolerances.
- Each project needs to be considered on its own, often adapting previous designs. This allows more efficiency.
- This type of manufacture requires management and engineering overhead.
- The most successful projects have been where Monarch manages the project from the early stages – after the architect has provided the concepts. This way the project management can be optimised to use the building system and vice versa.
- Works best on large scale projects where there are many standard units.

4.8.8 Acknowledgements

Nathan Warner – Projects Manager, Monarch Building Systems

4.9 Summary

This chapter presented seven case examples from across Australia that illustrated the drivers and constraints, identified in chapter three, within a project or organisational context. Confirming the findings of the web survey in chapter 3, the cases were dominated by level 2 pre-cast and panelised systems, however level 3 and 4 examples were also included. The concluding chapter (Ch. 5) reiterates the project objectives and provides an 'Action Plan' for OSM.

5 THE FUTURE OF OSM IN AUSTRALIA

5.1 Introduction

The concluding chapter reviews of the project objectives and suggests the next steps for OSM to be supported and sustained within the Australian construction industry. The results of the workshops, interviews and case studies have provided a list of drivers, benefits, constraints and barriers to OSM in Australia. This furnishes the industry with a basis for formulating a series of research projects and initiatives to promote or facilitate OSM in construction. This chapter speculates on the opportunities, initiatives and paradigm shifts necessary for OSM to become entrenched within the Australian construction industry. Opportunities flowing from chapter three and four are elaborated with conclusions as to where further development may be possible. The paradigm shift required within construction to significantly progress OSM is briefly discussed, indicating that next generation manufacturing thinking is necessary.

5.2 Project objectives

The main objective of the study, which was to produce a report on the current state and future opportunities of OSM in Australian construction, has been fulfilled within this document. Certain objectives have only been partially fulfilled due to the lack of available data, although objective three has been exceeded by studying a greater number of cases than was planned. Each objective is reviewed below.

Objective 1 *- Review work already done in the area, particularly from the UK, US and Japan, providing a context against which Australia can be compared*.

Literature specifically providing a context for comparing drivers and constraints in Australia was reviewed. This largely came from the UK, with some US housing reports being consulted. Literature specific to Japan was not reviewed, although OSM writings are replete with manufacturing philosophy examples from Japanese industry. This objective is fulfilled within chapter 2 and section 2.3.

Objective 2 *- Provide a definition and basic theoretical framework for future work in OSM, whilst also ensuring a common nomenclature is established in the industry.*

A common and broad definition of OSM is established in chapter one. Further, a system of classifying the various levels of OSM is adopted from the UK. It is a useful and fully adaptable framework for progressing OSM research in Australia.

Objective 3 *- Determine the key economic, social and environmental benefits of OSM within the Australian context, whilst also identifying the real and perceived barriers to the use of OSM.*

A comprehensive list of benefits, drivers, constraints and barriers for OSM in Australian construction is derived in chapters three and four of the report. These results form the workshops, interviews and case studies undertaken, and consequent lists form the bulk of the report findings.

Objective 4 *- Ascertain the key suppliers and sectors of the industry engaged in OSM within Australia.*

This aspect was partially fulfilled through desk research and anecdotal evidence, although the findings were unreliable. A comprehensive industrial survey would be necessary to satisfactorily complete this objective. Such a methodology falls outside of the scope of this study. Chapter 3 offers some insight into the industry, although it does not fulfil objective 4.

Objective 5 *- Recommend how OSM can be driven through the industry, and where future research efforts should be concentrated, particularly noting the role of technology in OSM.*

Recommendations based on the conclusions drawn from the data analysis are provided as an action-plan in section 5.3 below.

5.3 The Way Forward – an action-plan to promote OSM

A recommended action-plan for driving OSM through the industry is presented in Table 5.1 overleaf. This is an extraction of the recommendations in Table 3.4. Initiatives largely revolve around skills training, education and knowledge provision. These will help address almost all issues identified. The responsibility of the action-plan is however unclear and would require clarity before any actions could be commenced.

Table 5.1: Action Plan for OSM in Australia listed in order of relative priority (cf. Table 3.4)

Theme and Actions
1. Skills & Knowledge Skills training in trades and OSM skills required to ensure the industry is well furnished; Regular conferences/meetings should be arranged to demonstrate OSM projects and benefits; Encourage government to provide improved research incentives to stimulate local innovation and business start-up; Increase appeal for manufacturers to employ apprentices; Encourage location of manufacturing plants in areas with suitable labour source; Conduct career days at schools to interest people in the OSM market; Create online portal to disseminate international trends, products and processes associated with OSM; Conduct market research study to ascertain market opportunities.
2. Process & Programme Disciplines and processes need to be streamlined using integrated IT systems. Including development of IT based project management system to coordinate subcontractors and integrate the process. Need to learn from other industry's systems – from design through order and production; Advice on information and document distribution and management protocols required in high IT environment; Advice on storage and ownership of digital information should be addressed; Encourage design of OSM into the project from concept stage through education and showcasing.
3. Industry & Market Culture Establish annual OSM products and careers expo to showcase and promote OSM. Include trade shows and seminars; Commence initiatives to ensure that tertiary education focuses on future trends and ideas including OSM and manufacturing (CM, engineers and architects); Marketing emphasis should be on mass customisation rather than mass production, includes increased standardisation but not necessarily repetition; Improve government standards for civic architecture intended to improve building quality and longevity, thus, showcasing OSM products in operation and dispelling negative perceptions. Showcasing will demonstrate all benefits of OSM; Establish government funded display centres showcasing OSM products in use.
4. Cost/value Whole-life cost needs to be emphasised with understanding of value rather than purely direct costs. A system or method is required to show and convince clients that OSM is beneficial.
5. Regulatory Energy rating systems to be used to demonstrate that OSM can <u>exceed</u> current standards; Appropriate authorities need to examine the potential for OSM skills accreditation; Appropriate authorities need to examine introduction of separate section to code for pre-cast.
6. Logistics & Site Operations Inventory management research and advice necessary for manufacturers; Advise on location of manufacturing plant close to the project to reduce transport costs and logistics.
7. Environmental sustainability Demonstrate that better efficiency ratings due to better dimensional tolerances are possible; Demonstrate sustainability benefits.

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APPENDICES

Outline of the Case Study Protocol

The structure for the case study will be based on the format below but will alter where necessary depending upon the nature of the product/process/application etc.

The company

- Brief information about the company

Thoughts on the current industry of OSM in AU

- What steps need to be taken to encourage OSM?
- What new areas do you see that need to be exploited?
- What advantages do foreign suppliers/importers currently have?
- What do you see happening in the future?

Historical context of case study

- How the example of OSM came about and what were the driving forces behind it.

The Product

- Describe the project (product) under consideration.
- What was/is done – the process?

Benefits achieved by this example

Covering areas such as:

- Cost
- Quality
- Construction interfaces
- Safety

Disadvantages

Main Lessons

Acknowledgements and credits

CRC Construction Innovation
BUILDING OUR FUTURE

Typical Agenda of Workshop (Example of Brisbane Workshop)

09:30	Coffee and Introductions	
10:00	Opening	Keith Hampson
10:10	Introduction	Thomas Fussell
10:20	Presentation	Prof. Ron Wakefield
11:00	Morning tea	
11:15	Research Findings	Dr. Nick Blismas
11:45	Discussions on Current situation	Peter Hope/All
13:00	Lunch	
13:45	Opportunities for the Future	Peter Hope
15:00	Summary	Peter Hope/Nick Blismas
15:30	Close	

GLOSSARY

SIPS	Structural Insulated Panels
ICF	Insulated Concrete Forms
PATH	Partnership for Advancing Technology in Housing
OSM	Off-site Manufacture
OSP	Off-site Production

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Richard has an Honours Degree in Industrial Design (Eng) and a post Graduate Diploma in Ergonomics. He has worked for 10 years as a consultant Ergonomist at ICE Ergonomics in the UK (now ESRI), working in many areas including the safety of consumer and industrial products. This work was approximately equally divided between Research and commercial work. The Research work was mainly large scale Government funded research, predominantly relating to the safety of products. More recently Richard has been working in the commercial sector developing new concepts and products predominantly within the toy industry. Since coming to Australia Richard has been involved as a researcher on two CRC projects though his work at the School of Property, Construction & Project Management, RMIT University.

Nick Blismas

Senior Lecturer, School of Property, Construction & Project Management, RMIT University

Nick is a Senior Lecturer in the School of Property, Construction & Project Management, having joined RMIT University from Loughborough University (UK) in February 2004. His main research fields are: construction OHS; multi-project and programme management; and off-site production. His research has always been industry focussed, involving significant numbers of collaborating organisations. In addition to his 10 years construction management research experience, both in Australia and the United Kingdom, Nick also has 3 years industry experience as a project manager.

Scott Brotherwood

Research Associate, Department of Construction Management, Curtin University of Technology

Scott is a third year Urban and Regional Planning student and sessional tutor with Curtin University's, Bentley Campus. A keen advocate of sustainable development, he has previously been involved with Alcoa's Stronger Communities and intends his thesis studies to centre on social capital and local economic development. Recognised by the UDIA for his exemplary work in local planning Scott excels in his academic stream.

Peter Bullen

Lecturer, Department of Construction Management, Curtin University of Technology

Peter Bullen is a lecturer in project management, environmental management, sustainable development and construction technology in the Department of Construction Management in the Faculty of the Built Environment, Art and Design at Curtin University of Technology. He has over thirty years of experience in private and public sector commercial and residential construction project management, quantity surveying and facility management in the UK, Europe and Australia. Peter is currently a doctoral candidate with the Division of Resources and Environment at Curtin University. His PhD research is investigating the adaptive reuse of commercial buildings and he has published several research papers concerning sustainable buildings and adaptive reuse. He is a member of several working for the international research organization the Conseil Internationale du Batiment. He is also a corporate member of the Australian Institute of Building and Australian Institute of Project Management.

Thomas Fussell

Director and Chief Architect, Project Services, Department of Public Works Queensland

For the past fifteen years Thomas has been directly involved in the establishment of Project Services as a successful commercialised business within the Department of Public Works. This process has challenged the business to establish different relationships with its untied clients and to find more effective and more efficient ways to deliver its services. Thomas is focused on the greater use of advanced technologies to enable that improvement to be achieved. He is responsible for implementing the use of “virtual buildings” integrating the contribution of all of the disciplines into a single digital model to be used throughout the design, construction and operation of a building. The Off-site manufacture of components and assemblies has an important place in this new approach and has prompted his involvement in this project.

Willy Sher

Head of Building, School of Architecture and the Built Environment, The University of Newcastle

Willy Sher is Assistant Dean, Teaching and Learning in the Faculty of Engineering and Built Environment at Newcastle University. He is also Head of the Discipline of Building in the School of Architecture and Built Environment. Before coming to Australia he was Senior Lecturer in the Department of Building and Civil Engineering at Loughborough University (UK). He worked at the University of the Witwatersrand (South Africa) in the Department of Building and Quantity Surveying prior to this. He is a Fellow of the Australian Institute of Building and a Fellow of the Chartered Institute of Building.

Mark Vines

Program Director & Senior Lecturer, School of Property, Construction & Project Management, RMIT University

Mark is the Programs Director in the School of Property, Construction and Project Management and has been at RMIT for 16 years lecturing predominantly in the technology areas. Mark is also a registered Building Practitioner with over 20 years of housing experience, and is a member of the Australian Institute of Builders. Current research interests are focused in alternative wall systems for housing with ongoing industry collaboration.

Ron Wakefield

Professor and Head of School, School of Property, Construction & Project Management, RMIT University

Ron is currently Professor of Construction, and Head of the School of Property, Construction and Project Management at RMIT, Australia. He is also Program Director for Program C - Delivery and Management of Built Assets for the Cooperative Research Centre for Construction Innovation. His research and teaching is focussed on construction with particular emphasis on production systems, management of construction operations, use of information technology and whole of life performance of built assets. Prior to joining RMIT in 2005, Ron was the William E. Jamerson Professor of Building Construction in the Department of Building Construction, Virginia Tech, USA. He was Principal Investigator for the Industrializing the Construction Site project (Phases I, II, III, IV, V, Stage V extension) a multi million dollar research effort that lead to the Industrializing the Residential Construction Site series of monographs prepared for the Office of Policy Development and Research, US Department of Housing and Urban Development. Dr. Wakefield has over 20 years experience as an international researcher, consultant, and engineer in construction. Prior to joining Virginia Tech, Dr. Wakefield taught at The University of New South Wales, Sydney, Australia. He was a visiting Fellow at City University of Hong Kong in 1995.

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Established and supported under the Australian Government's Cooperative Research Centres Program