J. Zuo, L. Daniel, V. Soebarto (eds.), *Fifty years later: Revisiting the role of architectural science in design and practice: 50th International Conference of the Architectural Science Association 2016,* pp. 1–11.

Translating architectural research into construction practice: A case study of introducing new construction techniques into building practice.

Gregory Nolan[1], David Bylund[2] and Matthew Gee[3]

[1,2] *The School of Architecture and Design, University of Tasmania, Launceston, Australia*

Gregory.Nolan@utas.edu.au, David.Bylund@utas.edu.au

[3] *Prefab Lab Pty Ltd., Electrona, Tasmania, Australia*

matthew@prefablab.com.au

Abstract: Significant tension can exist between the goals of architectural research and those of architectural and building practice. Worthwhile research involves generating risks as the benefits from its outcomes are uncertain and they require interpretation in practice as new design approaches or construction methods. In contrast, architectural and construction practice generally involve managing building procurement risk. This can encourage the practitioner and construction team to resist changes to their methods to enhance solution reliability, even if the method delivers less than optimal performance. Practitioners can be innovative but often only by incremental development: each step within the bounds of risk acceptable to others in the design and construction team. This paper continues discussion of the complexities of translating architecture research into innovative construction practice as observed in a case study first reported in 2014. The focus project applied research results into local practice through the design, prototyping, and construction during 2015-16 of a 120-unit development in northern Tasmania. The solution was based on prefabricated timber-framed apartment modules and other innovative timber construction techniques. This paper explores the themes of innovation and risk as the case study building moved from the design phase through prototype development and into tendering, construction and completion.

Keywords: Prefabrication, innovation, project risk management, timber construction.

1. Introduction

This paper continues discussion of the complexities of translating architecture research into innovative design practice as observed in a building case study first reported in Nolan, Shanks and Clark (2014). Significant tension can exist between the goals of architectural research and those seeking to deliver innovation in architectural and building practice due to differing perceptions of risk in solution development and delivery. Worthwhile research involves risk through uncertainty in the outcomes of systematic investigation. Successful outcomes then require realization in practice as innovative design approaches or construction methods. In contrast, architectural and construction practice generally involves managing building procurement risk. This often encourages the practitioner and construction team to resist changing successful methods, even if the result delivers less than optimal performance. Unlike the researcher, the professional pursuing innovation needs to balance potential benefit against the realities of the project budget, supply chain capability, and partner professional preference, and client comfort. Practitioners can be innovative but often only by incremental development. To see benefits from their work, the researcher can be an adoption catalyst. Innovation in the built environment through the effective adoption of research outcomes often needs to be a collaborative and educative process between researchers and practitioners where risk is to be expected and managed to realise potential benefits.

2. Risk, research, innovation and the building procurement process

Risk is an uncertain event or condition, that if it occurs, has positive or negative effects on a project's objective (Weaver 2008). The potential level of risk is assessed by comparing the likelihood of an event occurring against the consequences of its occurrence. Risks can occur at several scales. In architectural practice, project scale risks include events such as failure in material delivery or weather damage during construction. Strategic scale risks are more varied and can apply to a building sector or all buildings of a type. These include reliance on a single construction system to poor licensing procedures for builders or tradespeople. The building procurement process can generate significant risk through: the need for the completed building to satisfy its performance requirements; the quality of action of those involved in the delivery process; and the performance of building materials, equipment and system supply chains. As the likelihood of adverse events in the building procurement chain is high and events occur regularly, supply chain participants: clients; design professionals; and builders, are sensitive to risks and act to mitigate them through deliberate and structured risk management processes in their practice. These inevitably encourage a preference for proven solutions over potentially innovative but unproven ones.

2.1 Innovation in the built environment

Research is the creation of new knowledge or the use of existing knowledge in a new and creative way to generate new concepts, methodologies and understandings (Australian Department of Education 2014). Innovation is different. It is the process by which organizations successfully transform the products of research, new concepts and ideas, into improved products, services or processes, in order to advance, compete and differentiate themselves (Baregheh et al. 2009). Research, particularly scientific research, often limits the number of variables addressed to reinforce the validity and reproducibility of results. However, due to the number of unique project variables, building design innovation - the translation of research results into improved built solutions - is far from predictable but is messy, uncontrollable, unpredictable and difficult to define (Loosemore 2014).

Creative research and innovation processes invariably involve and generate risk. Technically-focused architectural research necessarily involves outcome uncertainty as the researcher seeks to enhance building or material performance through focused and systematic investigation. If successful, the researcher's conclusions require interpretation through innovation in the design and construction process: change in practitioner behaviour, or adoption of new design approaches or construction methods. However, innovation through the adoption of new methods generates risk in its application. Something can go wrong and adverse events occur. As a result, innovative methods inevitably face resistance to adoption. This is a normal reaction and results from the real and imagined risks perceived in procurement process change. The level of resistance at key decision points in the procurement process is critical to adoption. If the perceived risk of innovation is felt to be higher than identifiable benefit at any given decision point, it will generally be abandoned. The novelty of innovation can also undermine confidence in its delivery and generate caution. The standard response to caution in building is consultants over-specification or builders over-pricing. Both can kill off effective innovation.

The researcher seeking to realise the finding of their work should expect and, if possible, help manage these reactions. Collaboration with the design team can not only create the broad knowledge and skills-base needed to convert new ideas into reality but also spreads the significant risk associated with innovation (Loosemore 2014). Collaborative engagement between the researcher and the design and construction team can assist participants adjust their perceived risk/reward ratio, develop innovation adoption approaches, or identify means of risks mitigation. This is an educative phase where the researcher can become an intelligent innovation broker between the parties, training and building confidence in the design team, cost consultants and the risk managers in innovation's delivery and benefits. Separating this phase from the standard procurement process and prototyping the solution can significantly reduce perceived risks. With better knowledge gained during this separate, prototyping stage, practitioners can take informed decisions and confidence in solutions increases (European Commission 2010 p.97). 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 (Edgerton 2006).

Open, competitive tendering processes can preclude collaborative approaches and limit the benefits of innovation brokerage. Open tendering requires contract requirements to be fixed, documented and available equally to all tenderers. While early integration with building contractors may be possible, a preferred contractor's eventual appointment is not guaranteed. The alternative is for a nominated subcontract to supply the innovative components. This reduces innovation risk but increases the risk of excessive costs. This is another constraint on innovative: to be accepted, a range of potential contractors has to be able to supply the solution.

3. NRAS Inveresk – A case study

In November 2013, a consortium of Tasmanian architects invited academic researchers 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 tender called for proposals for a student accommodation building of 120 discrete apartments and associated common and services spaces to be built 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 start in early 2015, and building hand-over to occur 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 in the series set the acceptable default solution for this project type. It used tilt slab concrete panels as the base structure with internal joinery, fit-out and services installed on site. The Inveresk site challenged this default solution's adoption. Located on a flood plain, ground conditions were known to be very poor with a thick layer of sludge occurring between the effective ground level and a solid foundation. A workable solution had to either accept the cost of piling through this sludge or be light and resilient enough to make a raft slab a viable option. The invited researchers had research and practice experience in prefabricated module construction and advanced timber engineering with wood, and exposure to European design and construction practice. As part of the design team, they proposed that the preferred innovative approach for the project be based on the construction of factory-built apartment modules, assembled from readily available timber systems by local building contractors offsite. Complete with lining, joinery and services, these modules could then be transported to site, stacked and connected in position. Other innovative approaches were proposed, such as the inclusion of cross laminated timber (CLT) panel as floor plates and stairs.

3.1 NRAS Inveresk Design Scheme and Technical 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. In addition, CLT panels were to be used as floor plates in the central common spaces, external walkways, and as prefabricated stair units.

Figure 1: NRAS Inveresk preliminary proposal:
From the left clockwise: Site plan, Perspective view, and Section.
Image credits. Morrison & Breytenbach Architects

The use of largely complete, prefabricated timber modules was novel in Australia. Multi-level timber framed residential buildings are built, but are invariably site assembled solutions, usually combining prefabricated timber wall and roof frames with commodity joist or trusses products for the intermediate floor plates. 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 house lots (Nolan 2011). They are wary of involvement in larger projects.

The CLT use was also novel. There is no indigenous CLT production and in 2014, Australian CLT use was limited to two major buildings and series of display structures constructed by major developer Lend Lease. The major buildings were on sites with poor soil conditions but considerable market potential. While these examples supported CLT's use at Inveresk, the delivery conditions for these buildings were considerably different. Lend Lease was the client, developer and builder in these projects, and having had experience with CLT in Europe, could make a strategic decision to innovate and introduce the technology. In contrast, the NRAS project had multiple decision makers, none with CLT experience: an institutional client, an innovative but conventionally structured consultant team, and a builder selected through public tender.

3.3 Managing the risk of innovation

Though prefabricated modules and CLT construction are increasingly commonplace in Europe and the solution suited the client's call for innovation, securing the project with an innovative but locally untried solution and satisfactorily delivering that solution required the core design team to develop explicit risk-reduction strategies, using tacit *research-in-action* approaches *(Schon 1983).* The team sought to systematically identify and provide solutions to the potential technical and non-technical risks to the project's successful completion (Manley, K. 2006). Identified risks included client acceptance, consultant skill, builder confidence and with the structure of relationships along the procurement chain.

Risks to client acceptance were generated by understandable doubts about the structural capacity and rigidity of the modules, and the capacity of the Tasmanian building supply chain to successfully deliver a timely and cost-effective timber solution. For its part, the consultant team had to recognize and address the additional technical challenges presented by novel construction approaches, such as identifying reasonable element to element tolerances and delivering the required fire separation. Builder confidence largely influences competitiveness of pricing before contracting and acceptance of the documented solution once the contract has been awarded. The proposed systems' novelty and the tenderers' limited involvement to the design process, a feature of competitive tendering, complicated this confidence.

Specific actions were proposed to address these risk and reinforce the proposition that the proposed innovation was simply a manageable refinement of accepted local building solutions for a project of this size. To remove any perceived material performance or availability risk, the consultants proposing the modules be constructed from readily available timber sections and engineered wood products. These were products the client, consultant team and local builder's understood. Further, a major builder and three F&T fabricators were consulted to confirm the supply chain's capacity to provide the necessary module components. Lastly, they recommended that a prototype module be built during design development to resolve module construction, prefabrication logistics, detailing and tolerances.

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 framed solution as a fall-back option. To confirm their risk exposure, they requested 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, and appointed them as principal consultants in mid-June 2014. 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 achieve this, project development was split into three distinct architectural design phases. The first two, schematic design, and detailed design development of the modules through prototyping ran in parallel. The last phase, design documentation, integrated the outcomes of the first two phases into an information set for tendering. In doing this, the higher-risk module development phase was effectively separated from the more low-risk design development activities.

To minimise the chances of adverse events, the client accepted the team's recommendation to prototype a standard accommodation module. This aimed to generate designer and builder knowledge, information and confidence in each module's components; test the module's performance and resilience; clarify fabric and services detailing; allow the module fabricator to confirm supply chain capacity; provide tenderers with sufficient three-dimensional information to allow them to price the project competitively and significantly address the logistical tolerances associated with timber modular construction. To achieve these aims, the prototype's construction was planned to include the structural frame insulated, wrapped, plasterboard lined and stopped, with full services rough-in, and doors and windows and portions of the external cladding fitted. To test acoustic separation between floors, an additional floor frame was also constructed and installed on the prototype. The prototype and its components were documented for manufacture and construction began in August 2014. See Figure 2 and Figure 3. Prefab Lab was the prototype's builder and responsible for testing material detailing and supply during the construction process and documenting assembly and coordination issues for tenders.

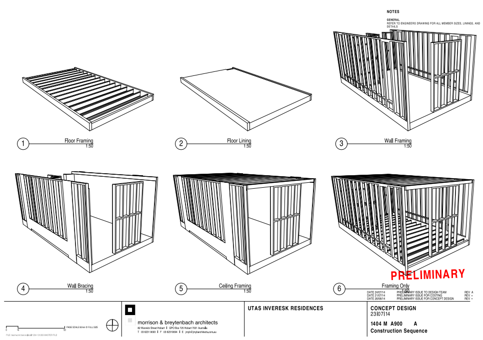

Figure 2: Computer model of the prototype structure.

Figure 3: Cut-away scale model of a module. Images credit: Morrison & Breytenbach Architects

Figure 4: Prototype frame under construction.

Figure 5: Clarifying assembly detailing.

The design team interacted face-to-face with the prototype construction at the Prefab Lab to address key structural details, refining servicing, and clarify assembly issues. See Figure 4 and Figure 5. To demonstrate the module's robustness in transport, the lined and wrapped unit was lifted from the workshop, loaded on a truck, driven about 20km and unloaded in the workshop's yard. See Figure 6 and Figure 7. This external storage was to demonstrate water-tightness and facilitate tenderer inspection. The returned module was accessed for transport movement and the client's risk managers inspected the plasterwork and fixings to identify damage. As the module proved robust and no damage was found, the client formally approved construction of the prefabricated timber option for the project.

As submitted for tender, the solution comprised 114 prefabricated timber-framed apartment modules, 6 conventionally-framed high-accessibility units, and CLT floor plates in the connecting walkways and common areas. These elements, in combination, were considered a manageable balance between existing builder knowledge and experience in prefabrication with timber and innovation in material and construction approaches for Tasmania. 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. The prototype remained available throughout the tendering process for builders to assess the construction methodology and understand the scope of the project.

At the end of the tender period, submitted prices were within the client's expectations and the project was awarded. At this point, the risk management processes adopted to support innovation appeared justified. Innovation had been adopted and adverse events has been avoided.

Figure 6: Wrapped and lined prototype with test floor over.

Figure 7: Wrapped and clad prototype lifted off after road testing.

3.2 Realising innovation through construction

While the design team's innovation adoption approaches could directly influence behaviour and decision-making prior to tender, they could only influence action during construction indirectly. Construction is the builder's domain. In pre-contract negotiations, the preferred tenderer approached the architects and client asking to remove the CLT from the project and its replacement with a traditional solution. The builder had experience with module construction for the mining sector and was confident that they could deliver these satisfactorily. However, they doubted the reliability of imported CLT supply and wanted to avoid the risk of delivery failure. 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. As a result, CLT was retained in the design. As a key intent of the project was to enable the use of locally available products and materials, with the exception of the CLT components, a local hardware store and frame and truss manufacturer were contracted to supply the majority of the project materials.

As work commenced, the builder engaged the prototype maker to inform the manufacturing and logistical aspects of the project and configured a warehouse close to the building site as a temporary module production facility. Using their previous experience, the builder established two rolling assembly lines in the shed, each with five work stations. See Figure 8. One line accommodated two modules at each work station while the other held one. Standing time at each station was three days, and subcontractors were required to complete work to a tight schedule. See Figure 9. With 15 modules under construction at any one time, one full module was produced on average per day. 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.

Figure 8: Modules under construction in the prefabrication factory.

Figure 9: Trade prefabrication schedule.

Site construction processes

Site construction processes differed significantly from traditional building sites. A group of 10 completed modules arrived by truck over a day and were craned into position and fixed into place. See Figure 10. This process allowed for a quiet, clean build with one floor per wing taking only one day. Once the three levels of modules were installed, prefabricated roof assemblies were craned and fixed into place. These were made of prefabricated timber trusses assembled into as a modular unit at ground level, with the sarking, roof cover and safety anchors fitted prior to being craned into place. See Figure 11. The central common space structure connected the four wings and featured CLT floor plates fitted between prefabricated steel columns and beam. Prefabricated CLT stairs were also assembled. Contrary to the builder's initial concerns, the CLT arrived on schedule and went together faster than expected. Once all four wings were completed, installation of fire and weather proofing began using traditional processes.

3.3 Outcomes and observations

While module manufacture proceeded relatively smoothly, site complications generated delays. The 'two sites' structure generated increased and unexpected management complexity in scheduling and resource allocation. Waterproofing prefabricated modules against the Tasmanian winter during storage and after installation proved problematic. While this issue had been discussed during the design phase, the design team could not instruct the builder on preventative practice. Several top floor apartments suffered water ingress resulting in significant post-installation rectification. Connection detailing between the CLT panels and the surrounding structure caused installation difficulties. Tradesman unfamiliar with large-scale timber panels struggled to install the interlocking detail designed by the engineer. This was compounded by inaccuracies in the prefabricated steel work. The CLT's precise sizing was not matched by the steel work's looser tolerances. In discussion, the contractor suggested that in future projects the use of CLT in a steel frame, shown in Figure 13, might be abandoned in preference for CLT only. This would potentially simplify the supply chain, limit dimensional conflicts and reduce scheduling risks. Unpublished cost comparisons between the as-built timber and the default tilt-slab solution, adjusted to provide a like-for-like comparison, indicated that only a minor premium was paid for the innovative wood solution, mostly in preliminaries. For their part, the client regarded the project and its innovation as a success.

Figure 10: Modules being lifted into place.

Figure 11: Line of modules with prefabricated roof units.

Figure 12: NRAS Inveresk complete

Figure 13: Prefabricated CLT stairs.

4. Conclusions

Risk and approaches to its management influence the effective adoption of research outcomes through innovation in architectural and building practice. Worthwhile research involves generating risks as the benefits from its outcomes are uncertain and require interpretation in practice as new design approaches or construction methods. However, the number of variables addressed can be limited. In contrast, architectural practice generally involves managing the risk of innovation in the building procurement process: a process far from predictable, messy, and unpredictable. While this uncertainty can encourage practitioner caution, collaborative engagement between the researcher and the professional can assist participants adjust their perceived risk/reward ratio, develop innovation adoption approaches, or identify means of risks mitigation. As each project is unique, the form of this collaboration will vary with the type of project, the level of innovation proposed, and the skill of the project participants.

For the NRAS Inveresk project, the researchers and design team sought to respond to the client's call for innovation by adapting and transferring solutions successfully developed elsewhere to the local building industry. In this, they sought to introduce novel building materials and construction techniques, CLT and factory-built modules respectively, to the construction of a 120-unit development in northern Tasmania. Securing the project and satisfactorily delivering the solution required explicit risk identification and reduction strategies. The project team sought to convince the client that the Tasmanian building supply chain could successfully deliver the solution and to reduce in the client's mind the perceived risk of the innovation being attempted. They proposed and the client accepted the construction of a full-scale prototype. This allowed the significant systems development required for effective technology transfer and was successful in building client and tenderer confidence in the solution. Notwithstanding these strategies, the successful tenderer still attempted to remove one innovative component of the project, CLT, due to supply concerns. Fortunately, these concerns proved unwarranted.

Overall, the innovation approaches and risk management procedures adopted appear to have been successful. Innovation was adopted, potential adverse events did not eventuate, and problems that did arise proved manageable. The project was completed in January 2016 on budget, on time and met or exceeded the client's expectations (Jordan T., pers. comm. April 2016). Initial occupant feedback is positive.

Acknowledgements

Thanks to Morrison & Breytenbach Architects, Circa Morris-Nunn Architects and Hutchinson Builders for their invaluable assistance.

References

Australian Department of Education *2014: Higher Education Research Data Collection: Specifications for the collection of 2013 data*. Available from: http://docs.education.gov.au/documents/2014-herdc-specifications> (accessed 24 July 2014).

Baregheh, A., Rowley, J & Sambrook, S. 2009, 'Towards a multidisciplinary definition of innovation', *Management Decision*, 47(8), 1323–39

Edgerton, D 2006 *The shock of the old: Technology and global history since 1900*, Profile Books, London

European Commission 2010, *Risk management in the procurement of innovation, Concepts and empirical evidence in the European Union EUR 24229 EN*, European Commission Available from: <http://ec.europa.eu/research/era/docs/en/investing-in-research-expert-group-risk-management--eur242209-2010-.pdf> (accessed 25 July 2014)

Jordan, T 2016. *Project Manager*, University of Tasmania, Commercial Services and Development Built Environment and Development.

Loosemore, M. 2014, 'Innovate or Perish? Exploring some of the Myths of Construction Innovation', *Australasian Journal of Construction Economics and Building Conference Series,* **2**(2), 44-55

Manley, K. 2006, *Identifying the determinants of construction innovation*, Joint International Conference on Construction Culture, Innovation and Management, Dubai, 26-29 November.

Nolan, G, Shanks, J, and Clark, G 2014 "Risk in translating research outcomes into practice", *Across: Architectural Research through to Practice - Proceedings of the 48th International Conference of the Architectural Science Association*, 10-13 December 2014, Genoa, Italy, pp. 279-290. ISBN 978-0-9923835-1-0

Nolan, GB 2011, *Timber in multi-residential, commercial and industrial building: Recognising opportunities and constraints, Project report PNA140-0809*, Forest Wood Products Australia, Available from: <http://www.fwpa.com.au/rd-and-e/market-access/226-timber-in-multi-residential-commercial-and-industrial-building-recognising-opportunities-and-constraints.html> (accessed 18 July 2014)

Schon, D. 1983, *The Reflective Practitioner*, Basic Books, New York, p. 138.

Weaver, P. 2008, *The meaning of risk in an uncertain world, PMI Global Congress 2008 - EMEA*. Available from: < http://www.mosaicprojects.com.au/Resources.html> (accessed 20 July 2014).

There is a section break below, please do not delete it.

There is a section break above, please do not delete it.