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NRAS INVERESK – A CASE STUDY IN TRANSITIONING TO ADVANCED OFF-SITE CONSTRUCTION WITH WOOD

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ABSTRACT: An increasing number of off-site construction projects utilising prefabricated timber solutions are now being attempted in regions outside of central and northern Europe. As these new developments appear, a variety of potential building case study projects present themselves, highlighting a range of regional issues that are unique to their situation such as the established prevalent building culture and knowledge base and the timber type and availability. One such example is the National Rental Affordability Scheme (NRAS) four-storey student housing project, situated on the University of Tasmania's Inveresk campus in Australia's most southern state. This paper will explore the Australian context that new building methods will encounter when entering an established building culture as well as a range of specific issues that have arisen from the NRAS Inveresk project as Tasmania's first building procured through the use of advanced off-site construction methods combining volume modules and Cross Laminated Timber (CLT).

KEYWORDS: Multi-residential, modern methods of construction, off-site construction uptake, Australia, prefabrication, Volume Module Construction, Cross Laminated Timber, CLT, Massive Timber, NRAS Invermay

1 INTRODUCTION

In keeping with trends across the developed world, Australia is experiencing an increased level of interest in modern methods of timber construction that have been inspired by practises in some parts of German-speaking Europe and Scandinavia and their surrounding areas over the past decade.

Due to its geographic isolation, Australia must observe these developments from afar. In conjunction with other factors, the impetus resulting from Europe's progress is beginning to influence in new developments in the Antipodes. These developments, while not unexpected, have been expressed with a degree of disjointed acceptance and a limited understanding of new technologies and their potential application/benefits to Australia's built environment.

Key projects, such as Lend Lease's Forté and Docklands Library in Melbourne, received extensive attention from the media and professionals alike, but limited cross project/industry knowledge transfer has occurred and as such, new projects must often overcome similar technical, cultural and material hurdles anew.

What implications does this have on the acceptance of new building techniques and how might these influence their uptake on a more regular basis?

2 BUILDING IN AUSTRALIA

Australia is an advanced economy operating with a well established design-focused construction industry. As with most developed countries, its construction market can be broadly separated into residential and commercial sectors. The majority of Australians live in free-standing single and double storey bungalows in expansive low density suburbs [refer Table 1] that regularly rate highly in world standard of living measures such as The Economist's *Global Liveability Ranking 2015* [1] and Mercer's *Quality of Living Rankings* in 2015 [2].

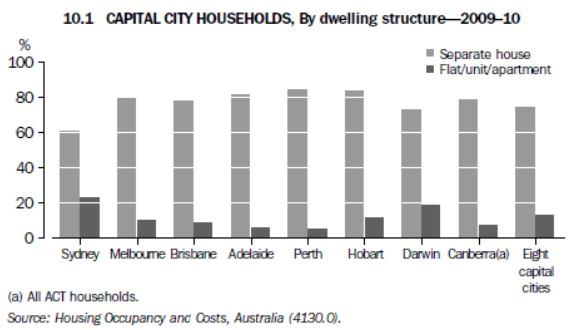

Table 1 : *Australian Dwelling Structure – Free Standing Houses & Multi-residential* [4]

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Both the residential and commercial construction sectors rely on sub-contractors for labour. Buildings are constructed on site in the traditional sequential manner using brick, or timber, (either prefabricated wall frames and roof trusses or with the 'stick' method), steel and concrete.

2.1 EMERGENCE OF PREFABRICATION OPPORTUNTIES IN AUSTRALIA

Factors, such as increasing urbanisation within capital cities, rising steel prices and the higher cost of available land, have combined in Australia to cause architects, builders and developers to consider international developments in advanced prefabrication construction. Other trending influences are increasing occupational health and safety requirements, constraints of on-site access, site noise restrictions and water shortages and escalating skill limitations. All of which are predicted to favour increases in off-site construction [5].

The increasing internationalisation of top tier Australian building companies, such as Lend Lease, who are experiencing a greater degree of prefabrication in their non-Australian building contracts, is also having a flow on effect in their Australian operations as exampled by their recent completion of the Forté building and Docklands Library.

The recent adoption of deemed-to-satisfy Fire Protected Timber solutions by the Australian *National Construction Code* (NCC) allowing timber construction in multi residential and commercial buildings (classes 2, 3 and 5 buildings) up to an effective height of 25 metres is also a key development [3].

The above factors, and others, have the potential to create opportunities for prefabrication which, in turn, can create opportunities for an increase in the use of timber in construction.

Currently, the use of massive timber systems such as CLT and largely complete, timber-rich prefabricated modules is novel in Australia. There is no indigenous CLT production and CLT construction has been limited to three Massive Timber buildings in four years. Apart from the Author's Wespine Kiln Control Facility project, completed in 2013 that utilised nail laminated CLT wall panels [9], the first predominantly CLT structures completed in Australia are the previously mentioned Forté apartments and Docklands Library building, designed and built by Lend Lease.

The location of the Lend Lease projects features very poor soil conditions location but considerable market potential. The poor foundation conditions suited an alternative 'light weight' building solution and the location suited large scale projects. The use of a novel, imported construction system, CLT panels from Austria, in a 10-storey inner-city apartment building in Australia generated significant project-based risk. However, the strategic risks potentially avoided were the exposure to additional costs and on-going building stability issues due to the poor foundations.

3 NRAS INVERESK – A CASE STUDY

3.1 PROJECT BACKGROUND AND OVERVIEW

In 2015, the University of Tasmania commissioned a four storey, 120 unit student accommodation building, funded by the Australian Federal Government's NRAS, on its Inveresk campus. The choice of material and off-site construction methodology represent the first of its kind in Tasmania and is now the subject of a national study by the authors, researching the opportunities and constraints facing Australian prefabrication and timber construction for commercial and multi-residential buildings.

In November 2013, a consortium of Tasmanian architects invited the authors to join a tender to the University of Tasmania for the role of principal design consultants in a National Rental Affordability Scheme (NRAS) project at the University's Inveresk campus in northern Tasmania. The project brief called for proposals for a student accommodation building of 120 discrete apartments and associated common and services spaces on a flood plane adjacent to the North Esk River. While strict cost and time constraints applied, the call for proposals specifically encouraged innovation. The successful tenderers were to be appointed in early 2014, construction started in early 2015, and building hand-over occur occurred in February 2016.

The NRAS Inveresk project was the last of the University of Tasmania's four NRAS-funded projects to be tendered. The first project set the basis as the acceptable 'default' solution for this type of project for the university. It used a basic pre-cast and tilt concrete slab structure with internal joinery, fit-out and services installed on site. The Inveresk site posed particular challenges to this 'default' solution's adoption. Located on a river flood plain, ground conditions were known to be very poor with a solid foundation about 18 metres below existing ground level. A workable solution had to either accept the cost of piling or be light and resilient enough to make a raft slab a viable option.

The authors had first hand experience in successful prefabricated module construction, advanced timber fabrication and engineering design with wood, exposure to European design and construction practice. They had also proposed that the preferred innovative approach for the project was a design based on the construction of complete, factory-built apartment modules, assembled from readily available timber systems by experienced local building contractor.

3.2 NRAS INVERESK DESIGN SCHEME AND INNOVATION

In shaping their proposal, the project team embraced the client's call for innovation and the need to avoid costly foundation works if possible. They developed a three storey solution on top of a concrete podium based on prefabricated, load-bearing timber apartment modules. The proposed modules would be finished in a factory, complete with internal finishes and joinery and external façade elements, arrive at site in protective wrapping and be lifted into their final position by crane.

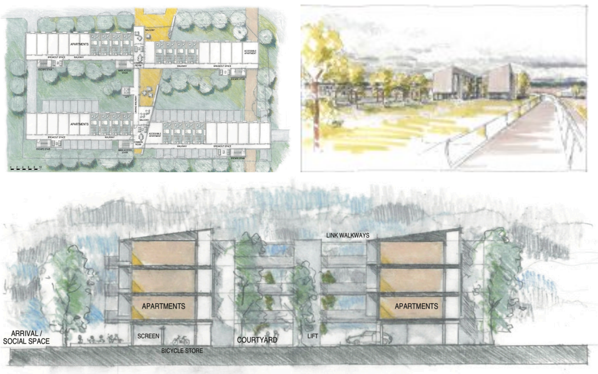

Figure 1. *NRAS Inveresk preliminary proposal: Top – Site Plan and perspective view. Bottom – Section. Image credits. Morrison & Breytenbach Architects*

The use of largely complete, prefabricated timber modules is novel in Australia. Multi-level timber framed residential buildings are built, but these are invariably site assembled solutions, usually combining prefabricated timber frames for the walls and commodity joist products or floor trusses for the intermediate floor plates. Plasterboard systems provide fire resistance between floors and apartments. Advanced timber prefabrication for multi-residential building is rare. Wall frame and truss (F&T) manufacturers provide the principal timber prefabrication capacity in Australia but their production is usually optimised to produce small to medium house and project lots efficiently [4]. Given this, they are wary of involvement in large projects or more complex prefabrication techniques.

Even though prefabricated modules are increasingly commonplace in Europe and they suited the client's call for innovation, it was novel solution in Australia; novelty generates risk, and risk makes all participants in the process nervous.

3.2.1 Managing the risk from innovation

Risk management influences the effective adoption of innovation. Design practitioners can be innovative but only inside the bounds of acceptable risk and within the reasonable constraints of experience across the whole design and construction team.

The likelihood of adverse events in building procurement such as unanticipated costs, unexpected construction delays, functional unsuitability and systems breakdowns is high and can occur regularly. The consequence of failure can also be high. In the worst cases, they can lead to death and significant injury. Invariably, building remediation is expensive and time-consuming.

Given the likelihood and consequence of adverse events, architectural practice generally involves deliberate and structured risk management processes. These inevitably encourage the practitioner not to change approaches or methods whose performance can be reliably predicted, even if they may be viewed as providing less than optimal performance.

New methods inevitably face resistance to adoption as the potential impact of adverse events that they may cause is often given more weight than the potential benefit of favourable events. This is based on an explicit sensitivity to risk by clients, architectural practitioners and partner professionals and an implicit lack of understanding and confidence in the delivery of innovation. This resistance is the norm and results from the real and imagined risks perceived at each stage of the procurement process. The level of this resistance at the key decision points in the procurement process is critical. If the perceived risk of innovation is felt to be higher than its identifiable benefit at any point in the process, innovation will generally be abandoned. As novelty undermines confidence in the delivery of innovation, participant caution is generated. The standard consultant response to caution is over-specification while the standard builder response is to load the tender price.

The preferred means of introducing substantially new approaches to building is by collaborative engagement between the researcher/innovation proponent and the design and construction team. This is an educative phase where the researcher introduces, trains and builds confidence in the design team, cost consultants and the risk managers in the delivery of innovation and its benefits. This allows them to adjust their perceived risk / reward ratio, or identify means of risks mitigation. In this role, the researcher can become an intelligent broker of innovation between the parties.

Disentangling this educative phase from the rest of the procurement process can also reduce perceived risks. With better knowledge gained during this separate stage, practitioners can make informed decisions and confidence increases [6]. Prototyping the solution enhances this educative phase.

Acceptance of innovation and confidence in its use is often incremental. The first application of innovation regularly involves excess discretionary tolerances until experience with the system generates confidence and increases efficiency [7]. As most architect-designed buildings are unique, each presents additional challenges or the opportunity to refine innovative approaches.

Open, competitive tendering processes can also limit the benefits of this educative phase as it can preclude collaborative approaches. Open tendering requires all enforceable requirements to be fixed, documented and available to all tenderers equally. While early integration with building contractors may be possible, a preferred contractor's eventual appointment cannot be guaranteed.

The alternative to this is for a nominated subcontractor to supply the innovative component. This may reduce the innovation risk but increase the risk of excessive costs. This is another constraint on innovative potential: to be most widely accepted, a range of potential contractors has to be able to use or supply the solution.

Securing the project with an innovative and locally untried solution and satisfactorily delivering that solution required separate risk-reduction strategies. These in turn elicited particular responses from the participants.

To secure the project, the project team had to convince the client that the Tasmanian building supply chain could successfully deliver a timely and cost-effective timber solution to the project based on prefabricated modules. To simplify this task, they sought to reduce in the client's mind the perceived risk of the innovative leap by:

- Proposing the modules be constructed from readily available timber sections and engineered wood products. This was to remove any perceived material performance or availability risk.
- Ensuring that several F&T fabricators would assemble the modules' floor, wall and ceiling panels. Three fabricators were consulted to confirm supply chain capacity.
- Inviting a major builder (and likely project tenderer) to view, cost and provide an opinion on the viability of the sketch design.
- Recommending that a prototype module be built during design development to resolve construction and façade details.

Each of these approaches reinforced the argument put to the client that the proposed innovation presented a manageable risk in a project of this size, and represented a manageable refinement of accepted local building solutions.

The builders and F&T fabricators consulted welcomed the project and the process of engagement. Having read about these practices internationally, they were glad that these techniques may finally be introduced to local construction practice. They confirmed capacity and provided the independent opinions requested.

The University of Tasmania's selection committee listed the team's proposal as the preferred option citing its evident innovation, but retained the 'default' concrete solution as a fall-back option. To confirm their risk exposure, they conducted a review of the preferred option: requesting supplementary tender information, and commissioning independent cost and engineering analyses. This was a time-consuming process but when positive assessments were returned, the client finally accepted the design team's proposal in mid-June 2014, and appointed them as principal consultants.

With the project secured, the design team had to ensure that the solution could be delivered through the supply chain in a timely and cost-effective manner. To minimise the chances of adverse risk, the design team proposed and the client accepted the construction of effectively a 1:1 model (prototype) of a standard accommodation module. The strategic aim of commissioning the prototype was to generate designer and builder knowledge and confidence in the module components. The more practical aims were to:

- Test the module's performance and resilience.
- Clarify fabric and services detailing and construction tolerances.
- Allow the module fabricator to confirm supply chain capacity.
- Provide tenderers with sufficient three-dimensional information to allow them to price the project competitively.
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In effect, the design team split the project development into three distinct phases. The first two, schematic design, and detailed design development of the modules through prototyping ran in parallel. The last phase, design documentation, is where the outcomes of the first two phases were integrated into an information set for tendering. In doing this, the module development phase, where innovation is translated into usable building solutions, was effectively separated from the more low-risk design development activities.

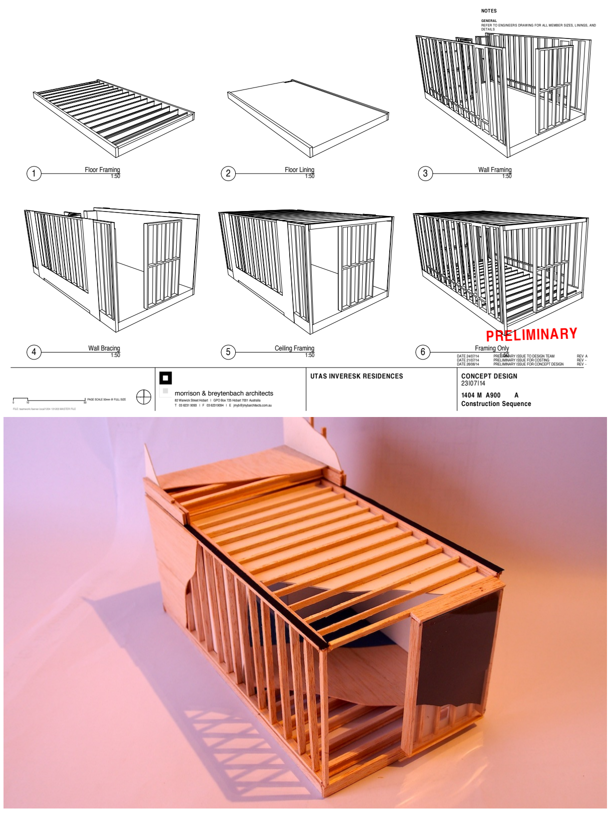

***Figure 2. Top -** Computer model of the prototype structure. Middle - cut-away scale model of a module. Bottom – The full scale prototype. Image credits. Module and scale model and 3D images: Morrison & Breytenbach Architects*

Module prototype development was also scheduled in stages to:

1. Develop and design the module through a series of pre-construction workshop sessions.
2. Construct the prototype structure with subcontractor-provided components, partially line it with fire resistant plasterboard, partially finish it internally and complete services rough-in.
3. Demonstrate the module's robustness in transport through a trial lifting, transport and return journey of more than 20km.
4. Use of the module to develop a wall cladding system including glazing details, fixing systems, and flashings.
5. Construct additional floor and wall panels to refine details of inter-module connections of adjacent wall and floor junctions. Test acoustic separation, junction details and tolerance.
6. External storage of the completed module to demonstrate water-tightness and facilitate tenderer inspection.

The prototype was documented and computer modelled three dimensionally (see Figure 2), and was under construction in August 2014. The completed prototype module was made available to the various builders throughout the tendering process to asses and confirm their price and construction methodology.

3.2.2 Tendering and Consequences

The building is comprised of prefabricated volume modules for the apartments and CLT for all connecting walkways and common areas. These two elements, in combination, were deemed to be the most suitable for the prevailing 18m deep silt river bank site conditions and, in conjunction with the expected speed of prefabricated construction, were instrumental in making the project feasible over traditional solutions. They were also considered a manageable balance between the builder's existing knowledge and experience in prefabrication with timber and the introduction of a 'new' material to Tasmania in the form of CLT.

Figure 3: *Modules under construction in the factory.*

Figure 4: *CLT being installed on site.*

Following the announcement of the successful building contractor, the architects and client were approached by the builder to remove the CLT from the project on the grounds of their preference for a traditional solution. The prevailing site conditions precluded the use of precast concrete due to weight and the cost of fire protection precluded the use of traditional timber or steel framing. These arguments resulted in CLT being retained.

Figure 5: *CLT expressed in the stairwells.*

The authors believe this to be the first building in Australia procured through a conventional tendering processes to use CLT as an integral part of the project.

3.2.3 Built with Locally Available Materials

A key intent of the project was to use locally available products and materials, with the exception of the CLT components, and as such, a local chain hardware store and a local frame and truss manufacturer was contracted to supply the majority of the materials.

3.2.4 Off-Site Construction Facility

An empty warehouse close to the building site was used to establish a temporary production facility for the construction of the modules. The building contractor had previous experience with prefabricated modular construction and in Australian terms, would be considered innovative because of their established use of rolling assembly lines. This method, which is fairly commonplace in parts of central and northern Europe, allows for each module to be built at 'stations' having been adapted from the automobile industry etc. Two rolling assembly lines were established to produce the modules, with the net result being one full module produced per day (refer Figure 3). Each module was finished with all services, insulation, cabinetry, internal and external linings and floor coverings. Labour was sub-contracted from local trades and inducted into the off-site construction philosophy specifically for this project. The work force's transitioning from traditional on-site sequential construction was initially slow, but improved as workflow management techniques developed and the workers' familiarity with the project and tasks increased. This resulted in a marked increase in productivity over the term of the build.

3.2.5 Site Construction processes

Site construction processes differed significantly from traditional building sites. Completed modules arrived by truck and were craned into position and fixed into place. This process allowed for a very quiet, clean build with one floor per wing taking only one day. The project featured four 'wings'. Once all three levels of modules were installed, prefabricated roof truss assemblies were craned and fixed into place. The roof assemblies utilised roof trusses manufactured off site. The roof was assembled as a modular unit at ground level with the sisalation, roof cover and safety anchors fitted prior to being craned into place. The four wings of the project were installed in modules in reverse order to their assembly on the ground.

The central tower that connected the four wings was framed with prefabricated steel and the CLT fitted into the steel on a floor by floor basis (refer Figure 4).

Once all four wings were completed, the process of installing the external timber frame, fire and weather proofing began using traditional processes.

3.2.6 Outcomes and observations

Site issues encountered during the preparation installation of the modules resulted in some delays to the projected project completion. The manufacture of the modules themselves proceeded relatively smoothly but were delayed or slowed down on several occasions due to issues encountered on site.

Providing adequate temporary waterproofing for the volume modules during installation sufficient for the Tasmanian winter proved problematic. Several top floor apartments suffered from extensive water ingress resulting in significant post-installation rectification.

Connection detailing between the CLT panels also resulted in on-site installation difficulties. Tradesman unfamiliar with large-scale heavy-weight timber panels struggled to install the interlocking detail as designed by the engineer. This was compounded by inaccuracies encountered with the prefabricated steel work. The high degree of dimensional accuracy achieved by the CLT was not matched by the steel work. In discussion with the authors, the contractor suggested that the use of both a steel frame and the CLT (refer Figure 4), might not be required in future projects in preference for CLT only. This would potentially simplify the supply chain, avoid dimensional inaccuracies and increase the speed of the build process.

The prevalence of sub-contractor labour impacted the knowledge flow resulting from the building experience. When introducing a new construction method or material, benefit can be gained via bottom-up feedback from trades' experiences throughout the build.

3.2.7 Construction Cost

At the time of writing, the project was being compared to a similar scale and type of project that had been built with precast concrete a year earlier. Preliminary indications are that as a site specific solution, the combination of modular timber and CLT was the most economical and time efficient method of construction.

Figure 6: *NRAS Inveresk complete: Top – View of Eastern wings. Bottom – High standard of finish.*

Figure 7: *NRAS Inveresk complete: Top - The main entry. Bottom – View at ground level and of projecting balconies.*

4 CONCLUSION

Projects such as the NRAS Inveresk student accommodation building provide a valuable insight into issues pertaining to adopting previously unfamiliar building materials and techniques. Despite the technology becoming commonplace in parts of Europe, this project required significant systems development to ensure its success and will inform projects of a similar nature in the future.

Risk and approaches to its management influence the effective adoption of research outcomes in architectural practice. Worthwhile architectural research invariably involves risk through uncertainty in its outcomes. If investigations are successful, the researcher's conclusions usually require a change in practitioner behaviour. In contrast, architectural practice generally involves managing the risk in the building procurement process. This often encourages the practitioner not to change approaches and methods so that the results can be reliably predicted.

For the NRAS Inveresk project, the authors and other members of the design team sought to introduce and apply technical innovation to the local industry by transferring solutions successfully developed elsewhere to the construction of a 120-unit development in northern Tasmania. Enabling the project and satisfactorily delivering the solution required separate risk-reduction strategies. These in turned elicited particular responses from the project's participants. The project team was tasked with convincing the client that the Tasmanian building supply chain could successfully deliver an innovative but timely and cost-effective solution. The project was completed in January 2016 on budget, on time and has met or exceeded the client's expectations [8].

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