PREFabricated MODular HOUSING

A Case Study

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Abstract: Prefabricated and modular solutions have formed a small part of the overall housing industry. This is particularly evident in Australia, where the market is dominated by hand-built housing using traditional construction techniques built by large-scale builders. This paper evaluates the ideal and the reality of prefabricated modular housing procurement in China for the Australian market. While there have been prefabricated components for the housing industry, primarily, most solutions are of volumetric nature. The findings question our understanding and methodology to prefabrication for Australia. The experiences of introducing building services into modules (pods) from overseas fabrication also have shortcomings. The case study presented indicates several of these problems and suggests a hybrid solution to volumetric delivery.

Keywords. Formatting; specifications; ASA; paper; template.

1. Introduction

Approximately 150,000 houses are built annually in Australia (HIA, 2014). It has been estimated that this represents a short-fall of 40,000+ houses compared with demand. As a result of recent economic climate and increasing land value over the last decade, land costs now exceed housing costs by a factor of two or three, hence the proportional cost of building is increasingly less. The designs will need to consolidate and become more compact to accommodate smaller (more affordable) lot sizes. Double story and duplex solutions may provide a promising solution (Luther and Collins 2009).
There have been partial answers to the housing shortfall in Australia with the introduction of several prefabricated and modular building companies. However, few of these have managed to reduce costs, provide for flexible design options, and actually advance the methods of the construction industry. Manufactured housing in Australia amounts to doing business as usual yet off-site. This process is costly because it involves the sourcing of materials delivered to the manufacturing plant (apart from typically going to the site) and then being manufactured (not too differently from the site) and then delivered to the site as a volumetric container type product.

Due to the high labor and material costs in Australia, many manufactures have been sourcing services and materials off-shore, in particular China. Nevertheless, in many cases, this has also not provided an answer to many of the problems encountered with product procurement, quality assurance and consistency as well as predicted. In a recent (and unnamed) case, prefabricated modular bathroom, kitchen and laundry ‘pods’ were manufactured in China and shipped to Australia specified for volume builder home designs. For these cases, an ‘immediate’ volumetric solution was designed to ‘connect’ with the on-site services in a conventionally built house. The Australian provider was left with over 60 different pods rejected from clients, and returned to a warehouse to remedy the defects, primarily related to problems with the building services.

A recent publication ‘profiling the nature of the Australian prefabricated housing industry’ proposed the methods of construction in housing (see Table I, Steinhardt, et. al., 2013). It is interesting to note here that the ‘level of prefabrication’ is considered ‘High’ when complete, volumetric, or delivered to a building site. Whereas, contrary to this, a ‘component system’ is understood as pre-cut, preassembled or not feasible to produce on site, is labelled as a ‘Low’ level of prefabrication. Unfortunately, this is the perception and level of understanding of prefabrication as it is understood in Australia and not necessarily shared by industries of highly sophisticated prefabrication as in product manufacturing. In specific, a German company (Digitales Bauen, Karlsruhe) have demonstrated that one-off prototype commercial buildings can highly benefit from ‘component system’ prefabrication, especially when it is related to objects to do with building services (Hovestadt, V., 2005).

It may be unfortunate to limit our understanding of modular prefabrication as a finished delivered volumetric product. Nevertheless, this is quite evident in the recent manufacturing and fabrication companies, for example; Prebuilt, Modscape, Unitised Building (Hickory Construction), Pearls Mii Home, etc. The criticism is that it may not necessarily be appropriate or feasible to rule out a combination of several of the prefabricated modular construction methods for a project.
The forthcoming presents a case study where a hybrid prefabricated modular construction strategy is proposed as the potential solution to several of the encountered problems.

2. Prefabricated Modular Housing: A Practice Case Study

We explore a case study of PFM design, procurement and fabrication in practice. For purposes of commercial confidentiality, reference to the parties involved in the project will be de-identified.

The project was initiated by a Hong Kong based company (the Client) with a factory base in North-East China (the Factory). The client’s Hong Kong office housed a team of engineers and project managers and was the central liaison with the design team. The Client controlled a large Chinese factory of 80,000 square metres of factory, plant and administration buildings. Capacities included a steel coil colour coating line and continuous sandwich panel production line with a potential production capacity of 1 million square metres per annum. Automated production processes included a Salvagnini punching and bending production line and FrameCAD steel frame production plant. Products produced by the Factory included colour coated steel coil, PIR and PUR sandwich wall and roofing panels, cold rooms and cold room doors.

In 2011, a 30,000 square metre addition was made to the factory to provide capacity for the fabrication of modular housing for the Australian and Asian markets. This factory space held the potential to produce cladding ma-
terials, steel framing and to manufacture fifteen building modules simultane-
ously- a significant capacity, especially when compared with Australian op-
erations.

From 2008, the Client worked with a design team to produce a number of
prototypes to test various design, production, fabrication and transportation
methodologies. Methods tested included ‘flat-packed’ building assemblies
transported to Australia in shipping containers and ‘volumetric’ pre-
fabricated modular units. Following the design, fabrication, transportation
and construction of a small PFM building in 2009, focus shifted from flat
packed to volumetric methodologies. The principal reason for this was that
the cost of Australian-based labour required to assemble flat packed compo-
nents on site overcame any cost benefits of China-based manufacturing. The
low cost of labour in China meant that as much activity be directed there in-
stead of Australia.

2.1. DESIGN ISSUES

In 2011, the Client provided a brief to The Architect for the design of a large
prototype house for a coastal site in Western Australia. The brief served the
double purpose as being a holiday house but also an assembly of modular
units that would demonstrate the modular concept for mining and residential
uses.

The Architect responded to the brief by developing a design concept for
the house based on PFM’s measuring 14.2m (L) x 3.5m (W) x 3.3m (H) with
8no. “Isolock” lifting points set out to standard shipping container lifting lo-
cations. PFM sizes were determined principally by the limitations of trans-
portation by ship and by road- to fit three modules high in a cargo ship and
to conform to maximum heights for transportation on Chinese and Australi-
an roads. The house comprised six PFM’s with two two-storey modules for
the 7-bed bedroom wing and two ‘side-by-side’ modules for the living wing.
The bedroom PFM’s were designed to demonstrate both 4-bed (upper sto-
rey) and 3-bed (lower storey) layouts, typical alternative configurations for
small and medium-sized mining camp accommodation.
The Australian design team consisted of the Victoria-based Architect as principal consultant, a structural engineer and a services engineer for mechanical, electrical and hydraulic design and a Western Australian-based building surveyor consultant. Design occurred over a 9-month period from late 2011.

A primary issue in the selection of consultants was the absence of any available consultants to operate within a Building Information Model (BIM) environment. The use of BIM as ‘a dynamic process/component oriented model for digital practice,’ (Ambrose, 2009) although ideal, proved unattainable for this project. Thus, although the Architect completed the project from concept to completion in ArchiCAD™ the remainder of the design team operated using line-drawing-based AutoCAD™, which negated any opportunity for BIM-enabled clash-detection and integration of the structural, mechanical, hydraulic and electrical engineering information within the single building CAD model.

The Architects adopted a design strategy that prioritised repetition, mass production and modularity. Key to achieving this aim was the adoption of the ArchiCAD™ building model as a virtual environment for simulating fabrication and production issues. By adopting processes of repetition, mass production and modularity in building the ArchiCAD™ model, important insights into the work required on the factory floor were achieved. The more simple the ArchiCAD™ virtual building model, the more simple the real building would be to fabricate.
CAD production method aside, the design team encountered many significant challenges in the design of PFM’s for Australian conditions. The architect’s role, as principal consultant, relied heavily on the co-ordination of sub-consultants in a way that retained key design concepts of repetition, mass production and modularity. These are summarised below:

Structural Engineering:
- Structural steel design for static and dynamic (lifting) loads
- Structural cross bracing
- Connections between modules
- Weight of structure for transportation

Mechanical Engineering:
- Air-conditioning, refrigerant piping and condensate piping design
- Size, location and co-ordination of piping and ductwork (especially penetrations through structural members)
- Connections of ducts and conduits between modules
- Prefabricated vs on-site work
- Access to sub-floor and accessible spaces

Hydraulic Engineering:
- Sanitary plumbing, domestic cold and hot water supply
- Size, location and co-ordination of piping (especially penetrations through structural members)
- Facilitation of connections to water supply and reticulated sewage systems
- Connections of pipes between modules
- Prefabricated vs on-site work

Electrical Engineering:
- Lighting and fire detection, power and communication, switchboard
- Size, location and co-ordination of conduits
- Location of sub-boards at junctions between modules
- Connections of conduits between modules

2.2. REGULATORY COMPLIANCE
Following a comprehensive period of design development, a set of contract documents was produced by the design team for submission for building permit. These documents included 26no A3 sheets of architectural drawings, 8no A1 sheets of structural, 2no A1 sheets of Mechanical, 4no A1 sheets of Hydraulic and 15no A1 sheets of electrical engineering drawings, as well as
schedules and specifications, Bushfire Attack Level classification and Energy Rating report.

A consulting building surveyor was chosen to review the documents prior to certification by the local shire council as is required by Western Australian building regulations. No planning permit was required, however local planning regulations were required to be adhered to. Regulatory compliance proved to be a huge issue for the project, as all materials and components of the building were required to comply with a range of Australian Standards before the Building Surveyor would provide the necessary building permit.

The building was classified as BCA Class 1a, 360 sq.m. at wind region 1, category 2 and climate zone 5. The design reached compliance, but only after a period of 9 months after the initial set of drawings were lodged for building approval. Although a large number of issues were identified, we focus only on issues that relate to the practical implementation of PFM buildings in Australia. Main areas of contention in the Building Surveyor’s BCA report in relation to Chinese-produced PFM’s were:

- **Clause 1.2.2 - Evidence of Suitability.** Evidence to support all building materials meets the requirements of the BCA.
- **Clause 1.2.4 – Fire hazard properties of materials, linings and surface shall comply with the Specification A2.3 of BCA Volume One.**
- **Clause 3.4.2.0 – Steel framing.** The steel framing is to meet the requirements of AS4100, AS/NZS4600 and NASH – Residential and low rise steel framing – Part 1 Design criteria.
- **Clause 3.4.2.6 – Installion of services.** All services are to be installed in accordance with these provisions and certified accordingly.
- **Clause 3.5.1.3 – Metal sheet roofing.** Due to the location of the proposed two-storey dwelling, namely within 1.0km from breaking surf, the environment is classified as Medium and a minimum metal coating in accordance with AS1397 shall be provided dependant if metallic coated steel or metallic organic coated steel is provided. Certification is required from the manufacturer on the type of corrosion protection provided.
- **Part 3.6 - Glazing.** Certification must be provided for the glazed elements of the proposed two-storey dwelling. The glazing manufacturer is to ensure the window frames; fixing and glazing comply with AS 1288 & AS 2047 and be suitable for their intended location within Australia.

Meeting the requirements of BCA clauses, above, required The Client to undertake an extensive investigation into Chinese-produced building materials. Critical to this was the ability for the various companies to evidence their certification to Australian Standards. This investigation and sourcing took more than six months, however was achieved by the Hong Kong based
team to the satisfaction of the Building Surveyor, and a building permit was finally issued.

2.3. FABRICATION ISSUES

Compounding the issues of material sourcing and supply is the issues inherent in using Factory-based Chinese labour in the fabrication of PFM housing. Key to the success of the traditional Australian housing construction system is the tradition of masters and apprentices. Generally, a master builder is the principal contractor, who then sub-contracts work to licenced plumbers, electricians and other tradespeople. Each of these must have indemnity and other insurance to cover faulty workmanship, workplace accidents and other on-site issues. Trades must provide a warrantee to cover their work and Housing Industry Association provides warrantee insurance to cover non-completion or failure of the builder to correct faults due to death, insolvency or other reasons.

Tradespeople become licenced only after a period of site-based of apprenticeship coupled with technical classes and examinations. This work experience is generally overseen by a licenced tradesperson, the same person who is legally liable for the workmanship of the apprentice.

We find that the absence of master tradespersons and apprentices in the China factory caused significant problems during fabrication. Although there were project managers and engineers involved in overseeing the fabrication, a gap existed between management and the personnel directly involved in fabrication. That gap was the equivalent class of trades with building knowledge and experience. Other issues were found in project safety and quality control, which were addressed after a visit to China by the Architect. Although these represented problems during the fabrication of the prototype house, these issues can be corrected with changes in management.

The primary significant problem in the fabrication of the prototype was the requirement for all electrical and hydraulic (plumbing) works to be completed by licenced tradespersons. This issue is significant, and something that represents a primary factor that will limit the ability of Chinese-produced PFM housing for the Australian market. In this case study, a Western Australian-based plumber and electrician were flown to the China factory for one week to oversee and implement the electrical and plumbing work. Many issues arose here regarding tools, equipment, language and communication.

The singular biggest issue inherent in this element of the project was that Australian-based tradespersons (and the Building Surveyor) were unwilling to sign off (and risk their house) on work performed by Chinese factory la-
bourers. Consequently, only part of the work was completed in China and the remainder was required to be performed on site. This meant that the inside wall linings could not be completed in China as planned.

If an Australian-based fit-out could be accommodated, then this issue could have been overcome. Unlined modules could be delivered to an Australian factory for mechanical, electrical and hydraulic fit-out by suitably qualified Australian tradespersons. Arguably, the deferral of this work to Australian tradespersons would negate the need for comprehensive Mechanical, Hydraulic and Electrical engineering documentation. This hybrid model of procurement would then share the attributes of the traditional housing market.

2.4. PROCUREMENT ISSUES

Once the six PFM’s were fabricated in the China factory, they were wrapped in protective plastic and transported by road to the nearest port, then placed three modules high in the cargo ship bound for Australia. After quarantining process, the modules were stored then delivered to site. An important consideration in PFM production is accounting for the varied conditions likely to be encountered whilst at sea. In this case, the PFM’s suffered impact damage to the building envelope, leakage to the sub-floor modules and cracking of some internal linings due to rough treatment whilst at sea. The perfect nature of the sandwich panel construction made any scratches and dents easily visible, requiring replacement.

Other problems were encountered when lifting the PFM’s which, due to the weight of structural steel, bracing and interior linings, reached 12 tonnes. Co-ordination of screw pile locations with the Chinese-produced PFM’s also proved problematic, however this occurred due to communication problems within the construction team.

3. A hybrid Chinese-Australian produced PFM House

China undoubtedly possesses serious capacity to act as a supplier for PFM housing in Australia, however the industry is currently at its infancy. Chinese-manufactured PFM units are currently being used for the mining market for large developments in Western Australia and Queensland, however no manufacturers have reached the Australian housing market.

We propose the ideal PFM house is one that maximises the capacities of China but also recognises the limitations of working with the Australian regulatory regime. Thus, a hybrid China-Australia solution is proposed as the idea. We propose that the greatest potential lies in the manufacture of the PFM units in China, sea-based transportation to an Australian port for ‘fin-
ishing off’. An Australian-based factory located near the port would operate to provide mechanical, plumbing and electrical fit-off and also repair any damage to modules incurred during transportation.

This solution would overcome the need for Australian-based tradespeople to be located in China in order to satisfy strict regulatory requirements. Obviously, any proposal such as this would require significant investment in both countries, and would be subject to market research confirming the demand for PFM housing made in China.

4. Conclusions

The consideration that all buildings consist and should be recognized as ‘component systems’ may in fact lead to an answer where problematic results have existed in volumetric building. An understanding of simplification first, setting up standards, grids, locations and rules to be followed, are all part of prefabricated building processes. Companies such as Digitales Bauen have championed such examples where conventional building designs have been partitioned into a ‘least common denominator’ module. Issues of building services integration form the core of the problems of regulatory compliance that have impacted the case study discussed above. This approach, coupled with a hybrid Chinese-Australian model of mass production may provide a model for the future of the prefabricated modular housing to meet the needs of the Australian market.

References

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