Off-site manufacture in Australia: Current state and future directions

Featuring seven case studies

CRC Construction Innovation
BUILDING OUR FUTURE

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Edited by Nick Blismas

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Preface

Off-site manufacture (OSM) has long been recognised, 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 purpose of this CRC for *Construction Innovation* project was to determine the state of OSM in Australia. It confirms the benefits and identifies the real and perceived barriers to widespread adoption of OSM, and identifies opportunities for future investment and research.

Although numerous reports have been produced in the UK on the state of OSM adoption, no prominent studies exist for the Australian context. This scoping study is an essential component on which to build any initiatives that can take advantage of the benefits of OSM in construction. The *Construction 2020: a vision for Australia's property and construction industry* report (Hampson & Brandon 2004) predicted that OSM would increase in use over the next five to 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.

Section 1 contains a discussion of manufacturing principles, and identifies those principles that can be used to enhance OSM uptake within the construction industry.

Section 2 summarises the main drivers and barriers to OSM uptake within the Australian construction industry, based on the outcomes of the workshops and interviews conducted as part of this study, as well as the case studies undertaken. It also looks at the international context of OSM in the construction industry, with a particular emphasis on the UK industry.

Section 3 presents seven case studies of OSM product use in Australian construction projects. Each case study provides the background to the project or company, discusses the OSM aspects of the case, and ends with lists of benefits, barriers and lessons learnt from the project.

Finally, Section 4 provides a proposed action plan that can guide the Australian construction industry to a fuller understanding of the benefits of OSM, and allow the industry to take advantage of OSM's potential.

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

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Without the financial and collaborative efforts bringing together industry, government and applied researchers, this industry-aligned publication could not have been successfully delivered to our industry.

Project partners

Industry	Government	Research
John Holland	Building Commission	RMIT University
	BSA	The University of Newcastle Australia
	Queensland Government Public Works	Curtin University of Technology
	Department of Housing and Works	

About the Cooperative Research Centre for *Construction Innovation*

The CRC for *Construction Innovation* is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, *Construction Innovation* is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. *Construction Innovation* is a seven-year project funded by a Commonwealth grant, and industry, research and other government support. More that 350 individuals and an alliance of 27 leading partner organisations are involved in and support the activities of this CRC.

There are three research areas:

Program A — Business and Industry Development

Program B — Sustainable Built Assets

Program C — Delivery and Management of Built Assets.

Underpinning these research programs is an Information Communication Technology (ICT) Platform.

Each project involves at least two industry partners and two research partners to ensure that collaboration and industry focus is optimised throughout the research and implementation phases. The complementary blend of industry partners ensures a real-life environment whereby research can be easily tested and results quickly disseminated.

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 limited uptake corresponds to similar trends in the UK and US, although the level of OSM there appears to be increasing.

This project undertook three workshops — one each in Victoria, Queensland and Western Australia — and 18 interviews with key stakeholders to assist in identifying the general benefits and barriers to OSM uptake in the Australian construction industry. Seven case studies were also undertaken, involving construction projects that used OSM, ranging from civil projects through to residential. Each of these case studies has been analysed to identify what worked and what didn't, and suggest the lessons to be learned from each project.

The project found that there are numerous drivers and benefits of OSM in Australia. OSM was seen to:

- reduce construction time
- simplify construction processes
- provide higher quality, better control and more consistency
- produce products that are factory tried and tested
- reduce costs when resources are scarce, or in remote areas
- result in improved working conditions
- reduce on-site 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
- achieve better energy performance.

However, OSM also raises challenges that need to be overcome. Barriers to OSM, whether perceived or real, are:

- lengthened lead times
- need to fix designs at an earlier stage of the project process
- need to specifically design products and building components
- very low IT integration in the construction industry
- high fragmentation in the industry
- it appears expensive when compared to traditional methods
- high set-up costs
- possible increased consequences of incidents
- restrictive, fragmented, excessive, onerous or costly regulations, especially between geographic jurisdictions
- a lack of codes and standards
- a negative stigma and pessimism based on past failures
- union resistance
- a perception that it is restrictive and unable to deliver customer desires
- difficulties in financing

- loss of control on site and into the supply chain
- limited capacity of suppliers
- inter-manufacturer rivalry and protection
- low-quality imports
- a lack of professionals skilled in OSM
- a lack of manufacturer/supplier skills to enhance OSM efficiency
- insufficient industry investment in R&D
- lack of a knowledge portal
- difficulties in inventory control
- constraints due to site conditions
- difficult and expensive long-distance transport for large, heavy loads
- interface problems on site due to low tolerances.

The findings in the case studies confirmed the benefits and barriers of OSM found in the workshops and interviews. Significant improvement and industry changes are required for the Australian construction industry to fully realise the potential benefits of OSM, and overcome many of the barriers currently inhibiting its adoption

Opportunities to exploit OSM in Australia centre on detached houses, high-density multi-residential complexes, and public facilities such as hospitals, schools and prisons. Technical areas for research and development to aid OSM uptake include walling systems, modularised housing and lightweight concrete wall panels. Furthermore, risk identification and mitigation strategies for OSM also need investigation. A proposed action plan for driving OSM through the industry has been developed, with a key focus on skills training, education and knowledge provision.

See Case study 7 – Monarch Building Systems (Source: Monarch)

1. Manufacturing principles

Off-site manufacture (OSM) 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 off-site production consistently shows higher productivity growth than on-site production. Despite this evidence of greater efficiency and productivity, it appears the principles are generally ill-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, manufacturing resource planning, and enterprise resource planning systems, which are processes that are enabled by information technology
- concurrent design, where communication among designers and producers (e.g. construction forepersons, 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 in relation to on-site works. Two other areas where manufacture and construction have converged are product modelling, in the form of building information models, and lean construction.

Building information modelling (BIM) 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 defines 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. LC has established itself in certain sectors of construction, although is not yet widespread. The manufacturing principles underpinning LC lend themselves well to OSM (Ballard & Arbulu 2004). Its core concepts are encapsulated by Roy et al. (2003) and are that it:

- specifies work value in the eyes of the customer
- identifies the value stream and eliminates waste
- makes value flow at the pull of the customer
- involves and empowers employees
- continuously improves 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 — now and in the future. The rigidity of production processes is increasingly seen as a hindrance, 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

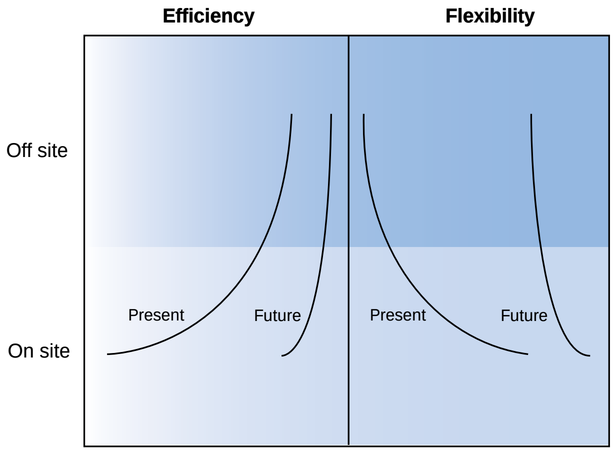
The tension that has naturally existed in manufacturing is that between volume and choice. High volumes and therefore economies of scale have naturally precluded variance among products, limiting customer choice. Manufacturers in construction have long argued that large volumes of the same product are 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 the interfaces between the components are important, rather than the components themselves (Gibb 2001). Future developments in non-construction manufacturing and OSM will see the replacement of mass production with mass customisation. Customers' needs and desires will be important drivers for such customisation, but 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), and it has called for increasing industrialisation in US house building towards the year 2010, mainly targeting an increase in flexibility. Figure 1.1 illustrates this concept, showing the shift required in the decade to 2010 for manufactured housing to improve in efficiency. Most importantly, it must make marked strides in offering the flexibility that is currently enjoyed by site-based construction. OSM must match this trend if it is to make inroads into the construction industry.

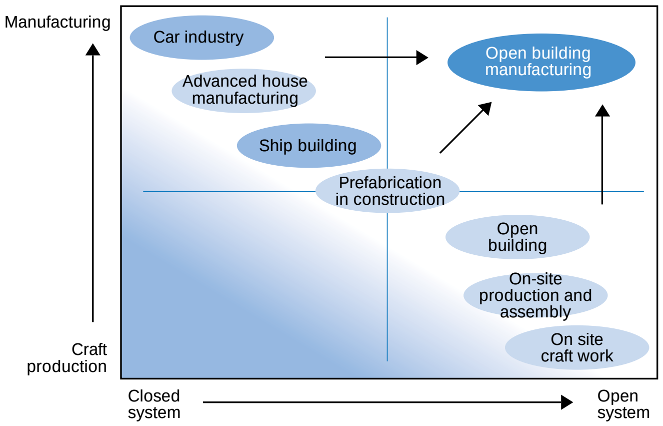
Figure 1.1 Industrialising the house-building process (PATH 2002)



Source: Technology Roadmap: Whole house and building process redesign, PATH (2002)

Another representation of this idea is communicated by Eichert & Kazi (2007) in Figure 1.2, which illustrates the state of construction manufacture, showing the array of sophistication across all types of construction delivery. While manufacturing (i.e. efficiency) aspects, such as advanced house manufacturing, are well understood by some sectors, 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 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, and OSM must be capable of combining efficiency and flexibility if it is to succeed in the future.

Figure 1.2 Open building manufacturing (Adapted from Eichert & Kazi 2007)



Source: Eichert & Kazi 2007

2. Off-site manufacture

Through a series of workshops and interview with key stakeholders, this project has identified the significant drivers of OSM in the Australian construction industry, and the constraints that are preventing the wider adoption of OSM.

This section summarises these drivers and constraints, and discusses the international context, particularly in the UK, where studies have identified OSM as an important contributor to progress in the construction industry.

Drivers and benefits of off-site manufacture in Australia

The drivers and benefits of OSM as described by respondents are summarised in Table 1.1.

Table 1.1 Drivers of OSM in Australia

Drivers	Description	Comments and notes	Action
Process and program	Reduces construction time	Significant contributor to reducing whole cost of construction, for example: • lower site-related costs for constructors • earlier income generation for clients	Benefits of speed of construction need to be emphasised
	Simplifies construction process	Quicker completion reduces site disruptions and hazards (e.g. decreased road closures)	
Quality	Higher quality and better control in the factory	Product testing allows for better control of safety factors/margins	Use this to mitigate negative sentiments about OSM (see constraints in Table 1.2)
	High levels of consistency	Can deliver better product quality, consistency, component life, reduced whole-life cost and defects through QA in controlled factory environment, for example: • level of accuracy for steel fabrication better off site • better surface finish achievable for precast concrete that is not being covered • can achieve better surface finish • some products offer 100-year design life, unlike in situ	
	Product tried and tested in the factory	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)	

Drivers	Description	Comments and notes	Action
Cost/value/ productivity	Lower costs where work is under resource pressure	Costs related to material and labour force pressures drive OSM, for example: • trade skills shortages such as bricklayers • reduced supply of formwork in Qld • brick shortage in WA	Whole-life cost needs to be emphasised with understanding of value rather than purely direct material/ labour costs
		Allows for more efficient designs that reduce need for high safety margins and specifications	
	Lower costs of work force in remote areas	Reduced labour/trade living expenses in remote areas	
	Lower whole cost of construction	Significant contributor to reducing whole cost of construction, for example: • lower site-related costs for constructors • earlier income generation for clients	

People and OHS	Improved working conditions for labour	Improved working conditions for workers, controlled environments to protect workers from elements such as rain and high temperatures	Take advantage of positive work benefits OSM can provide to a workforce to promote OSM
	Reduced on-site risks due to lower likelihood and exposure	Reduces OHS risks on site due to: • reduced time on site • reduced likelihood due to lower hazard exposure • 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 • a more stable work force and better loyalty Work ethic reported as very low in SE Qld due to high volume of work. High staff turnover, absenteeism and low loyalty	

Drivers	Description	Comments and notes	Action
Skills and knowledge	Significant shortage of skilled trades in construction, being acute in certain centres	Site skills/knowledge: • low skills bases in remote areas of the larger states • shortage of trade skills a major driver for OSM – fewer trades needed in OSM environment – reduce risk in boom times with shortages – during shortages, it is difficult to find good tradespeople and exposes poor tradespeople – systems that require lower skills may be favoured (e.g. steel frames), likening to 'Meccano-set' mentality Skills shortages identified in WA include: • bricklayers • form workers • plasterers • carpenters • shop detailers	Importation of 'cheaper' labour suggested by respondents as possible with new IR laws; but hesitation expressed due to resistance from unions Skills training
	Revitalisation of 'traditional' manufacturing regions with high unemployment	Off-site skills/knowledge: • can revitalise manufacturing sectors in 'traditional manufacturing' areas that have lost their industries (benefits especially in areas of low skills where labour costs are low) • improves local skills base	
Logistics and site operations	Fewer trades and interfaces to manage and coordinate on site	Fewer trades on site aid coordination and reduce interfaces	Demonstrate process improvements and interface reductions
	Ability to transport large loads easily	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	

Drivers	Description	Comments and notes	Action
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, for example: • one case study used waste from manufacture to fuel site • one precaster 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	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, and get the products onto site and in use in as short a time as possible	Requires government policy for this driver to be operational

Constraints and barriers of off-site manufacture in Australia

The constraints and barriers of OSM as described by respondents are summarised in Table 1.2.

Table 1.2 Constraints and barriers of OSM in Australia

Constraints	Description	Comments/recommendations	Action
Process and program	Longer lead times Inability to fix design without further changes OSM must be designed-in, not retrospective 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	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 • JIT 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	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 and OHS	May increase consequence of incidents	Need for cranes has safety issues associated with large loads	Perhaps use screen lifting and self-climbing cranes

Constraints	Description	Comments/recommendations	Action
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	Energy rating systems to be used to demonstrate that OSM can exceed current standards Regulators (e.g. BCA) need to look at precast accreditation for OSM skills Regulators need to look at precast, introducing separate section to code for precast Changes to fire engineering standards could be re-thought to open the steel market
		Legislation and qualifications unclear for precasters (versus concreters). Appears concreter needs more qualifications with manufacturing and installing tilt-up than a civil engineer with experience in manufacturing and installing precast	
		Inadequate codes for OSM varieties (e.g. addresses tilt-up but not other precast 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)	

Constraints	Description	Comments/recommendations	Action
Industry and 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 off-site 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, for example: - poor precast 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	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 construction managers 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, showcasing OSM products in operation and dispelling negative perceptions Establish government-funded display centres showcasing OSM products in use
Supply chain and procurement	Loss of control on site 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 relies on eastern Australia with high transport costs) Importation of OSM products prone to low quality and non-compliance to Australian standards Potential loss of project control, especially on site Different payment terms and cash flow arrangements required for OSM Market protection from traditional suppliers	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	Comments/recommendations	Action
Skills and 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 focused on current practices, not future ideas	Focus on future trends and ideas for construction managers, 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 manufacturing 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
		Site skills/knowledge: • requires higher on-site skill to deal with low OSM tolerances for interfaces • may necessitate higher levels of IT literacy, which is low in SMEs	
		Off-site skills/knowledge: • precasters 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. logistics management, coordination of OSM installation, erection skills)	
		Industry knowledge: • general lack of guidance and information on OSM available in the marketplace • lack of single information source, rely on experience —particularly disadvantages SMEs • lack of R&D in OSM	

Constraints	Description	Comments/recommendations	Action
Logistics and 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, for example: • 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 As an example, road travel restrictions in (NSW) include: • 2.5–3.5m can only travel between the hours of 9.00 am and 3.00 pm • 3.5–4.5m must have an escort vehicle • 4.5m + must have a police escort — which has massive costs High mass of precast concrete products results in higher transport costs Low tolerances increase problems when fitting components on site	Barcoding 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

International comparison

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, particularly the United Kingdom. However, no notable research or industry initiatives had been undertaken in Australia until the commencement of this scoping study.

In order to appreciate and interpret the barriers and constraints to OSM identified in Australia, an international context is required. This section provides an overview of research initiatives undertaken in the UK and other countries, and discusses the drivers, benefits, barriers and constraints to OSM in these countries.

Australian construction has been characterised as adversarial, inefficient and in need of structural and cultural reform (Cole 2003). Several government reports have called for significant improvement of the UK construction industry, which is likewise described as fragmented, adversarial and inefficient, requiring significant improvement (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 complementary 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 (Egan 1998; Barker 2004).

Given the high profile offered to OSM in the UK, activities to encourage the adoption of OSM are considerable, involving several research initiatives, communities of practice and government-sponsored forums (e.g. Accelerating Change). About £5 million was invested by the UK government between 1997 and 2001 in research projects that included construction OSM. This figure grows 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 into 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 the 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 about two per cent of the £106.8 billion 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 house building (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 is poorly understood by many of those involved in the construction process, 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, while 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 focused 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 present -day examples of OSM, ranging across all building types, from military installations, civil structures and 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.

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.

While the uptake of OSM in Australia may seem very small, interest within the industry is increasing. Nevertheless, government initiatives in the UK over the past few years far outstrip those in Australia. In parallel, private spending in the US to make gains through OSM are proportionately far larger than in Australia. The outlook for Australia is, however, positive, as OSM has now begun to attract attention through the *Construction 2020* report, and research such as that funded by the CRC for *Construction Innovation* and AusIndustry.

3. Australian case studies

This section provides an analysis of the seven case studies of OSM product use in Australian construction projects, undertaken as part of this project. Each case study provides the background to the project or company, discusses the OSM aspects of the case, and ends with lists of benefits, barriers and lessons learnt from the project.

Case study 1 – Bull Creek Station Project

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 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 western side of the freeway.

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

Completed Bull Creek Station (Source: New Metrorail 2006)

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

- bridge spans
- wall abutment systems
- lifts
- escalators
- balustrade.

Products

The various precast products used on the project are briefly described below.

Leach Highway Bridge T-Roffs

Duplicating Leach Highway Bridge, 10 precast 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 (36.6 metres) and the eastern span (39.5 metres).

Locally manufactured by Delta Corporation, the precast T-Roffs weigh between 120tonnes and 145tonnes and were transported to 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 millimetres.

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

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 precast concrete abutment walls. Manufactured locally by Paragon Precast, the concrete panels generally measured 7m x 3m x 175mm, and were transported to 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, precast concrete panels from Paragon Precast was again used. Measuring 7m x 1.6m x 175mm, these items were transported to site and craned into position.

Elevator and escalators

The elevator at the station was manufactured entirely off site by Schindler Lifts Australia, and lifted into position fully assembled.

Otis Elevator Company Pty Ltd, a West Australian supplier, was awarded the contract for escalator supply and installation. The escalators were manufactured in China and ordered well before construction of the station started, and were installed with no problems. They were lifted into place using two mobile cranes, and the installation process took around two hours to complete.

Structural steel

The structural steel was supplied prefabricated 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 they were left off during manufacture. This necessitated a consultation with electrical services personnel, and significant fabrication delays occurred as a result of having to make changes.

Pedestrian footbridge balustrade

The pedestrian footbridge comprises three spans. The main span is a precast T-Roff beam; the remaining two are Delta Corporation precast 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

Prefabricated steel section being placed (Source: New Metrorail 2006) 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 — very detailed design and an inexperienced fabricator combined resulted in a poor product, and the fabricator had to carry out many on-site rectifications in order to meet design specifications.

Near complete station with footbridge to the left (Source: New Metrorail 2006)

Benefits

- All of the precast concrete items were successfully integrated on the project.
- The use of precast 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. Despite the management complexities associated with the coordination of multiple OSM suppliers (e.g. steel fabricators, lift manufacturer) and individual contractors (e.g. concreters, electricians), there were no problems with product quality or component integration.

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.
- A design oversight in the steel OSM items 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.
- 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.

Lessons

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

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Case study 2 – Melbourne EastLink Project

The project and company

The EastLink Freeway project in Melbourne was undertaken by the Thiess 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 precast 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, and with little to no impact on the actual construction site. Morwell, about 130 kilometres away from the construction site, was selected as the location. The region had a reasonably high rate of unemployment from which to access labour, and the joint venture presented to the government that if successful, the project would provide employment to the region.

The precast manufacturing plant was located in a disused steel fabrication plant for the duration of the project. Converting the existing plant into one suitable for precast 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 as prestressed moulds from China were designed and the procurement process started. As part of the precast operation, the joint venture then appointed a senior person as the precast facility manager (PFM). The PFM had little prior knowledge of the precast 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 seven staff with different skills in precast concrete. These employees spent many months developing the existing plant into a working precast concrete manufacturing plant. The PFM also employed various senior engineers experienced in the manufacture of prestressed concrete. Employment of about 200 workers followed. The PFM was advised not to employ those with concrete experience, opting rather to skill workers up over a three-week period, providing a potentially superior quality of product by reducing the likelihood of bad practices being brought from site to the factory.

Transport

The newly opened rail network through Morwell provided a possible means for delivering components to site. However this notion was quickly dispelled as the cost of loading and unloading the concrete precast elements would have been prohibitive. The train option would require four lifts in total, compared to trucking the elements by road, with only one lift onto the carrier, and one lift into the final position. The 130 kilometres distance from the factory to site did not pose any problem as precast 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.

The process and products

The system and process allowed manufacture of concrete precast bridge components and assorted sound barriers off site, while earthworks were under way at the main EastLink 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 prestressed beams exceeding 90tonnes. Much of the plant's capacity was designed around these products. Manufacture of large prestressed 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 using a new hot water plant specifically designed for the curing process
- attaching safety platforms and rails before loading onto the jinker.

Manoeuvrability of these heavy components required specific attention, and necessitated the mobilisation of an 85-tonne straddle carrier, 50-tonne rail-mounted portal gantry cranes, and a 70-tonne mobile sling crawler for handling prestressed beams from the moulds and

Boiler system used to accelerate curing of the moulded concrete

Jinkers being loaded with post-tensioned bridge beams

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 around half a metre of stabilised crush rock at significant cost.

These heavy prestressed 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 EastLink site) around 10.00 pm, recommencing the last section of the trip at 6.00 am. The transport often slowed to 20 kilometres per hour on the highway.

Sound barriers

Apart from the bridge beams, smaller sound barriers were also produced at the plant, using vertical (battery) moulds. Using the gantry, these were easily transported outside for storage. Re-usable impression moulds were also used for many of the barriers.

The larger 'rock face' sound barriers were produced horizontally. The 'rock face' mould was made using 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

Safety rails fitted to beam and loaded onto jinker for transportation

Vertical sound barrier moulds (battery moulds)

was about one third that of the more traditional supplier with an original $1.5 million 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 increased labour costs associated with laying the styrene.

Lessons

The 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. In hindsight, the RFID system set-up costs would have been recovered.

The set-up of the temporary production plant 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 off-site options were not restricted to fixed, long-term facilities, but rather were more about understanding the concepts of production and manufacture.

Acknowledgements

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

Case study 3 – Newcastle Mercure Apartments Project

Historical context

Mercure Apartments is a new development in Newcastle, New South Wales. It is a mixture of new build and the adaptation of an older structure. The finished building will have 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 of using a number of different factory-made modules for the bathrooms, ensuites and kitchens in the development. Together with another company in China, Timwin 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 with the new branding and use. Duc Associates has a reputation for specialising in the design of large-scale hotel projects. Its work ensured that standards were met and the designs fit in with the Mercure brand.

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

The product

The building uses the following modules:

- bathroom
- kitchen
- laundry
- ensuite.

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

Construction

The modules consist of a 75 millimetre steel tubular chassis into which a concrete reinforced floor is poured. The finished floors are approximately 80 millimetres 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.

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.

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 on site, 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 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.

Modules in position (note void above for services)

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 it is more cost effective to use 'higher quality' materials.
- By making the modules 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.

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 watertight. The modules are therefore exposed to rain ingress, 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.

Kitchen module in place by window (note drop down floor)

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 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 has been contacted by another hotel group, and is currently working with the module manufacturer to refine the design/production/integration process for new projects.

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Case study 4 – Prep School Capital Works Project

Historical context

Prep is a new school year which has been introduced into Queensland. Getting ready for Prep has meant the Queensland Government has taken on one of the largest-ever capital works programs in the education department's history. It involves providing around 400 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 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 for the start of the 2007 school year for the first cohort of children, with the balance to be completed for the start of the 2008 school year — about 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 the concomitant pressure to succeed.

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 to integrate the new classrooms into the existing school site. One of the recommendations 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 to the Department of Public Works Joint Venture. The joint venture was formed from personnel within the commercialised business units (Project Services and Q-Build) of the Department of Public Works.

Another key requirement was to provide the new buildings with an appearance of permanence so that they blended well into the existing school infrastructure. The buildings were also intended 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.

Classroom on site and in use

Design

The basic design of the classrooms was developed by the Department of Public Works. The manufacturers were responsible for the engineering design and resultant production drawings. The design took the form of a rectangular, seven-bay module, with a classroom at each end. Kitchen and storage facilities were located in the central module. A five-bay offset version of the above was also offered. Originally there had been around 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. Secondly, the external joints between modules were effectively covered by a deliberate design detail that used full cladding sheets. These were a combination of compressed fibre cement sheeting and corrugated Colorbond cladding.

Completed roof sections assembled at ground level

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

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

Manufacture

The two manufacturers had similar approaches to the construction of the modules, but with some differences.

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 with local authorities. 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 seven modules of the floor were bolted together and levelled before the basic skeleton was built, which included the posts for the roof support. With this in place the roof sections were moved outdoors and attached to the framework. Once the roof section was attached, the walls and interior were fitted-out on site. Elements of the building were excluded at the module interfaces to allow the covering of joints on site 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 on site without any interface discrepancies and associated delays.

With completed roof in place the framework and fitting out commences

Completed classroom at factory showing cladding left off at module joints

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

On-site installation

Two processes took place on installation.

Modules

Once on site, the installers organised the set-out of the building and supervised installation. Trades (e.g. electricians, plumbers) followed to complete the fitting out of the classrooms and remove all evidence of the individual modules. The following main items were finished on site:

- battening under the building to hide the foundation stumps (Education Queensland does not normally do this with temporary buildings)
- the roof sheeting at the joint (referred to as the complex joint) left off so that standard roofing could be fixed on site, ensuring no joints could be seen
- the exterior walls received a full cladding sheet between windows or doors to hide joints
- internally, flooring panels completed to conceal joints
- full length guttering attached.

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 handrails for safety. Rails and balustrades were manufactured beforehand and were 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 meet individual requirements for the different sites, but this was restricted due to cost. The only situations where alterations were permitted related to works undertaken on or near historically listed buildings, where more appropriate colour schemes were necessary to meet planning legislation.

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 on site quicker.
- Less time spent on site, so less disruption to 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-handover' period of three 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.

Barriers

- Statutory approval process — approval of such items as services was mainly a documentation issue. Also, different local authorities were found to have slightly different requirements.
- Due to the large up-front investment needed by manufacturers to start manufacture, an 80 per cent 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 — but 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.

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, it is not known if this is achievable.
- Confidence to use the model again — one of the key messages from the government was that it saw it as a trial for further work, and wanted to make sure it would work because it can see many advantages in this type of program for the future.

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Justin McNamara – BRB Modular

Case study 5 – Skilled Park Project

Historical context

Skilled Park stadium at Robina is currently being constructed by Watpac for the Queensland Government's Major Sports Facilities Authority. The project has successfully used 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. The project's principal, the Department of Public Works, has used a Single Select Negotiated Guaranteed Construction Sum Managing Contractor contract to procure the project. Watpac was engaged shortly after the announcement of the stadium design competition outcome to assist the design development process and expedite the submission of a guaranteed construction sum (GCS). A GCS was submitted by Watpac at the completion of the schematic design stage. On completion of the GCS negotiations, the contract was let and the design team was novated to Watpac. Since letting of the contract, Watpac has been responsible for managing the design development and construction process to the agreed GCS.

The design of Skilled Park differed from other stadiums that Watpac had constructed. The winning designers, HOK Architects, are specialist stadium architects who had worked with Watpac on Suncorp Stadium. The Department of Public Work's initiative to engage an experienced managing contractor early in the design process enabled the team to consider buildability, OHS and industrial strategies and tailor the design to accommodate OSM. The system of construction was selected based on experience gained during the Brisbane Cricket Ground and Suncorp Stadium projects. OSM is particularly suited to stadium construction, which inherently has large repetitive 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 in an under-resourced labour market — the client requires the stadium to be completed in time for the start of a nationally televised sports code season
- minimisation of on-site work and more efficient off-site fabrication methods
- reduction in construction quality risks
- reduction in OHS risks.

Construction started on site in June 2006, and it is expected that the stadium will be completed in late 2007.

Robina Stadium site January 2007 (Source: Watpac Construction)

The product

Structural steel was selected for the main structural frame as it is traditionally constructed quickly and easily off site in many sections. Early in the design process, Watpac considered incorporating further OSM items into the development, eventually deciding to undertake the majority of the stadium's structural elements production processes off site. The structure consisted of the following OSM components:

- structural steel for the main structure of the stadium, including seating support members, curved roof beams and the four-level western stand facilities building
- seating plats, being the main precast concrete beams that support the stadium seating
- western stand building floors, consisting of precast planks forming the load-bearing floor structure that is placed on the structural steel frame before a topping is poured in situ to tie the planks into the structure
- all concrete vertical elements precast, including wall panels, stair shafts, lift shafts and vomitories (spectator exit points)
- roof and wall cladding, consisting of a fabric membrane manufactured in Germany and fabricated in Poland.

Steel

The main steel fabricator, Beenleigh Steel Fabrication (BSF), provided valuable industry input early in the design process. BSF's input into the project team value engineering process enabled options for key steel design elements to be reviewed and resolved efficiently. This initiative ensured the early bulk steel ordering of key structural elements from industry suppliers, while simultaneously allowing the refinement of design details prior to commencement of shop drawings for manufacture. This key initiative reduced the potential of later delays.

BSF tends to use shop detailing companies that work exclusively for it to ensure good levels of communication. BSF had two main roles on the Robina project — fabrication and erection.

Steel fabrication

Fabrication

The steel was constructed in a controlled environment to eliminate any adverse weather effects. BSF has two factory locations that, among other things, enable it 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. These were stored until they were dispatched for protective finishing and painting. 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 to site. Combining the erection of steelwork and precast elements under one package has streamlined BSF's erection methodology, reduced demarcation risk and aided the project's programming.

Erection began immediately the in situ foundations had been placed. The erection process had very low tolerances — typically a couple of millimetres — requiring precision in the on-site and off-site elements fabrication, thorough shop drawing coordination, and accurate survey and set-out work.

Concrete plats

Precast concrete plats (long beams to which the seating is attached) have for a long time been used as a standard element of stadium construction, as they are both cost and time efficient. Casting the seating tiers in situ would take considerable time, be costly and also

Off-site manufactured steel structures in place 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 with a large exposed surface area being steel trowelled. The plats for this project are T-shaped and were moulded at 90 degrees to the final orientation to reduce the amount of trowelling required. This gave the maximum amount of off-mould surface, which results in a high-quality seating bowl surface finish — typically a class 1 or 2 surface.

Pouring the concrete plats

The T-shape (on its side section) was designed to overcome a problem perceived 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 has four 60 metre moulds, and can make different length plats by using adjustable end plates. Using these moulds, it has 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 55–60°C and reduces the cure time. The process took around 18 hours from start to finish, with pours commencing at 2.00 pm and finishing by 8.00 pm. By 6.00 am the following morning, the plats could be removed from the moulds and stacked. Generally the plats required no patching or repair. The prestressing 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.

Concrete plats receiving seating

Steel structure and concrete plats on site

Benefits

- Reduced overall project time and associated cost savings — this was the main benefit.
- 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 significantly 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 any time without competing for common workspaces.
- Better environmental performance — reduced amount of waste and better recycling 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.

Barriers

- Mistakes made at the drawing stage may not have been discovered until the item was installed on site. The consequences of mistakes are more significant.
- In automated systems, single component breakdown 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 who are comfortable designing precast components is limited, and they tend to be conservative in their designs.
- Fastenings are a substantial cost of precast concrete elements — problems arise if the engineer does not understand precast or has limited technical knowledge. Knowledge in connection systems and their capacities is required.

Lessons

- Coordination 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 coordination and earlier commencement of off-site works.
- Allow architects and engineers enough time — they have been surprised at the speed of installation on site, with a basic stand structure being completed within a few weeks. There is significant pressure on the design consultants to develop the design and provide construction documentation at a much earlier stage when OSM is used.
- A large amount of trust is required — using people who have worked together before reduces this risk.
- Ability to discuss options and aspects with clients throughout the project is highly beneficial.

Acknowledgements

Gilbert Gouveia – Design Manager, Watpac Construction

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

Case study 6 – Hollow Core Concrete Pty Ltd

Historical context

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

Hollow-core 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 1950s and first used in Australia for industrial walling in the 1960s.

The company initially just produced hollow-core 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 the US and Europe were not suitable for the types of buildings and construction methods used in Australia.

Through its 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 and includes:

- 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 hollow-core planks for the transfer floor in domestic housing where basement carparking 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 in situ concrete or steel-frame designs. This allows the company to offer a ‘design, manufacture and installation’ package.

Hollow core production

Hollow core 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 undercover casting beds, each approximately 120 metres long. These act as forms for the bottom of the hollow-core planks. Steel strand reinforcement is laid out along the length of the bed and then stressed to a predetermined force. The number of strands and the force can be altered depending on the specification of the hollow-core plank.

Concrete is then fed into a machine that travels down the bed extruding the hollow-core 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 areas 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 predetermined 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.

Hollow core in production

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

Precast 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 hollow-core 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 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 T-sections and are designed so that no temporary support is required.

The hollow-core planks sit on the ledge of the inverted T-beams. On a typical system, an 80-millimetre-thick screed is used over the top of the hollow core and beams to tie them and 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.

Example in practice – GPO Building Melbourne

A new six-level glass-facade 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, the builders (St Hilliers) and the consulting engineers (Arup), in conjunction with HCC, decided prior to the start of the project to investigate the use of precast concrete components. One of the main drivers of this decision was the difficulty of using in situ construction in the confined central city location, with its associated access and time constraints.

HCC was asked to propose a suitable construction technique to overcome the technical difficulties of cantilevered floors on three sides and, due to the glass-facade, the lack of sheer walls to provide lateral stability.

The HCC solution incorporated the basic precast column, beam and hollow-core 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 precast moment resisting frame was incorporated at the western end of the building.

Constructed almost entirely out of precast components, the new building has around 2300 square metres of hollow-core plank floor area. The cantilevered sections are precast 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 facade.

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 precast construction can be adapted to suit an architecturally complex project.
- Significant formwork and scaffolding systems to handle the large floor-to-floor heights were 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.

Typical benefits

- Hollow core enables spans up to 17 metres. 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 formwork so there is a reduced on-site labour cost.
- Speed of construction.
- Early access of follow-on trades.
- The process of hollow-core manufacture is highly mechanised, resulting in high-quality products.
- Reduced on-site labour.
- Excellent surface finishes.

Barriers

- Over the years, precast concrete has been associated with low-cost housing blocks that have affected its image and restricted its uptake — the 'grey box' mentality.
- The construction industry is traditionally very conservative, so the introduction of anything perceived as new or different faces barriers.
- There is a 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 hollow core, 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, but it cannot compete on costs with traditional lightweight 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.

Lessons

- HCC works across all procurement methods, but has found that when it is 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 has 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 precast. HCC needs to generate greater publicity about the large number of projects it has successfully completed.

- More education is required to inform the industry of the advantages of precast concrete and prefabrication. Much of this education relates to understanding precast as a system rather than a series of individual components.
- Recent industry skills shortages in the standard trades (e.g. concreters, steel fixers, carpenters, crane operators) have necessitated more training and a shift to greater use of precast components. Internal corporate expertise in the products, and more broadly in OSM, is used to train new staff. HCC also runs training on other items such as industry standards, OHS, QA requirements and on-the-job training specific to precast.

Acknowledgements

Simon Hughes – Hollow Core Concrete Pty Ltd

Hollow-core planks, beams and columns (showing support) on site (Refer page 31)

Case study 7 – Monarch Building Systems

Historical context

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

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

- Pantex — 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 independence with regard to standards, and building requirements and regulations.

The product

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

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 a number of whole wall panels which are built in the factory, and include all frames and sheeting ready for on-site erection.

The process

The wall panels comprise 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, and sounded solid when hit by the hand (no 'drumming').

The cement-based panels are 26 millimetres thick and comprise a lightweight concrete of proprietary composition and a waterproof membrane. The board has been tested for impact, fire, waterproofing and insulation. The finished panels meet most Queensland insulation requirements without the need for additional bulk

Lifting completed wall panels onto site (Source: Monarch) 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 house 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 on site, 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, 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.

Construction on site (Source: Monarch)

Once at lock-up 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 plasterboarded conventionally. At this stage, such items as push-fit, pre-finished window/door architraves help to reduce fit-out time and painting further.

Completed house (Source: Monarch)

Modular

The modular system which has been developed is based on the construction techniques used in the panelised system — a steel frame on a precast 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 are described below.

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 on requirements, typically either panelised wall colourbond steel pre-finished weatherboard or corrugated profile. This gives durability and long life.

There are a number of different types made:

- single-person accommodation facilities for sites such as mining towns, comprising two-, three- and four-bedroom modules, each typically with its own ensuite for privacy
- residential homes of conventional architecture
- commercial office buildings, particularly in remote areas
- tourist accommodation which has been designed to provide tourist park operators, with three- and four-star standard facilities.

Wet room modules

These comprise bathrooms, toilets, ensuites, laundry rooms and linen cupboards. Depending on 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 storey and multi-storey developments.

Bathroom modules in production (Source: Monarch)

Benefits

- The manufacturing process enables the production to be very efficient and cost effective.
- Quality controlled construction delivers a consistent product.
- Short delivery times and very quick on-site construction time.
- Minimal trades requirement on site, 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 'prefab'.
- Suits low-rise multi-residential applications in remote areas and regional centres, where access to trades can be difficult.
- Minimal on-site disturbance, giving a tidy work site with minimal waste or pollution.
- Minimal disruption due to weather delays.

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.

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.

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Nathan Warner – Projects Manager, Monarch Building Systems

4. The future of OSM in Australia

Given the drivers and constraints of OSM in Australian construction, as identified by this project, an action plan is needed to furnish the industry with a basis for formulating research projects and initiatives to promote or facilitate OSM in construction. The plan must have a key focus on skills training, education and knowledge provision to enable a broader understanding and acceptance of the benefits of OSM and overcome the constraints currently limiting its widespread adoption. Table 1.3 presents a proposed action plan, listed in order of relative priority, that can meet these needs and realise the potential for OSM in the Australian construction industry.

Table 1.3 Action plan for OSM in Australia

Theme and actions	
1.	**Skills and knowledge**
1.1	Skills training in trades and OSM skills required to ensure the industry is well furnished with labour.
1.2	Regular conferences/meetings should be arranged to demonstrate OSM projects and benefits.
1.3	Encourage government to provide improved research incentives to stimulate local innovation and business start-up.
1.4	Increase appeal for manufacturers to employ apprentices.
1.5	Encourage location of manufacturing plants in areas with suitable labour source.
1.6	Conduct career days at schools to interest people in the OSM market.
1.7	Create online portal to disseminate international OSM trends, products and processes.
1.8	Conduct market research study to ascertain market opportunities.
2.	**Process and program**
2.1	Disciplines and processes need to be streamlined using integrated IT systems, including development of IT-based project management systems to coordinate subcontractors and integrate the process. Need to learn from other industrys' systems — from design through order and production.
2.2	Advice on information and document distribution, and management protocols required in high IT environment.
2.3	Advice on storage and ownership of digital information should be provided.
2.4	Encourage design of OSM into the project from concept stage through education and showcasing.
3.	**Industry and market culture**
3.1	Establish annual OSM products and careers expo to showcase and promote OSM. Include trade shows and seminars.
3.2	Commence initiatives to ensure that tertiary education focuses on future trends and ideas including OSM and manufacturing (construction managers, engineers and architects).
3.3	Marketing emphasis on mass customisation rather than mass production, includes increased standardisation but not necessarily repetition.
3.4	Improve government standards for civic architecture intended to improve building quality and longevity, showcasing OSM products in operation and dispelling negative perceptions. Showcasing will demonstrate all benefits of OSM.
3.5	Establish government-funded display centres showcasing OSM products in use.
4.	**Cost/value**
4.1	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**
5.1	Energy rating systems to be used to demonstrate that OSM can exceed current standards.
5.2	Appropriate authorities need to examine the potential for OSM skills accreditation.
5.3	Appropriate authorities need to examine introduction of separate section to code for precast/OSM.

Theme and actions			
6.	**Logistics and site operations**	**7.**	**Environmental sustainability**
6.1	Inventory management research and advice necessary for manufacturers.	7.1	Demonstrate that better efficiency ratings are possible due to better dimensional tolerances.
6.2	Locate manufacturing plant close to the project to reduce transport costs and logistics.	7.2	Demonstrate sustainability benefits.

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Off-site manufacture in Australia: Current state and future directions

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