Wall Panelisation – Offsite Manufacture and Construction of Houses

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Abstract

Off-site manufacture offers the means to achieve more efficient construction and improved building performance. Current building practices have predominately evolved from traditional trades and practices, without a re-engineering process to take advantage of current materials, equipment and engineering. Off-site manufacture presents an opportunity to improve many aspects of construction, whilst satisfying aesthetic, design and long-term quality requirements.

A key technology is the factory manufacture of wall panels comprising framing, external cladding and finishes, windows and doors and a straight forward means of site assembly and fit-out.

Monarch Building Systems commenced a major R&D Project in 2002 to develop a new, more efficient method of building houses to lock-up stage. It set out to avoid bricklaying, rendering and on-site installation of windows and insulation. Simplification of on-site tasks and safety issues were also targeted. R&D activities covered the development of an advanced cladding product and a large scale manufacturing plant for the cladding material and wall panels utilising advanced automation and robotics.

To further increase manufacturing efficiency, detailed design solutions have been developed utilising the Autodesk Revit Building Information Modelling (BIM) environment, and custom engineering to take full advantage of the systems. This fully flexible system directly outputs custom data files for each stage of the automated manufacturing process along with construction and quality assurance documentation.

The technology and systems for design, manufacture, logistics and site construction, including complimentary products and systems for floor slabs, internal walls and roof and eave framing, have been proven with hundreds of conventional houses constructed achieving aesthetically pleasing finishes, economical construction costs and improved building performance.

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The panelised wall systems have now proven to be commercially viable in residential construction and Monarch Building Systems are ready for the technology, manufacturing plant and systems to be taken up by other building organisations both in Australia and elsewhere.

Keywords: panelisation, prefabrication, house construction, efficiency, light weight cladding.

1. Introduction

House building in Australia for the last 50 years has consisted predominantly of brick veneer construction, with a concrete slab floor, timber framing to walls and roof, and a plasterboard internal lining. With consumer preferences shifting to rendered external wall finishes combined with industry pursuit of cost reduction and improved sustainability, house construction is ready for a change in technology associated with the external building fabric.

Various themes have emerged as possible directions for the future of house building, each having the common element of performing more processes in a factory environment instead of trade work on a building site. We have categorised the majority of the innovative proposals into 3 themes:

- Supplying house construction with a standardised kit of parts where the assembly logic is derived from another industry e.g. Toyota Housing Corporation where the thinking comes from the Japanese car industry and the IKEA Flat-Pack house where the thinking comes from the Swedish furniture business.

- Panelised wall construction where large sections of external walls are pre-assembled with external cladding in a factory and craned into position on the construction site e.g. American builders are adding plywood sheathing and installed windows to timber wall frames to speed up and simplify on-site construction.

- Modular construction with all finishing components for joining together on-site with minimal trade work. This approach has appeal for remote area construction where trades labour is not available or expensive.

Pantex Pty Ltd, a privately owned Queensland based builder and its manufacturing arm, Monarch Building Systems Pty Ltd (Monarch) embarked on a project in 2002 to develop and refine a new panelisation system suited to warm and temperate climates, which addressed the issues of labour cost minimisation and the need for improved sustainability performance. The Monarch Panelisation System is now a proven viable approach to house and other low rise construction. It has been used extensively in building designs embodying contemporary architecture.

2. The Monarch Panelisation System – Wall Panels

Panels for residential construction are typically 2500mm or 2800mm high to suit 2400mm and 2700mm ceiling heights respectively. Panel width is 105mm. The panel length often suits the length and articulation of the house external walls, with a maximum of 6500mm. A full component specification is listed in Annexure 1. The main components of the wall panel are:

- A steel frame comprising elements of high tensile (450-550 MPa) steel with a zinc aluminium coating. The steel studs have a flange design suited to the screws and joints holding the cladding material. Various aspects of the steel frame are unique to Monarch to accommodate roof frame point loads, bracing requirements, and a flush internal surface as a base for quality plasterboard finish. Pre-punching for services holes and bolt attachments is an important feature. Monarch has created a certified manual for standardised engineering performance covering a significant range of house architecture and size.

- A light weight concrete sheet product as exterior cladding. Calsonite®[4] is a composite of light weight concrete, a dense surface layer, internal reinforcement and reflective foil bonded to the back face. Calsonite is 27mm thick and is produced in sheet sizes of 1200mm x 2358mmm and 1200mm x 2700mm. Full properties of Calsonite are listed in Annexure 2.

- Panels are created by screw fixing Calsonite to the steel wall frame. The jointing system between sheets of Calsonite incorporates an imbedded micro-expansion joint to accommodate minor building movements. A full masonry expansion joint is set between panels to comply with building codes (typically at 4.5 to 6.0m centres). Panels have Calsonite horizontally protruding or retracted at their ends to suit building external and internal corners. Calsonite also vertically overhangs the frame bottom-plate to provide weathering in a standard slab recess.

- Window and door frames have extended fins for factory sealing onto the Calsonite face except for the frame head which weathers behind the Calsonite. The window and door frames are screw fixed to the steel frame. Trimming the aluminium frame on the interior is an aluminium extrusion which snaps into a recess and holds against the internal plasterboard, creating an aluminium reveal and architrave. This extrusion is normally installed after painting of the plasterboard.

- Panel finishing occurs after the panels have been stood vertical and level in accordance with the architectural layout, secured in position and the roof framing and cladding have been installed. The panel surface is smooth and has a basic sealer to prevent moisture uptake. Panel corners and main expansion joints are set using unique jointing methods. The joint between the Calsonite and the concrete slab is filled with a polymer sealant which cures to form an elastomer. Walls are then ready for the application of a coloured acrylic based render as the finished surface. The render finish provides the first stage of water proofing.

3. Facilities

Monarch have completed a manufacturing plant with 10,000m² of floor area at Narangba (northern suburb of Brisbane) for the manufacture of 500 house lots per annum on a single

[4] Calsonite® is a registered trademark of Monarch Building Systems Pty Ltd

shift basis. The plant comprises a Calsonite manufacturing line including curing ovens, a panel production line, and plant for the fabrication of steel framing to complete the whole house. The plant is highly automated. It is serviced by a digital network, many roll formers, press tooling, wall and truss assembly and overhead crane transfer of incoming goods and product despatch.

Embracing the manufacturing, transport and erection of houses is the detailed design function. Detailed design takes place in the Autodesk Revit Building Information Modelling environment principally direct from architectural drawings. Subsequently the manufacturing data is transferred directly to relevant work stations. The manufacturing data is complemented by automatically generated quality assurance checklists and diagrams for on-site assembly of panels and other structural components. The fully flexible manufacturing environment has been designed and equipped for high labour productivity despite the norm where each house is an individual product, with little repetition between successive houses.

Factory facilities are complemented by delivery trailers, a long-reach crane equipped prime mover, scissor-lifts for on-site assembly and racking for safe handling.

4. Issues in House Construction impacted by Panelisation

For panelisation to be effective as a means of speeding up house construction and reducing cost there are a number of adjoining components and tradespeople which are impacted compared with traditional brick veneer.

- Slab – Bonus useable floor area is typically 5% compared with brickwork due to reduced external wall thickness

- Incoming power – must go up through framing or be external to wall (with a cover plate)

- Frame should be earthed during construction

- Electrical and plumbing – grommets are fitted in service holes to isolate the services from the house frame

- Steel roof framing of a style similar to framing used in commercial construction has been developed by Monarch. Features of the roof framing system are:
    - Trusses at 2400mm maximum centres
    - Purlins for roofing attachment instead of battens
    - Ceiling joists support the plasterboard ceiling and create a ceiling diaphragm
    - Bolted connections throughout the roof framing to facilitate efficient on-site assembly

- A unique solution has been developed for eaves involving a purpose designed pre-painted steel fascia

- Plasterboard sheeting, carpentry, electrical and plumbing fix-outs are entirely conventional except for the type of fasteners

- Various trade activity is eliminated altogether from site work:
    - Window install and sealing
    - Damp course install
    - Bulk insulation install
    - Cladding install
    - Building wrap
    - Frame straightening and bracing
    - Roof frame tie-down rods

5. So How Much Faster is Panelised Construction?

Our experience is that a competent carpentry gang comprising 2 tradespeople and 1 apprentice would require:

- 170 man hours to erect and anchor wall panels, frame non-load bearing internal walls from stud and plate, erect roof and ceiling framing, assemble and underline eaves

- 94 man hours to install safety wire, perimeter safety rail, insulation blanket, roofing sheet (pre-cut Monarch System) and gutters

- 4 man hours to install front and side swing doors and double panel lift door

These times apply to a 200m² floor area, 4 bedroom house on a concrete slab with a 25° pitch hip roof and 600mm eaves. Reflecting much of coastal Queensland, the times allow for a house built to withstand a tropical cyclone in a non-exposed location.

In other words, for 3 men it takes 10 x 9 hour days (30 man days) to achieve full lock-up with full internal framing. The comparable labour times for an equivalent brick-veneer and roof sheet house are estimated at 52.5 man days.

6. Implications of Panelisation on the Cost of a House

The cost of building a house obviously depends on a multitude of factors, with the more obvious related to house design, specification, location and labour costs. Our analysis is based on regional Queensland with characteristics of long-distance supply chains and extremely high labour costs on an international comparison. Our economic terms of reference are based on recent experience in project home construction which has seen a cost structure of frame and lock-up as a proportion of total house costs as shown in Figure 1.

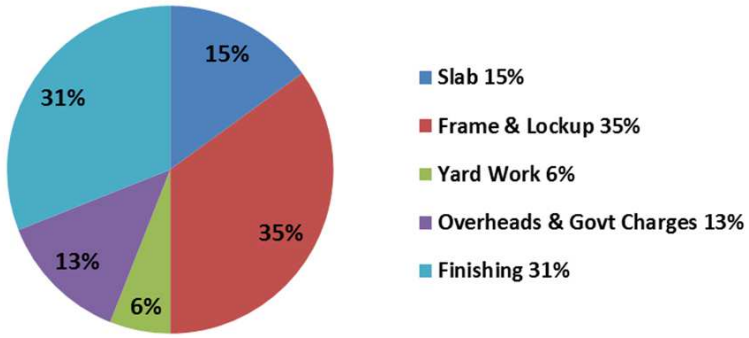

Figure 1: Breakdown of project home construction costs in Regional Queensland

Realistically the frame and lock-up component of the total cost of a project home is only approximately one third. While worthwhile savings can be achieved by a builder using the Monarch Panelisation System, we do acknowledge that the impact on total house costs will only be incremental. For example, a 10% reduction in material and labour costs in frame and lock-up translates into ~3.5% of overall house cost which may become ~2% of a House & Land package.

The cost of the panelised product is also subject to on-going improvements, particularly in relation to the costs of the very mature technology of the timber frame and brick veneer alternative. For panelisation to be competitive, the technology of its manufacture must be advanced and this has been substantially achieved. The on-going potential for further cost structure improvement is mostly related to increased scale of manufacture. Monarch's facilities have the capability of manufacturing at a nominal rate of 1000 homes per annum with little change to existing equipment or configuration (dual shift). The change in cost of manufacture as a function of production volume is forecast in Figure 2.

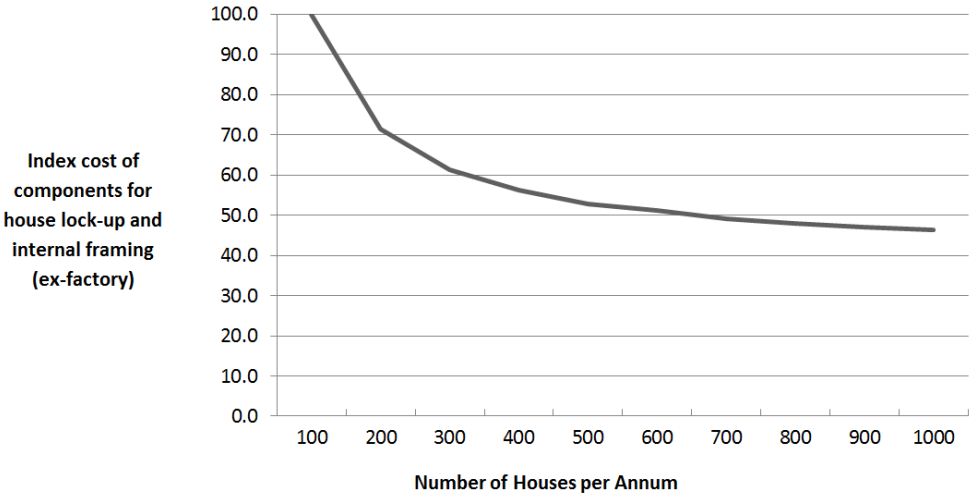

Figure 2: Effect of Manufacturing Volume on Panelisation Supply Costs

This graph shows that the panelisation product and manufacturing methods have significant potential savings as the extent of adoption grows.

7. Sustainability

The Monarch Panelisation System's sustainability advantages are as follows:

a) The most obvious is the very high standard of durability – this is not temporary housing!

- Complete waterproofing afforded by 2 stages of moisture resistance
  - Render finish layer
  - Aluminium foil layer - this double waterproofing avoids rotting in the frame and internal finishes and the formation of mould

- Complete termite resistance

- No timber reveals, door sill or jambs which deteriorate under the influence of sun and rain

b) Lower energy consumed in the building products (embodied energy). Table 1 shows a detailed calculation of embodied energy in the Monarch wall panels compared with an equivalent house with brick veneer construction and render finish.

Table 1: Embodied Energy (MJ) in External Walls and Windows (60 linear metres of wall)

Material / Component	Timber Frame and Brick	Steel Frame and Calsonite
Frame and bracing Ply	9,754	34,800
Hold-downs, Brick Ties, Nails, Straps	9,267	950
Insulation & Sarking	2,880	0
Brick & Mortar/Calsonite	57,678	44,640
Finishes & Jointing	30,796	13,609
Windows, reveals, architraves	8,260	11,168
Total	**118,635 MJ**	**105,167 MJ**

Data for embodied energy in various construction materials has been sourced from:

Hammond G and Jones C (2011) Inventory of Carbon and Energy V2.0 University of Bath, UK

Alcorn A (2003) Embodied Energy and CO_2 Coefficients for NZ Building Materials Victoria University, NZ

Manufacturer data has been used for unique constituents incorporated in Calsonite and materials for jointing and applied finishes.

8. Conclusions

The house building industry is under pressure to build in a more sustainable manner and to use modern technologies to build more efficiently (cheaper). In most of Australia, timber framing and brick veneer cladding is still the norm but with a relative lack of quality timber resources in Australia, there is a gradual change to steel framing. A further shift from brick veneer is likely to be driven by an unwillingness of younger generations to follow the bricklaying trade.

These basic factors provide background to the need for a change to greater use of technology for external wall construction. Monarch has embraced the challenge to develop a replacement technology. This has resulted in a new cladding product, an innovative means of volume manufacture whilst satisfying customised design requirements, and handling and on-site installation.

Comparisons have been made relative to traditional housing construction of timber frame and brick veneer, together with the modern trend of a smooth rendered finish. Panelisation can simultaneously deliver advances in durability and in embodied energy. The use of steel house framing and the Monarch aluminium framing system for windows and doors avoids ongoing maintenance but at the expense of initial embodied energy. Nevertheless the sample analysis of embodied energy present here demonstrates that worthwhile reduction in embodied energy can be obtained even with metal frame systems.

Panelisation will also lead to cost reduction in house construction and these benefits will increase as Panelisation is adopted on a larger scale.

The benefits of panelisation are particularly significant in regional locations where the systematic approach to construction adds to labour cost efficiencies. Experience in the housing market indicates that early adopters of the panelisation system include multi-residential project developers, project builders and franchise builder groups.

Monarch has developed manufacturing equipment and systems which provide building efficiencies from the use of panelisation compared with traditional material supply and construction methods. Continuing research and development will ensure that even greater sustainability and efficiencies will be achieved in future.

The photograph gallery shows examples of recent Queensland housing under construction and completed with panelisation.

Annexure 1: Component Specification of Wall Panels

Steel Frame

- up to 3200mm high, 6500mm long panels
- nominal 78mm width incorporating
- studs from G500 & G550 steel ZnAI coating
- pre-punching for electrical, data, water services
- heads for point loads from roof structure
- bracing required in excess of that generated by attached cladding
- trimmings for window and door openings and noggings for attachment loads
- holes for floor and roof connections
- self-piercing rivets as primary connection within the frame supplemented by tab and slot and welding
- pre-engineering of frames based on extensive manual of design reference verified by comprehensive testing
- maximum weight of panels ~ 400kg

Calsonite® - Light Weight Concrete Cladding

- nominal 27mm thickness
- reflective foil bonded to back sealed for waterproofing
- screw fixed to steel frame at centres dependent on wind and bracing loads
- micro expansion at 1.2m max horizontal centres (not transmitted to the render face)
- installed with full expansion at centres nominated in the masonry code
- performance established for impact resistance, sound transmission, fire rating, water proofing, structural strength
- subject to rigorous QA in manufacture

Aluminium Framed Windows and Doors

- customised frame integrating reveal and internal architrave
- fully tested and accredited sash and screen systems for sliding glass windows and doors, fixed glazing, double hung windows. Casement and louvre windows are also available
- customised frame and sill for panel doors
- frames sealed against the face of panel in panel assembly
- screw fixing of aluminium frame onto steel frame

The window and door frames have been developed by Monarch and are used in conjunction with sashes designed and manufactured by G. James Glass & Alum (Qld) Pty Ltd.

Wall Finishing Render System

- wall panel surface is factory finished both smooth and flat
- the cladding is offset at corners to accommodate jointing and continuity of smooth surface
- a polymer sealant seals the joint between wall cladding and the concrete base (or steel & plywood flooring system)
- a 1 coat acrylic based render system is applied on-site to give a final coloured trowelled texture finish
- stipple can be incorporated in the finish by appropriate trowelling techniques

Annexure 2: Properties of Calsonite

Property	**Performance**
Construction	Lightweight concrete composite
Outside Face	Cementitious Render
Inside Face	Reflective Foil
Thickness	27mm
Density	600kg/m³
Bend Strength (3 point bend, 300mm length, 1200mm width) - Average load at break - Average deflection at break	 3324N 10mm
Impact Resistance (70mm x 1.4kg steel ball from 3.3m) - Maximum indent depth	 4mm
Moisture Transfer	Waterproof, Zero transfer
Termite Resistance	Termite Proof
Flatness (maximum deviation of surface from a plane in any 2m length)	< 2mm
System Thermal Performance*	1.06m² K/W (R value)
System Fire Resistance* (structural/integrity/insulation)	- / 60 / 60
System Acoustic Performance* (predicted by computer modelling)	Frequency (Hz) R(dB) 100 19 125 19 160 25 200 31 250 36 315 41 400 45 500 48 630 50 800 52 1000 53 1250 54 1600 56 2000 55 2500 50 3150 50 4000 53 5000 56
System Bracing Value (2490mm wall height)*	8kN / horizontal metre of panel

* when installed to manufacturers recommendations