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OFF-SITE MANUFACTURE OF APARTMENT BUILDINGS

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ABSTRACT: The populations of major cities in Australia are increasing rapidly and facing an acute housing shortage. Traditional apartment procurement techniques involve lengthy lead-times and factory-based, or off-site manufactured (OSM) multi-storey apartment buildings may offer the opportunity to help fulfill the need by significantly reducing build times.

Other advantages of OSM may include superior quality, low weight ratios, economies of scale achieved through repetition of prefabricated units, use on infill sites, sustainable design standards and better occupational health and safety. There are also positive labour and training implications, which may help to alleviate an industry-wide shortage of skills through use of semi-skilled labour.

Previous uncertainties about the adoption of offsite due to the high capital costs and perception issues were generally based on pre-cast concrete structures, which are quite a different building type in terms of flexibility, construction, delivery and finishes.

Identification of drivers and constraints assists in the determination of current industry status, allows for a benchmark to be established and future opportunities and directions for OSM to be determined.

Keywords: Off-site manufacturing, Project Delivery Systems, Sustainability and the Environment, Light-weight Structures, Occupational Health & Safety.

1. INTRODUCTION

Off-site manufacture (OSM) is not a new concept in apartment building, but the uptake as a building procurement methodology has been slow and somewhat doubtful until recently. Initially involving largely concrete pre-cast building techniques there has been a resurgent use of steel in off-site production. OSM is seen by Blismas (ed.) as offering the ability to produce high-volume, high quality products based on the efficiencies of general manufacturing principles common to many industries. The potential advantages of OSM are well-documented, yet there have been a range of barriers prohibiting active integration of off-site building into standard construction practice as a total procurement methodology.

Analysis of current projects in Melbourne allows greater insight into the future of off-site procurement in Australia, and in particular into the construction of multi-storey apartment buildings. The main case study used to develop the OSM concepts and drivers identified by Blismas (ed.) is the Little Hero apartment development, a seven-storey apartment building designed by Fender-Katsalidis and constructed by Hickory, a joint-venture known as Unitised Building (UB), in the Melbourne CBD. The apartment 'pods', similar to steel shipping containers, were made locally in a factory, and installed onto a traditional concrete core and podium on a "difficult site", over an inner-city, underground electricity sub-station.

2. BACKGROUND TO OSM

2.1 Previous research - Blismas (ed.) conducted research into OSM in 2007, conducting seven case studies in Perth, Melbourne, Newcastle, Brisbane and Robina and found that there are numerous drivers and benefits of OSM in Australia.

In particular OSM has been 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 and reduced on-site risks; alleviate skills shortages in certain areas; revitalise 'traditional' manufacturing regions; provide fewer trades and interfaces to manage and co-ordinate on site; facilitate the incorporation of sustainable solutions and achieve better energy performance.

These aspects of off-site were the result of Australia-wide research and may be considered as being current and applicable, and accordingly have been adopted as a basis from which to proceed with this research paper.

Rogan et. al. state that modular construction is driven by two key imperatives: to build quickly on-site and to improve quality by adoption of off0-site activities. They identify the key advantages of off-site construction as follows:

- Short build times – typically 50-60% less than traditional on-site construction,
- Superior quality – achieved by factory-based quality control,
- Low weight – 30% of weight of traditional methods,
- Economy of scale – repetition of prefabricated units
- Environmentally less sensitive – efficient factory production techniques are much less wasteful
- Use on infill sites – modules are useful on small urban & roof-top type sites,
- Safer construction – modular construction sites have proved to be safer construction sites,
- Reduced labour requirements – less workers on site,
- Reduced professional fees – standardised design details simplify & reduce the need for specialised design input, &
- Services & bathrooms – service modules can be used.

Further, Rogan et. al. surveyed the practitioners in case studies and identified the following benefits:

- Improvements in quality – reduced 'call backs',
- Reduction of site waste by 70%,
- Faster construction times of up to 50%,
- Lower capital costs – reduction by up to 10%,
- Better predictability – 'just-in-time' (JIT) delivery to site.

These benefits are comparable in terms of current OSM practice when applied to the UB apartment project ‘Little Hero”, in particular the call-backs which were minimal. Rogan et. al. particularly notes the advantages of light steel framing, as being strong, durable, lightweight and dimensionally stable.

Lovell discussed the use of pre-fabricated housing in Britain and the use of Modern Methods of Construction (MMC) to meet the UK housing shortage, identifying the following issues requiring discussion:

- Cost – increased costs of 7-10% are reported; although this is qualified by reduced on-site labour costs of 50% - factory overheads are fixed costs whereas on-site costs are variable.

- Industry capacity – a shortage of skills and factory capacity will prevent increased output, so there is a lead time to train staff and build capacity. The advantage of MMC is that factory workers can be utilised and there is 50% less on-site work requiring fewer trade-qualified persons.

- Environmental benefits – reduced waste due to exact factory specifications and greater recycling capacity, energy savings due to increased levels of insulation and less air leakage, and lower transport costs due to site trips.

- Public attitudes – negative attitudes stemming from historical use of prefabricated housing and the traditional use of bricks and mortar have prohibited widespread acceptance of prefabricated housing.

- Health and safety – there are considerable advantages due to the reduced risks to workers in a controlled environment.

With respect to fixed factory costs Lovell notes that site-based costs are only incurred when construction actually takes place, whereas factory costs are fixed and ongoing, requiring a guaranteed workflow.

Given the common advantages identified by these three researchers it would seem apparent that general acceptance and uptake of off-site procurement would occur. However, there are other factors which also influence adoption of off-site in the immediate future as a procurement method.

3.0 OSM DRIVERS, CONSTRAINTS AND SOLUTIONS

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

Other impediments identified were a 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 or suppliers skills to enhance OSM efficiency; insufficient industry investment in research and development in OSM; lack of a knowledge portal; difficulties in inventory control; constraints due to site conditions and difficult and expensive long-distance transport for large, heavy loads; interface problems on site due to low tolerances.

These factors and others need to be discussed and developed in the context of and application to a commercial project, in this case the Little Hero apartments in Russell Place, Melbourne CBD, which involved sixty three (63) apartments over seven (7) levels.

3.1 Process and program – OSM is used to reduce construction time and simplify the construction process, and Blismas (ed.) claim this is a significant contributor to lower site-related costs and earlier income generation for constructors. UB claim an overall reduction in construction time of 60% due to the parallel processes of on-site and off-site production. Typically the on-site works will include excavation, concrete foundations and podium, on which the pods will be placed. In parallel to this the pods are manufactured in a typical large scale factory utilising robotics and assembly-line techniques.

Whilst there are certainly less staff and subsequently fewer on-site costs there is an obvious transfer of costs off-site, which creates further dilemmas for financiers. Traditionally payments are made to constructors when certain stages are reached in terms of project progress. In this case the pods may be complete, but not installed to the Client's site, and thereby technically still in the control of the manufacturer, which raises a number of cash-flow and ownership issues.

OSM requires a major capital investment, with no guaranteed return in either the short or long term, and at a time when construction and manufacturing finance is difficult to source. UB has quite successfully attracted finance to establish the manufacturing plant and also for current apartment projects.

One of the greatest advantages of OSM is the short completion times on-site. Delivery of the Little Hero pods was completed within ten days, thereby reducing the overall impact on the surrounding CBD streets, traffic and general amenity. Within that time there were strict controls over traffic management, with mandatory pod deliveries before peak traffic flows, control of pedestrians and on-lookers and closure of the adjoining street for pod lifting.

3.2 Quality – the intention is and all indications are that the factory environment ensures better quality control. Establishment of assembly-line techniques, including robotics allows for close tolerances, predictability and consistency based on a grid design.

The initial steel pods are made from roll-formed sheet and purlins, spot welded to form a monocoque structure or outer shell. Four columns with a patented locking mechanism absorb line loads, whilst tortion and sheer loads are absorbed by the box shell. Sheet bracing is added to the end of the pod, and the structure typically braces against the core. The pods are manufactured in a jig, which is calibrated to ensure levels are within a one millimeter tolerance.

The fixed column design, which is essentially a tapered plug, is designed in consideration of the installation sequence, and allows a point of relativity to ensure facades meet on installation. This is very effective and once again ensures close tolerances.

3.3 Construction processes – the controlled manufacturing environment allows protection from inclement weather conditions, simple materials delivery and storage, close sequencing of trades, ready access to the individual pods, encourages repetition work and safety. The working 'platform' is on a single level, and designated areas may be established for each trade to work from. Workers do not need to remove tools and equipment each day, and access is immediate. Staff may have the advantages of reduced travel times, less travel cost, regular and predictable employment.

The pods constructed in the UB factory are initially manufactured using a linear assembly-line process, but are stationary for fitout and remain in sequence in terms of final delivery and installation. Accordingly pods may be manufactured just-in-time, which reduces lead-times, but would consume considerable factory floor area if there are delays on site. The current production cycle is 20 modules per week, with floor space for 120 modules.

Elimination of the measuring trades has allowed UB to attain further efficiencies. Setout within the pod is achieved by use of a laser projector, which shines a typical floor plan into the module. All fitout components are ordered using this method, thus reducing the fitout cycle. Conventional fitout time of 95-105 days from formwork stripping to completion is reduced to 30 days, with further efficiencies expected. The need to fix designs noted by Blismas (ed) is far more manageable when a closely integrated team approach is taken, with all participants working together, and where the traditional adversarial relationships between designers and constructors do not exist.

Greater design resolution is required for services and cores, particularly hydraulics which currently involves pre-manufactured PVC pipework which is joined on installation. Vacuum pump systems are being considered, as are pre-cast concrete lift shaft and stair components.

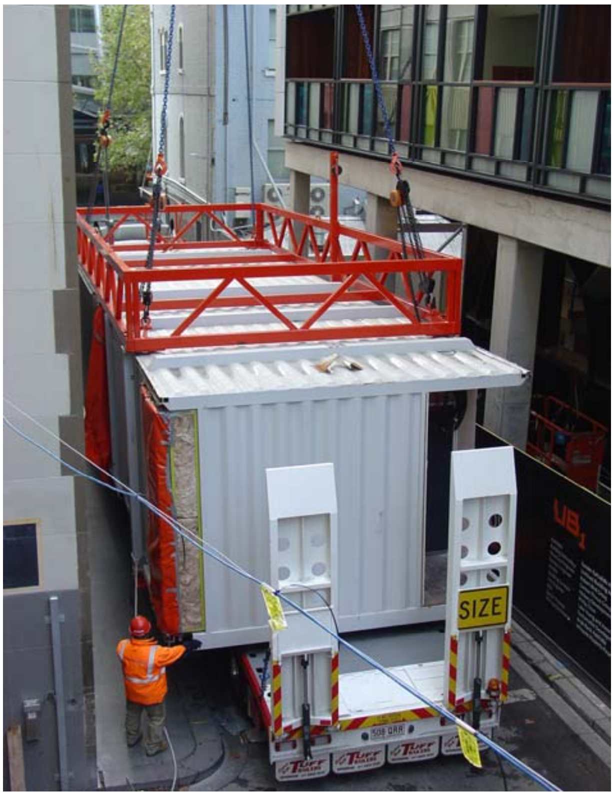
3.4 Resource pressure – the shortage of trade skills are an ongoing difficulty for the construction industry and off-site production allows for the use of semi-skilled labour due to the predictability and lower-scale tasks required. Efficiencies gained through the controlled environment typically reduce the number of skilled trades required, and UB has instigated an accredited program to train apprentices in the factory procedures. Delivery of off-site buildings to remote locations typically involves far fewer staff and subsequently resolves many remote site issues such as availability, accommodation and costs.

3.5 Occupational Health and Safety - safety is considerably enhanced within the controlled factory environment and a subsequent reduction of lost days also reduces the number of persons required, and fewer staff also reduces the likelihood of hazard exposure, congestion and allows better control of risks. The relatively low-scale nature of both on-site and off-site works leads to significantly reduced risks attached to working at heights and encourages a safety ethic. A major benefit of the UB approach is the elimination of faced works – all glazing, balconies and associated works are factory installed, and the pods have gasket joins which seal perfectly.

3.6 Skills and knowledge – the shortage of trades and closure of factories as Australia divests its manufacturing allows potential re-deployment of workers and factory space. Off-site production has the potential to revitalize at least part of the manufacturing regions, and employ factory workers, who may well understand and accept the manufacturing process better than trades persons do. It is apparent that 'stick-build' trades may not adapt well to the factory environment, and the different cultures will undoubtedly produce a different kind of tradesperson. Either way the training of new apprentices has the support of the unions and Government, with subsequent local benefits of revitalisation to be observed.

3.7 Logistics and site operations – the reduced numbers of trades and staff on-site also reduces the interfaces required. Management is located at the factory rather than on-site, and lower levels of management are able to manage the site. Blismas (ed.) indicated concern at the lack of control, however UB report increased control as management is located at the factory, which allows for greater integration of design and manufacture, easier supervision, reduced travel times between site and office, and vastly improved communications.

The scope of off-site is limited by the organisation's ability to transport large components to local or remote locations and the size of the transportation available. The interface reductions and process improvements on offer relate to and may be limited by the logistics of delivery and installation.

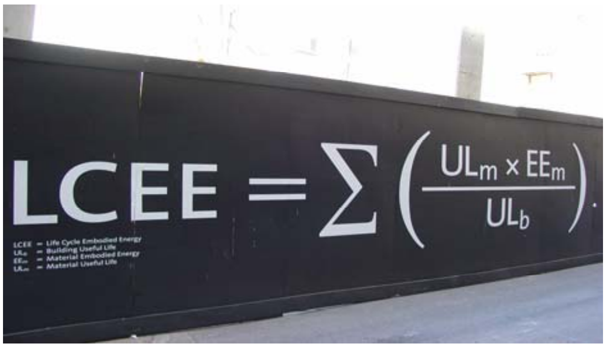


Factors identified by Blismas (ed.) included site access and space to manoeuvre, availability and access for cranage, high winds and available hook time. Factors encountered by UB included power lines and other services on-site or on route, road width, bridges and turning circles available for delivery, Council restrictions on CBD access during business hours and cranage. Subsequently the project required permanent installation of a Tower Crane in an adjacent car-park.

Lovell et. al. note the sizes of modular units are dictated by the economics of transportation, and UB have adopted the strategy of utilising container trucks, and the pod designs allow for open sides to facilitate larger room sizes.

3.8 Sustainability – a significant factor in building, on-site waste contributes up to 40% of landfill, according to Blismas (ed.). OSM offers the opportunity to reduce waste to virtually zero. At the UB factory all materials are carefully managed and waste is recycled, even plasterboard offcuts. Quantities are estimated and materials used on a more efficient basis as dimensional tolerances are exact; on-site waste is fully recycled, as only steel and concrete are generally utilised and excavated soil is fully relocated or treated if contaminated. The elimination of wet trades, for example automatically reduces poor practices generally associated with plastering and painting on-site.

As off-site designs and technology improves so to will general sustainability of the projects. There are significant opportunities offered by the steel monocoque shell design, such as temperature control achieved by air-conditioning the air space between pods, and fire separation; water collection, storage and dissemination; integration of solar hot water and electricity generation.



Localised energy systems that may be integrated are consistently being developed. In the Little Hero project a 3000 litre water tank was installed to the Level 6 floor plate, and the water collected used to service ground floor café toilets and landscaping.

The overall ESD benefits identified by GIW in an ESD report for the project were –

- Manufacturing efficiencies (materials and usage)
- Manufacturing waste minimisation,
- Increased material recyclability and access to streamlining waste processing,
- Reduced overall embodied energy in building construction,
- Reduced transport energy,
- Reduced carbon footprint,
- Greater accuracies/tolerances achieved by providing tighter thermal envelope,
- Reduced urban sprawl by opening access to brownfield sites,
- Sustainable urban lifestyle option.

Further advantages of steel pods include less embodied energy, in both construction and over the life of the project, than concrete; reduced weight and subsequent loading to on-site structures; reduced water consumption; reduced material transportation; natural cooling through steel walls and eventual reuse or complete recyclability of the building materials. Aluminium cladding used on the building has a recycled content, as most metal products currently do.

The pods may be quickly removed and replaced in the event of fire or terrorist attack, or relocated to an alternative site if the site requires a change of use. It may be that refurbishment is achieved by a future pod replacement program, eliminating on-site noise and inconvenience by achieving one or two day turnarounds in replacement.

3.9 Finance – initially a major difficulty for the UB joint venture, the Little Hero Apartments were financed by the Arab Bank rather than the major Australian banks, who were perhaps more familiar with traditional building practices, known as an obsession with ‘bricks and mortar’. A subsequent project for VicUrban at Coburg to produce low-cost public housing was successfully funded by an Australian major as a result of the Government Contract in place, and the established track record and publicity created by Little Hero.

UB were also able to access construction funding and receive project progress payments for completion of un-installed pods which were stored at the factory, a new paradigm in an industry where Contracts usually require materials to be delivered to the site, to be fixed and consequently transferred into the Principal's possession; on-site completion of a specified stage is normally required also.

3.10 Industry and market culture – a perception that OSM is restrictive and unable to deliver customer desires may have had some credence in terms of past projects. Early precast concrete OSM projects were not popular due to the heavy nature of the materials used, poor quality finishes exacerbated by poor maintenance and static, inflexible floor plans.

Alternatively OSM has been considered a 'transportable' solution to temporary accommodation for building sites, schools, mining camps and remote sites. One of the advantages of the UB design approach has been that the completed building has the appearance of a typical apartment block, not of a transportable building. The 'normalising' of the building facades and integration into the CBD building fabric of the Little Hero apartments has resulted in some quite favourable Media reports in local newspapers, and within the building community the perception is that the "future is here".

Association of high-profile architects and apartment builders with the project has benefited OSM and the industry considerably, which highlights the importance of perception in the market. Further support by the Victorian Building and Plumbing Commission adds weight to a previously little-considered building type.

However, the shift from private apartment developmental typology to low-cost housing developments may inadvertently encourage a return of sentiment to negativity, although the high design standards set may alleviate this somewhat given the appearance of the apartments is of a similar standard.

A further risk to the local OSM industry is the advent of Chinese manufacture. A proposed OSM apartment building designed for a Merri Creek location is awaiting approval by Darebin Council and has attracted 90 objections, according to the Melbourne Age. The developer has stated that he is expecting to manufacture off-shore and import the completed pods for local installation, raising the possibility of substantial union and political activity which may not assist in the development of positive perceptions of OSM as a quality building type, although flat-pack kitchens and other OSM products have been imported for some time, and are very popular.

4.0 CONCLUSIONS

It is evident that OSM has taken a major step forward in development through adoption by UB as an apartment construction methodology. The use of robotics, JIT and manufacturing techniques and technology has allowed for major advances in project delivery. The future of OSM appears to be sustainable and based on current levels of demand the substantial investment by UB appears well advised.

Further investigation by this author is due to commence with statistical analysis of building data to be provided by UB in terms of detailed costs, time and quality measurement, ROI and future directions of OSM.

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