Learning through prefabrication

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Abstract

The use of prefabrication in design exemplar houses has escalated in Australia in the past decade. The same level of design quality has not been applied to the design of prefabricated school buildings. As CADCAM technology becomes more prevalent within the construction industry and greener, smarter materials are developed, new opportunities arise in the design of learning spaces. What can be learnt from bespoke prefabrication techniques being developed in other industries and overseas in order to advance the design and delivery of learning spaces within Australia?

This research investigates whether industrial design methodologies might be strategically adopted into architectural design in order to incorporate mass production techniques. Learning environments need to be designed to be environmentally efficient, place specific and better suited to user needs. By including both macro and micro oriented scenarios, the research aims to clarify the challenges for using prefabrication in the design of learning environments.

While this ambitious research is in its infancy, the complex framework and support from industry is relevant for other researchers who are seeking to have an impact on design practice using an action research methodology. The research is timely. Following in the footsteps of the United Kingdom, Australian state and federal governments have committed to reinvigorate our aging school stock. This research led by an interdisciplinary team is being developed in partnership with Departments of Education in three Australian states. The aim is to align designers with experts in prefabricated construction and delivery.

The research proposal is positioned within current knowledge as demonstrated through a literature review. Its focus is in response to needs expressed by providers of school buildings in three Australian states. The key innovation is to undertake research concurrently as micro and macro scale in order to capture the potential for industry wide change.

Keywords

Learning spaces, school design, bespoke prefabrication, prefabrication in architecture, design research, CADCAM.

Prefabricated relocatable classrooms have been used for decades within the Australian Government school system to respond rapidly and economically to changing school enrolment levels. Designs have been expedient rather than inspirational. Learning from experience overseas and in other industries, there

is untapped potential to develop the Australian prefabrication industry to transform the design of current relocatable classrooms but also for use more broadly within school facilities. Inherently, prefabrication brings with it waste saving and efficiency saving. It also has the potential to offer ongoing operational savings if designed using passive techniques, advanced materials with lower embodied impacts, embodied renewable energy production, water collection and consideration of context and use of smart systems.

The research context

The research issues are complex and draw together diverse communities of practice. Both the education and design professions are in flux. Digital technology, environmental imperatives and changing pedagogy are having an impact on the way school facilities are being designed and used. For educators, digital technology is impacting curriculum and pedagogy. For designers, digital technology has transformed the processes of design, representation and communication. Construction is also changing as the industry becomes more globalized and automated and responds to issues of sustainability with new processes and materials.

The education context

Schools are best understood as complex systems in which the physical environment interacts with pedagogical, socio-cultural, curricular, motivational and socio-economic factors as well as providing benefits or costs in environmental terms. Figure 1 below illustrates a system but misses the key complicating factor of change across time.

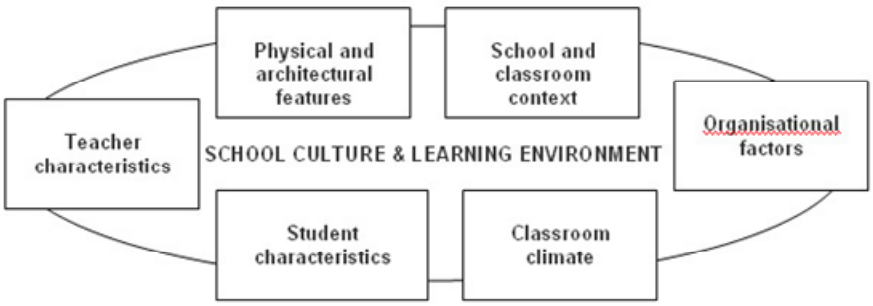


Fig 1. Adapted from Moos' (1979) model of the determinants of school culture

The `cell-and-bells' school model which has existed since the 19th century is disappearing in response to new knowledge about education arising from research into pedagogical, psychological and social variables (Clark, 2002). Students' learning environments are now linked into information rich resources via computer technology. In education, digital technology has democratized access to information.

Today's children are natives in a world of information technology. They are adept at learning using digital media. Schools are shifting from teaching institutions to learning organisations through increased connectivity between students and their local and global environments. In particular, knowledge is increasingly being constructed across disciplines rather than within the traditional subject 'silos', necessitating a rethinking of how space can support this interaction (Gibbons et al, 1994).

Research into pedagogy is impacting on curricula and delivery with new understanding of learning styles, multiple and emotional intelligences, and formative assessment. Teachers are no longer the gate keepers of knowledge providing children with a didactic education. Teachers are becoming facilitators and mentors supporting children's individualized learning plans. The trend for student directed learning has spatial implications. Spaces need to support a broader range of learning modes requiring new types of furniture and fittings.

Community use needs to be further considered as education becomes perceived as a lifelong endeavour. With community use, school utilization can increase from the typical rate of 18% (Harrison, 2006, p6) as long as complications arising from timetabling, access and security can be resolved. The social learning spaces such as libraries, cafeterias and sports facilities have community use potential which need to be considered in the design process and therefore as part of this research.

Does design impact on education?

Evidence correlates shabby environments with negative impacts on students and teachers (Schneider 2002; Young et al. 2003; Hallam 1995). This body of research has controlled variables to show that building condition alone impacts on student test scores (National Research Council 2005; 4-7). What is less clear is whether the physical school needs to be anything more than adequate. Some researchers argue that good learning outcomes can be achieved despite unpromising environments (Earthman 2004; Rutter 1979). Stricherz did not find that student performance rose when improved from the equivalent of ford to a ferrari although he did accept that achievement lagged in shabby buildings (2000). The issues are complex. Secondary school heads strongly correlated the physical environment with pupil motivation while primary heads perceived younger students to be more motivated by teachers (Clark 2002, p11).

Evaluation by Higgins et al (2005: 6) of recent research suggests that benefits from changes have less to do with the specific element chosen and more to do with how the process of change is managed. This indicates a strong link between effective engagement with all building users and the success of the environmental changes: "School designs cannot be imposed nor bought off-the-shelf. Success lies in users being able to articulate a distinctive vision for their school and then working with designers and architects to create integrated solutions" (Higgins et al 2005: 3).

The need for new spaces for education

As elsewhere in the world, Australian governments are facing educational imperatives to respond to changes in learning approaches, student retention

rates, learning modalities to suit multiple intelligences and to engage reluctant learners. Clark (2002, p1) quotes Berner as saying that "For a society searching for ways to address the educational needs of the future, the building itself is a good start"

A substantial part of the school building stock within Australia needs replacement or refurbishment. Embodied energy, environmental impacts, operating costs and life-cycle costs demand cost-effective decisions. Careful orientation, use of materials and design will enhance the intrinsically green nature of prefabricated designs which can be relocated according to changing schools needs. If environmental and educational imperatives are not brought together in innovative ways then embodied energy costs and government funds will be wasted on buildings that do not last.

The architecture and construction context

As in education, environmental imperatives and the impact of digital technology are transforming the architecture and construction professions.

Building information modeling was introduced less than a decade ago. Known as BIM, building information modeling is allowing a more integrated approach to design and construction using CAD as a vehicle to manage the building from conception and construction into occupation. By linking information to drawn objects within buildings, BIM is used for modeling, testing and coordination of buildings from environmental performance to construction and facility management. Because it relies on the accuracy of it content, BIM is influencing architects to think more about how buildings are composed and constructed. In this sense it is ideally suited to prefabrication.

Another influence on the design and construction professions is the outsourcing of labour or manufacture. Components of the design, drafting and construction are being outsourced by some firms to cheaper overseas locations. One of Australia's experts in BIM, Professor John Frazer, describes the example of a designer based in a farmhouse in Ireland using BIM as a device for electronic craftmanship to design and document boats to fine tolerances and in enough detail for them to be built in a German shipyard (Tombesi, Gardiner and Mussen, 2006, p104).

New lean and green materials along with rating tools for environmental sustainability are impacting design and construction. Building skins are being carefully designed to filter and moderate the external environment. Passive design systems for shading, heating, cross ventilation and cooling through night purging are common elements of design. New materials often utilize composite properties to ensure improved weight to strength ratios over more traditional monolithic constructions. Construction processes are being modified to reduce waste and increase the use of recycled materials. Mixed mode systems of air-conditioning increase fresh air intake and reduce power consumption. Photovoltaic cells, solar panels and grey water systems are becoming more efficient. Buildings using advanced environmental components are increasingly programmed using building automation systems to maximize user comfort while minimizing power consumption.

Why prefabricate?

Prefabrication is not mainstream within Australian architecture and construction although the technology is being adopted within parts of the domestic sector. This section lists both the factors which have inhibited prefabrication to date followed by an argument for reconsidering prefabrication now.

Factors inhibiting take-up within architecture are construction costs and the perception of prefabrication as suitable only for the mass market willing to accept standard designs. Unlike industrial designers, architects are relatively untrained to develop products for mass production and have little experience working with design engineers who can facilitate the manufacturing process. .

Housing precedents are showing that high quality design can be achieved using prefabrication techniques. Australian precedents have not followed any one prefabrication system. Some use quite conservative timber framing, other borrow insulated sandwich panels more commonly seen within the refrigeration industry. Some take a kit of parts approach and others market a suite of modules. One firm developed an innovative folding mechanism to avoid the extra costs of transporting wide loads. Prefabricated housing precedents in Australia do not always have design and construction occurring within the same location. Some Australian designs are fabricated overseas and shipped to site. The New York firm, SYSTEMarchitects won the prestigious RAIA Wilkinson Award for their prototype house composed of laser cut panels which they designed halfway around the world from its Australian location (PARISHhouse, 2005).

The costs of prefabrication are becoming more acceptable in comparison to on-site construction because of increasing labour shortages in the Australian construction industry largely due to the resources boom. These shortages are particularly felt within rural areas and states with more active mining industries and are anticipated to worsen over the coming decade. The potential of prefabrication to advance design is relatively unexplored within the education sector but advances in computer-aided manufacture, the need to construct energy efficient buildings and increasing labour shortages suggest that prefabrication techniques should be reconsidered. Within this context, this research into the application of prefabrication for school buildings has been supported by education departments.

Knowledge within other industries can be applied to the design of prefabricated general purpose classrooms. New design and delivery methods such as BIM and CADCAM have the potential to transform prefabricated classrooms into energy efficient buildings which are not designed as a `one size fits all' but are adaptable depending on the site location and educational needs of the school clients. The green component of the research will not only focus on efficiency of resources, energy and water but also include air quality, material use and the potential of automony.

Significance and innovation in the research approach

The concurrent investigations at macro and micro levels within a systems framework, the embedded nature of the research, and the bringing together

of diverse communities of practice are the key innovations in the research approach.

Investigating from both macro and micro scales

The research approach is outlined in figure 2 below. The potential of prefabrication will be investigated concurrently at macro and micro scales in order to develop possible scenarios on the transformation of educational buildings. This research will lead to a DOS (design oriented scenario) and POS (policy oriented scenario) propositions which will be analysed and tested across the range of stakeholders using an action research approach. A research cycle of hypothesis based on investigation will lead to propositions and prototypes for testing and critique. This process will highlight educational, design and construction opportunities as well as difficulties in the use of prefabrication for learning spaces.

Learning from and adapting practice developed and tested in other countries is a strategy for building knowledge. Internationally, particularly in Japan, prefabrication is facilitating cutting edge materials and techniques to be more easily incorporated in the construction process.

Also learning from other industries can be applied to the design of prefabricated general purpose classrooms. Smart materials, recently developed energy-saving products, computer-aided manufacture and new delivery methods focusing on user-defined design have the potential to transform prefabricated classrooms into energy efficient buildings which are not designed as a `one size fits all' but are adaptable depending on the site location and educational needs of the school clients. The green component of the research will not only focus on efficiency of resources, energy and water but also include air quality, material use and the potential of automony depending on use.

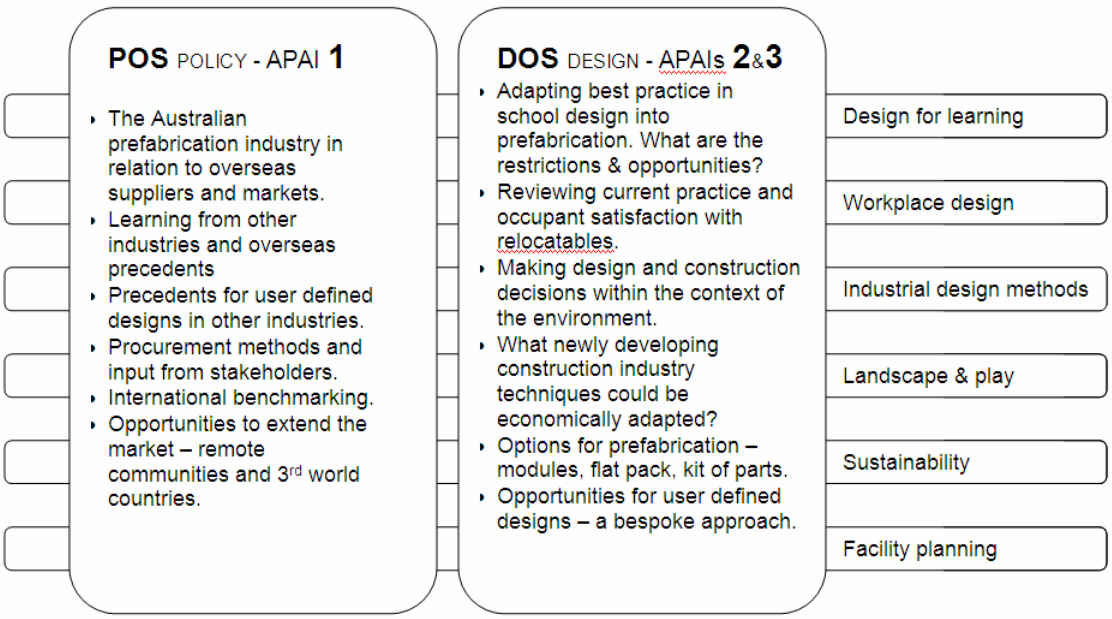


Fig 2 The research strategy by the author in consultation with the research team

Figure 2 lists six strands of research loosely aligning with the research interests of the investigators. The strands will be interwoven during the three year research program to provide a more comprehensive performance evaluation in which pedagogy is mapped alongside space and environment. The research will be organised in three stages that each approximate to one year.

The cross-disciplinary research touches upon many of the key National Research Priorities. Children spend a large proportion (up to 15,000) of their waking hours within a school environment. A healthy and stimulating school environment has economic, social and environmental benefits for the larger community.

Embedded research within a systems framework

Architects design learning environments for unknown users but rarely have an opportunity to get feedback from users to avoid repeating mistakes. Reviews of current prefabricated classrooms in terms of the design ambitions, the built reality and the users' observations will form a rich source of information revealing difficulties as well as unexpected benefits. A systems approach where existing relocatables are reviewed in a range of contexts will allow comparisons between users, climates and locales.

It is proposed that a form of action research be undertaken in order to trial techniques that facilitate engagement between the educators and architects during the design and implementation of the new learning environments. Embedding architects into the research and delivery process moves away from the idea of the impartial observer using instead a proactive research in which all stakeholders participate in the research discussion. Action research is a useful technique for gaining insight into 'wicked' problems as defined by the planning theorist, Horst Rittel. These are problems which are so complex, messy or unique that you need to effectively solve them in order to understand them. This methodology has been used by researchers Clune and Webb (2001) to gain greater insight into complex problems.

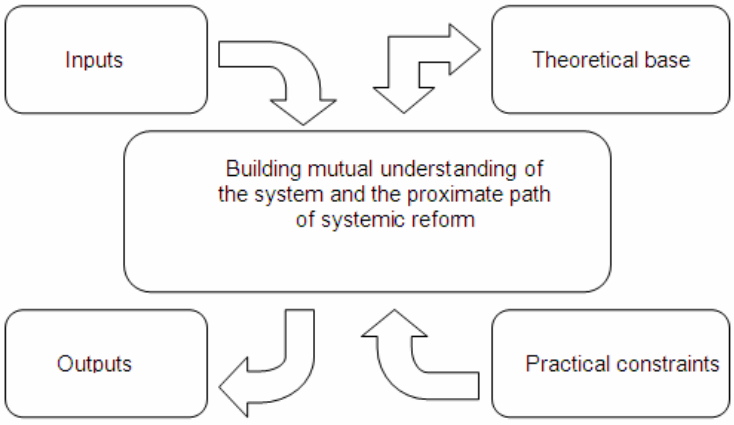


Fig 3. Adapted from Clune and Webb (2001) Five components of

The research methodology proposed does not attempt to simplify the organic processes of design, occupation and engagement. Rather, using a mix of qualitative and quantitative research methods, a better understanding will be achieved regarding different perceptions and needs of all parties including the users and designers, attitudes of teachers and whether they engage dynamically with the space and staff and student morale.

The underlying question is how the environment is supposed to impact on the users. This cannot be understood simply as architectural determinism where the space enables and controls the activities within. Relationships between people and their settings are complex and likely to result from involved chains of events. It is defining and understanding these chains of events which is the key innovation proposed within this research.

Resarch aims

The specific aims are three-fold:

(1) to analyse a cross-section of existing relocatables in terms of users, the locations and ESD issues such as energy, water, waste and lighting.

(2) to explore a more complete range of prefabrication techniques which might be adopted and adapted into the design of learning environments.

(3) to reinterpret prefabrication use as a design-led issue which can contribute to qualities of place and space, learning outcomes and policy implementation.

Currently prefabrication use with schools is driven by expedient construction methods rather than design outcomes. The research aims to find a nexus between design and delivery.

The three year research framework in Figure 4 shows the involvement of three PhD students known as APAIs under the funding nomenclature. The parallel strand of construction research will intersect with the design research intermittently throughout to ensure the micro impacts on the macro issues and visa versa.

The research framework recognizes that the skill sets of designers differ from the skill sets of experts in construction and yet both are needed. To deal with this dilemma, the suggested approach is to undertake parallel research while building regular links between the macro research approach and the micro research approach.

The research during the first year will primarily investigate the current situation. Based on those findings, propositions will be developed during the second year for presentation to industry, providers of school buildings and educators. The final year will draw together strategies and recommendations for improving the quality of prefabricated schools buildings in Australian states.

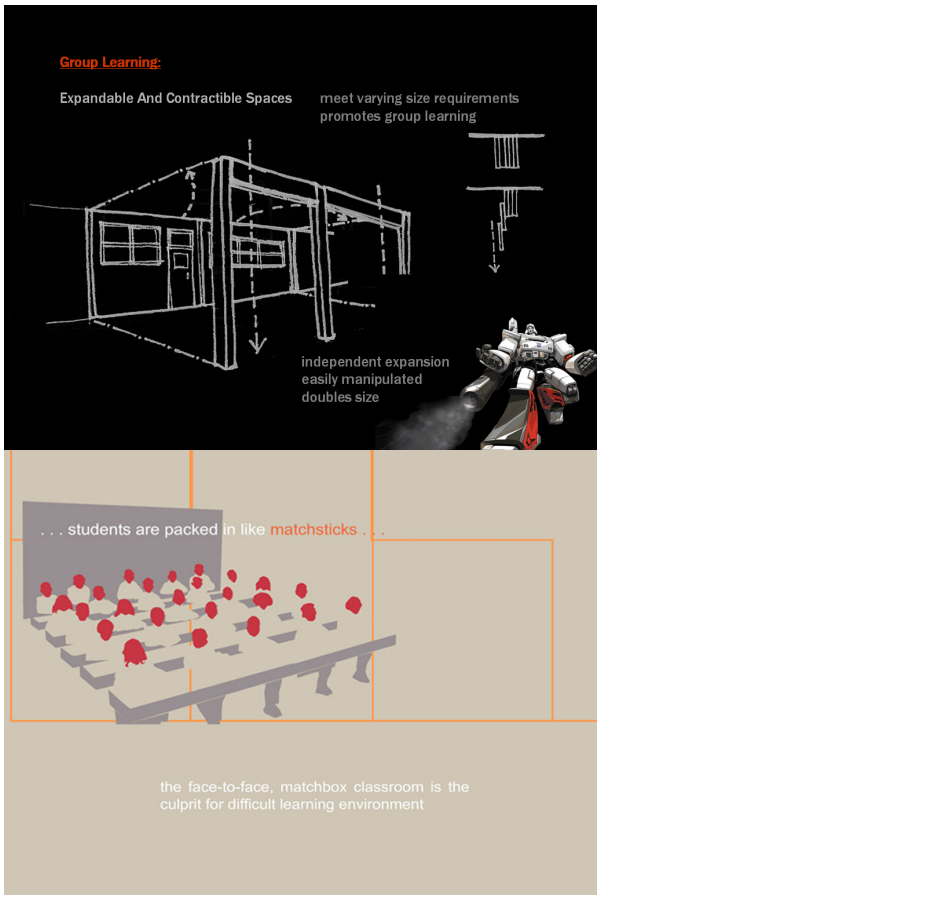
Year 1 – reviewing the current state of play	
POLICY **O**RIENTED **S**CENARIOS	**D**ESIGN **O**RIENTED **S**CENARIOS

APAI **3– a person with FM or construction skills**	APAI **2– an architect,** APAI **3 a designer**
ıment review Current provisions for relocatables *truction review* Current prefab providers, techniques in Australia and internationally *iews with prefab companies* Ex'g techniques and future directions *iews with education departments* Ex'g policies and future directions *s groups with industry partners* Opportunities for improvement in design and construction process.	*Questionnaires, interviews and focus groups* with education leaders, providers, students and parent groups to evaluate existing use of prebab buildings. *Observation* of current practice in terms of teaching, play, IT provision and use, community, maintenance, ESD. *Literature analysis* Recent international and Australian developments in the design of learning spaces.
Year 2 – proposing and testing opportunities for improvement	
POLICY **O**RIENTED **S**CENARIOS	**D**ESIGN **O**RIENTED **S**CENARIOS
Construction propositions Compilation of techniques and opportunities from existing prefabrication industries and related industries. *Industry structures* Compilation of techniques and opportunities from existing prefabrication industries and related industries. *Policy changes* Suggested changes to policies to suit better outcomes *Focus groups with industry partners* Opportunities for improvement in design and construction process.	*Develop a design briefing document* based on consultation with education leaders, providers, students and parent groups. *Propositions* to influence practice in terms of teaching, play, IT provision and use, community, maintenance, ESD. *Design propositions* to suit changing modes of learning.
Year 3 – review of finding and compilation of recommendations	
POLICY **O**RIENTED **S**CENARIOS	**D**ESIGN **O**RIENTED **S**CENARIOS
Construction recommendations for techniques and opportunities from existing prefabrication industries and related industries. *Industry structures* recommendations *Policy recommendations* *Workshop discussions with industry partners*	*Prefabrication strategies* critique a range of strategies for prefabrication – kit of parts, modules, components. *Recommendations* to influence practice in terms of teaching, play, IT provision and use, community, maintenance, ESD. *Design recommendations* to suit changing modes of learning.

Figure 4 A three year research framework by the author in consultation with the research team.

Dissemination of results

Outcomes from this research will be disseminated in scholarly and professional communities. Of more immediate impact, the ideas and approach to school design have been tested by final year students in studio classes. Images of the student work reveal a range of positions and designs for prefabrication and learning environments.



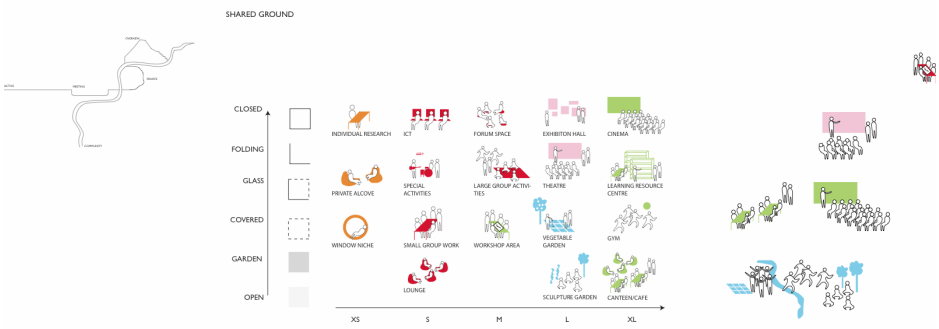


Fig 5 Schematic student work developed in the author's 2006 studio

Conclusion

Research into educational space is beginning to gain momentum after an 'absence of concern' for 25 years or so during which educational discourse has tended to ignore schools as physical entities (Jamieson et al 2000). After the post-war 'golden age' years in which school buildings were discussed particularly in regard to open planning, the physical environment has been largely ignored in favour of research into pedagogical and social contexts.

Production in quantity through prefabrication has advantages and disadvantages. Mistakes are amplified by being produced in quantity. There is a risk that designs become duplicated and ubiquitous rather than acting as templates which can be adapted, modified and personalized by users. If these disadvantages can be avoided, then the potential is for prefabricated

buildings which incorporate refined systems for saving energy, accommodating the education needs of students and providing exemplar school space.

In recognizing the conceptual difficulties associated with prefabrication, the researchers have developed a proactive research approach linking a theoretical base with practical constraints. Embedded the researchers into the context of the wicked problem of school design has the potential to change how education facilities are conceived as well as influencing accepted construction methods.

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Clare researches and teaches in the areas of design, construction and sustainability. Prior to working at The University of Melbourne, Clare was a Director of the architectural firm, Newton Hutson Pty Ltd. She retains strong ties with practice; was the Victorian Convener of Continuing Education for the Royal Australian Institute of Architects (RAIA) and is an RAIA nominated Competition Advisor. She was recently competition advisor for the $150 million Centre for Neuroscience at the University of Melbourne and has also advised on competitions for new schools and a range of other project competitions. She is an examiner for the Architects Registration Board of Victoria and has chaired four National Visiting Panels to accredit Australian architecture schools.