The Live Project and Prototyping as a Paradigm for Linking Teaching and Research in the Architectural Design Studio


Authors

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Abstract

This paper presents a series of interrelated architectural design studios and technology electives at the University of Technology Sydney (UTS) that ran over three years from 2009 to 2011. They involved a long running, live project partnership with Ku-ring-gai Council and integrated student collaboration with local fabricators, culminating in the 2014 construction of a prototypical park structure at Greengate Park in Killara, Sydney. In the context of the live project, the role of prototyping is explored as a specific form of inquiry-based learning that may optimise learning experiences applicable to architectural design and facilitate creative outcomes through linking teaching and research. It is increasingly being introduced into university architecture courses as an analogy to the activities employed by innovative professionals in architecture but the impressive visual imagery of student prototypes being produced is often divorced from any consideration of a broader theoretical context that might allow an assessment of pedagogical value. The question remains whether deep learning is occurring and whether the teaching processes and learning outcomes successfully link teaching and research. This paper identifies factors in the UTS case studies that influenced the students’ learning experiences and their
Introduction

This paper presents a series of interrelated architectural design studios and technology electives at the University of Technology Sydney (UTS) that ran over three years from 2009 to 2011. They involved a long-running, live project partnership with the civic authority Ku-ring-gai Council (KC) and placed an emphasis on prototyping through integrated student collaborations with local fabricators. Multiple cohorts of students participated from the UTS Architecture Masters and Bachelors degrees and their work culminated in the 2014 construction of a prototypical park structure to the students’ design at Greengate Park in Killara, Sydney (Figure 1). This has been a success story as far as UTS and KC are concerned. UTS financially supported the development of innovative learning and teaching strategies that would nurture the students’ experiential learning through prototyping and subsequently awarded the author a highly competitive UTS Learning and Teaching Citation in 2011. Following the 2014 construction of the prototypical park structure, the project was also awarded the Parks and Leisure Australia Award for Open Space Development for the State of NSW, Australia. The 2011 and 2014 awards both recognise the partnership between UTS and KC as exemplary, with the live project enabling UTS to integrate new design and fabrication technologies and practice-oriented learning experiences in teaching at the same time as allowing KC to explore options other than the standard off-the-shelf shade structures commonly found in suburban parks. Accolades aside however, deeper pedagogical questions remain as to the nature of learning taking place within the live project and prototyping paradigm and the degree to which the linking of teaching and research was actually achieved.

Figure 1 Prototypical park structure built in 2014 to students’ design at Greengate Park in Killara, Sydney. (Photographs: Adrian Boddy)

Volkmann makes clear that ‘prototyping as material-based designing, should be considered
research’ because it depends on a risk-taking process of trial and error in order to ‘develop something extraordinary’ (Harriss & Widder, 2014, p.126). In the context of the live project, this paper considers a series of case studies from UTS to examine the role of prototyping as a specific form of inquiry-based learning that may optimise learning experiences applicable to architectural design and facilitate creative outcomes through the linking of teaching and research.

It is important to acknowledge at the outset that the linking of teaching and research has always been considered an essential ingredient of a university education to develop graduate competencies in ‘critical thinking, analysing, arguing, independent working, learning to learn, problem-solving, decision-making, planning, co-ordinating and managing, and co-operative working, etc’, to which should be added, for architecture graduates, discipline-specific knowledge and skills. The Commission of European Communities reported in 2002 that these are the ‘core competencies that appear central to employability’ (Simons & Elen, 2007, p.618). In the university situated architectural design studio, the linking of teaching and research is important to equip students with these higher-order skills needed to support active inquiry in a rapidly changing profession.

The problem for architectural educators lies in defining the nature of research as it relates to a creative discipline. Research is fundamentally a knowledge-producing activity that has been typically defined as a systematic inquiry leading to verifiable conclusions. In the sciences, new knowledge is commonly obtained through empirical enquiry, while in the humanities, the methodological principle is an interpretive one in which investigators or researchers evaluate data through a subjective or hermeneutic lens. In applied fields, knowledge production frequently comes about through acts of innovation or ‘testing the boundaries’ within a particular problem context (Griffiths, 2004, pp.715-717). Research in architecture can span all three methods but Wortham (2007) claims it has been undervalued by the constraints of a scientific paradigm and therefore calls for a broader understanding of research that recognises methods and processes as forms of knowledge creation in themselves. This is because creative outcomes can be difficult to quantify given their evaluation is often subjective and not based upon established critical consensus (Maloney, 2000). Varnelis (2007) would argue that ‘works of architectural research aspire not just to represent the world but to help us look at the world in a fundamentally new way’ and that this is the way in which architectural research makes a contribution to knowledge (p.13).

Work produced in the university architectural design studio often has claims to being research, producing knowledge not obtained by a reliance on facts, hypotheses and reproducible results, but through speculative and inventive inquiry (Wortham, 2007, p.46).

**Prototyping in the context of the Live Project**

Inquiry-based learning has been identified by Griffiths (2004) as an effective method of linking teaching and research in the built environment disciplines. It is a ‘research-based’ method with a focus on active critical inquiry into the processes of knowledge creation rather than the passive acquisition of subject content and vocational skills. Griffiths refers to Brew and Boud (1995) who
find that learning is the vital link between teaching and research and that inquiry is a common element of research and learning. Deep learning is more likely to occur when students are engaged in producing knowledge through their own inquiry-based research activities than when they borrow knowledge from their teachers. The methods and values of inquiry-based learning have been extensively investigated across a wide range of contexts to elicit optimum learning outcomes (Boud et al., 1993; Deignan, 2009; Kahn & O’Rourke, 2005). One context is the live project, which establishes a collaborative engagement between an educational institution and a real client in response to a real brief, time frame and budget in real-time, resulting in a defined product (Harriss & Widder, 2014, p.13). Inquiry-based learning can range from a more structured approach to a totally open-ended approach, the latter of which has attracted criticism (Kirschner et al., 2006).

Prototyping can be used as a specific form of inquiry-based learning and as a type of design/build method within live projects. It is increasingly being introduced into the university design studio as analogous to the prototyping activities employed by professional practices engaged in innovative architecture. The prototyping process is generally understood to involve the creation of a specific type of model, built from representative materials in three-dimensions, often at full-scale, to explore design alternatives, test theories and confirm performance of materials, structure and assembly processes prior to starting production. Like other inquiry-based learning activities, including problem-based learning, practice-based learning, experiential learning and active learning (Mantzoukas, 2007), learning is student-centred and takes place through reflection on what has happened and why. The students construct their own experience in the context of a particular social and cultural environment and the role of the teacher is to act as a facilitator. The live project provides a context that can enhance student prototyping activities by exposing students to the ‘variety of people implicated in architectural processes’ and real issues of context, community engagement, socially responsible design conditions and uncontrollable complexities which might not otherwise be appreciated when prototyping is employed in isolation (Morrow in Harriss & Widder, 2014, pp.xix-xxi). It also invites students to work between theory and practice: between the speculative and the proven in materials and construction, between the innovative and the conventional in architectural form and between the extraordinary and the mundane in spatial experience. The lines between the pedagogical and the practical are often blurred as student prototyping investigations embrace ‘design speculation, sociological strategies, and construction technique’ (Zeiger in Harriss & Widder, 2014, p.xxv).

In recent years there has been a proliferation of publications showcasing the eye-catching student work coming out of the university architectural design studio accompanied by profiles of noteworthy studio programs. The impressive visual imagery of student prototypes is often divorced from any consideration of a broader theoretical context that might allow an assessment of pedagogical value. Fleeting references are made to Dewey’s (1933) theories of education and project based learning and Schön’s (1987) theory of reflective learning as applied to the university architectural design studio, in which a problem is framed and re-framed to generate problem-solving actions. The general lack of pedagogical and theoretical basis was noted a decade ago in the introduction to the special issue on ‘Architecture, Technology and Education’ in the Journal of
Architectural Education:

Architectural educators frequently refer to their work in the studio, and in technology generally, without reference to any pedigree … much work needs to be done to establish the parameters and content of that teaching. (Cavanagh, 2004, p.3)

The omission has been partly addressed within the framework of the live project by Harriss and Widder’s book, Architecture Live Projects: Pedagogy into Practice (2014), which documents the pedagogical and theoretical underpinnings of projects that range from prototypical propositions through to 1:1 scale buildings.

Some of the creative outcomes of the architectural design studio have been written about at length as products of research-based processes, such as the ‘Rural Studio’ at Auburn University (Hinson, 2007) and the prototypical pavilions constructed annually by students at the London Architectural Association (Architectural Association, 2006; Hensel & Menges, 2006; Dempsey & Obuchi, 2010; Self & Walker, 2011). The success of both programs is that they build upon a well-established knowledge base and are part of an extended research program and pedagogical plan.

Much of the literature on prototyping emphasises the exploration of contemporary architectural problems. Case studies include exploring ‘the gaps between digital design and making and between scales and modes of production’ (Iwamoto, 2004); experiments ‘to push material limits for greater performance and at the same time to investigate their aesthetic values and psychological effects’ (Schroepfer & Margolis, 2006); and collaborative studio projects ‘to learn about performance and its concrete relation to spatial situations’ (Tisi, 2008). The Journal of Architectural Education, Volume 60, Issue 2 (2006) was devoted to featuring case studies from American universities of full-scale prototype constructions linking the digital and material worlds. Many European examples use reverse engineering to break a digital form into component parts, variously skin and structure, that can be physically reconstructed (Scheurer, 2005; Larsen & Stori, 2006). Such case studies challenge traditional university teaching methods by foregrounding the practical and applied, rather than the academic and abstract. There is strong evidence of student involvement and relevance to the profession. However, questions remain: Is deep learning occurring through participation in these activities? What is good practice and how can it be conceived? And do the studio processes and outcomes link teaching and research? These questions are examined in the UTS case studies described below.

UTS case studies and methodology

A live project partnership was initiated in 2009 between the author and the civic authority KC, which was seeking to explore alternatives to standard off-the-shelf shade structures for its parks. It was initially conceived as a single-semester, single course commitment but the design challenges made that impossible. It was extended over multiple semesters from 2009 to 2011 and across a series of interrelated design studio and technology elective courses: 11506 Fabrication
Technologies Design Studio, 11362 Fabtech Special Project Elective, 11505 Material Technologies Design Studio and 11362/11307 Concrete Special Project Elective. Table 1 provides a detailed account of the four courses that provide the case studies for this paper. The table details their characteristics in terms of brief and community of practice, external collaborators, product / student outcomes, timescale and other features. All four courses were carefully structured with reference to the findings in the literature. The decision to follow the methods of inquiry-based learning was particularly motivated by the desire to foster links between teaching and research because this is a fundamental objective of design studio teaching at UTS Masters level.

![Image](image_url)

**Figure 2** Alucobond® prototype designed by students Kevin Lee and Peggy Wong (pictured) and Domenico Ciccio. It was modeled at 1:20 before a 1:1 prototype was constructed. (Photographs: Kirsten Orr)

The prototyping approach necessitated group work because of the large scale, considerable cost and time constraints but the group work was also an important element of the approach, reflecting the emphasis in architectural practice on teamwork that is often of an inter-disciplinary nature. The students and tutors worked together as a team, with the students initiating ideas that drew on their individual knowledge, experience and research and with the tutors bringing additional knowledge to their development. After a number of cycles of experimentation and reflection a plan of action was agreed upon and a prototype of the virtual design was built to test it against the reality of factors such as gravity, material properties and performance of connections, none of which could be fully understood in the virtual environment. The final step was to reflect on the prototype’s performance and whether there could have been other or better solutions to the original problem.
An important element of the four courses was gathering qualitative staff and student feedback. At the conclusion of each, students were interviewed in focus groups conducted by an independent and experienced focus group convenor. Questions explored the students’ understandings of the purpose of the course: their awareness of participating in a research-like activity; their perceptions of working within a community of practice; their understanding of the nature of the interface between the digital and the material; the value they placed upon having a real client / live project; and whether they thought the structure of the studio came close to simulating what goes on in practice. Students also maintained a regular blog documenting their personal design and research processes, identifying their perceptions of the strengths and weaknesses in the group process, critically evaluating the outcomes and reflecting on what they thought they had learnt. The resulting data was interpreted against findings in the literature on the research-teaching nexus as it relates to the built environment disciplines and is referred to later in this paper, particularly some of the students’ open-ended responses.

<table>
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<tr>
<th>1506 Fabrication Technologies</th>
<th>11362 Fabtech Special Project</th>
<th>11505 Material Technologies</th>
<th>11362/11307 Concrete Special Project</th>
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<td>1:1 prototype folded Alucobond© &amp; 1:2 prototype of vacuum-formed panels</td>
<td>New techniques for casting mass-customised precast concrete elements &amp; prototypes at 1:1, 1:2</td>
<td>Resolved design in precast concrete &amp; models, prototypes, working drawings for tender/construction</td>
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<td>Fictional – Great North Walk</td>
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<td>Consolidation / manufacture of prototypes</td>
<td>Ideas generation — new concrete casting methods / up-skilling in CAD/CAM</td>
<td>Consolidation / realisation of buildable proposal / documentation</td>
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<td>1. Research into 5-axis CNC milling and fabrication of a test prototype (I)</td>
<td>1. Roof canopy development exercises in Rhino &amp; Grasshopper (P)</td>
<td>1. Experimentation with innovative concrete casting techniques (P)</td>
<td>1. Preliminary documentation package, models &amp; prototypes (P)</td>
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<tr>
<td>2. Design for picnic shelter (I)</td>
<td>2. Resolution of roof canopy and fabrication / construction of prototype at 1:1 or 1:2 (G)</td>
<td>2. Design for walkers’ huts (I)</td>
<td>2. Tender / construction documentation package (G)</td>
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<tr>
<td>3. Development of selected design to fabrication ready (G)</td>
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<td>3. Fabrication of mass customisable forms and concrete prototypes (I)</td>
<td>3. Personal reflection on learning (I)</td>
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**Funded by UTS Teaching & Learning Grant**

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**Taught in Sydney with Aarhus School of Architecture (Denmark)**

**Student design was constructed by others in Greengate Park, Killara**
As Table 1 demonstrates, each course developed its own particular character. In 11506 Fabrication Technologies, the students worked closely with a local fabricator with a five-axis computer numerically controlled (CNC) milling machine to explore its architectural applications. In 11362 Fabtech Special Project, a spin-off from 11506, the students developed the design of the roof canopy as a single layer system and explored the possibilities of applying the CNC technology to innovative materials. They constructed a full-scale prototype from Alucobond®, cut, scored and folded using CNC tools available at Make Good Pty Ltd (Figure 2) and a half-scale prototype of vacuum-formed plastic roof panels that were shaped from a CNC milled mould fabricated by Warringah Plastics (Figure 3). In 11505 Material Technologies students were introduced to precast concrete as a material and developed individual approaches to casting concrete that led to the development of an innovative casting system for mass-customised concrete elements produced from moulds of folded, CNC-cut and scored polyethylene terephthalate sheet. In the spin-off elective, 11362/11307 Concrete Special Project, this casting technique was refined and applied to the final design for a park structure at Greengate Park in Killara, Sydney that was built by a commercial construction company in early 2014 (Figure 4).
Integrating knowledge within a live project prototyping inquiry

Prototyping falls into the category of inquiry-based learning that Spronken-Smith and Walker (2010) identify as a ‘guided inquiry’ in which ‘teachers provide questions to stimulate inquiry but students are self-directed in terms of exploring these questions’ (pp.726-727). The UTS students needed additional support of the kind they refer to as ‘scaffolding.’ This involves the teacher providing support to students that gradually tapers off as they become more confident and able to do the task themselves. Therefore, in structuring prototyping activities, careful consideration has to be given to methods of providing students with enough knowledge to support each stage of their investigation. At UTS guidance was provided in the form of lectures, structured research activities, teaching of software, visits to industry, guided workshops and input from architectural practitioners and other members of the construction industry. Along the way, the teachers adopted the role of co-learners, supporting the students’ discoveries and mistakes. The students learnt to utilise the generative, computer-modelling tools available in Rhinoceros® design software with the Grasshopper® plug-in, so that their three-dimensional digital designs could interface directly with the fabrication machinery and predict physical outcomes and structural performance. In 11506 Fabrication Technologies, the students’ research involved a practical exercise in which they designed and milled the surface of a plywood panel to introduce them to the subtractive three-dimensional numeric fabrication process of CNC milling, tool choices and tool path strategies (Figure 5). In 11505 Material Technologies the students’ research was guided by a lecture series on precast concrete and visits to a precast concrete factory and local precast concrete buildings. Students also participated in an intensive concrete casting workshop where they were required to follow a highly prescriptive process to understand the material properties and methods for casting it (Figure 6).

![Figure 5 CNC milling of plywood panels by students in 11506 Fabrication Technologies. (Photographs: Kirsten Orr)](http://bejlt.brookes.ac.uk/paper/the-live-project-and-prototyping-as-a-paradigm-for-linking-teaching-and-research-in-the-architectural-design-studio/)

After the initial ‘scaffolded’ activities, students were required to pursue their own lines of inquiry in formulating an innovative design proposal, moving into what Levy identifies as a ‘discovery frame,’ as distinct from an ‘information frame’ (Spronken-Smith & Walker, 2010, p.735). The
students moved from a teacher-led stage of acquiring existing disciplinary knowledge – through both theoretical and practical research exercises – into an increasingly student-led and discovery-active stage in which they produced creative research outcomes. Their research processes were similarly creative to those adopted by architectural practitioners engaged in practice-based research but the outcomes were limited by the constraints of the course timescales. They were also limited by the students’ lack of architectural experience. Particularly in the 11506 Fabrication Technologies studio, some of the students thought that the teachers should have acted as project managers,

‘because in a work situation the project manager knows a lot, has a lot of experience and has to have this body of experience that you draw on to initiate something or to terminate something and their decision making is informed by their experience.’ (Student comment, focus group convened by UTS Institute for Interactive Media and Learning (IML), 2010)

![Intensive concrete casting workshop in 11505 Material Technologies. (Photograph: Kirsten Orr)](image)

**Strengthening the research link**

**Establishing communities of practice**

The live project lends itself to establishing communities of practice because of the importance placed on collaboration, open-mindedness and good communication, which are at the ‘crux’ of its success (Harriss & Widder, 2014, p.5). Moreover, the sharing of responsibilities and distribution of authorship is essential as the project scope exceeds the abilities or capacity of any individual student. The UTS case studies successfully established their own communities of practice by bringing together teachers and tutors from academia, architectural practitioners with expertise in computer aided design (CAD) and computer aided manufacturing (CAM), industry fabricators, a structural engineer and the student body. The students valued the richness of the collaborative environment and discovered the benefits of collaborating with industry and of drawing upon its wealth of construction knowledge. Likewise the two fabricators, Make Good Pty Ltd and Warringah Plastics, benefitted and advanced their understanding of CNC fabrication processes
not common in local construction practice.

An important aspect of the community of practice is the linking of research interests of academic staff with student investigation. As teachers communicate their passion for the subject and students become motivated by being involved in discussions of their teachers’ research a research-teaching nexus is established. The 11505 Material Technologies studio was built around staff expertise in precast concrete: ‘it’s very stimulating and obviously very academic and I enjoy that’ (Student comment, IML focus group, 2011). Brew (2003) argues that ‘if the relationship between teaching and research is to be enhanced it is necessary to move towards a model based on the notion of academic communities of practice’ (p.3). In this model ‘research and teaching are both viewed as activities where individuals and groups negotiate meanings, building knowledge within a social context’ (p.12). Furthermore, Wareham (2008) suggests that Brew’s communities of practice model is an effective method of linking teaching and research in the creative arts.

**Focussing on process rather than product**

The significance of speculative and inventive inquiry in architecture lies both in terms of its process and its product. Wortham (2007), searching for a new way of thinking about research in architecture, explores the relationship between process and product. She finds that ‘in an architectural schema, it is not just the product that is of consequence. The process itself, the search, the inquiry, can be as substantial if not more so, than the rendering of conclusions’ (p.46). Spronken-Smith and Walker (2010) confirm that the research-teaching nexus is strengthened when the focus of learning is discovery-oriented and focuses on an inquiry process (p.736). Within the specific context of the live project, Anderson and Priest observe that the ‘positive learning cycle’ is made more significant by its ‘authentic context’ which leads students to more willingly absorb the lessons learnt from the experience and to draw upon this knowledge to inform ‘their future practice and own critical judgement’ (Harriss & Widder, 2014, p.11). Hughes goes further, claiming that the contingent character of the live project process is as important as any physical outcome because it empowers ‘students with the instrumental agency and improvisational intelligence necessary to navigate the unknown, and unknowable, that defines all real-world endeavours’ (Harriss & Widder, 2014, p.129).

The live project underpinning the UTS case studies gave them an authentic structure modelled on real architectural practice, in which the architectural team sought to satisfy a client’s requirements. The client, KC, was unwavering in its requirement for a robust roof to the park structure that would be strong enough to withstand the nocturnal activities of vandalising teenagers. This directly contradicted the students’ preferred concept for a light canopy, poetically abstracted from the canopy of a tree. It also appeared to be incompatible with the fabrication processes and innovative materials that the students were seeking to employ. As a result they were required to embrace the ‘contingent character of contemporary architectural practice,’ to navigate – rather than ignore – the real-world constraints and ultimately to adapt their use of technology and approach to materiality in their design for the park structure. In the prototype finally built at Greengate Park, CNC technology was employed indirectly to produce moulds for mass-
customised precast concrete panels that evoked the original tree canopy concept through structure and surface rather than through material, light and shade as originally intended (Figure 7).

![Image](image_url)

**Figure 7** Detail of the under-surface of the concrete roof canopy as built at Greengate Park. (Photograph: Adrian Boddy)

The first architectural design studio, *11506 Fabrication Technologies*, aimed to produce a series of designs and prototypes for the park structure but was too ambitious for the 13 week semester. The students followed an iterative process, applying the possibilities of CNC fabrication technologies to their designs, which were evaluated against the client’s requirements and other construction criteria. Abstractions of a tree canopy resulted in series of proposals exploring issues of light and shadow, weatherproofing, materiality and fabrication (Figure 8). However the students were inhibited by the physical constraints placed by the client on the nature of the product and expressed the sentiment that: ‘All these practical considerations ended up just killing what could have been’ (Student comment, IML focus group, 2010). They were also frustrated by the fact that there was insufficient time to construct full- or half-scale prototypes of key design elements. Moreover, they did not recognise their iterative process as research despite working in a community of practice that established a rich collaborative environment for exploring new directions in the application of CNC fabrication technology to architecture. Nevertheless the keeping of online blogs was appreciated by the students as a record of their process and as a tool for making their findings public. One student said it was ‘like a process blog or a process file … where you’ve got all your information in one file so you can see where you’re coming from and
where you’re going’ and another responded: ‘Yes. You can personally reflect on what you’ve learned yourself. It’s the best thing you get out of it’ (Student comments, IML focus group, 2010).

**Figure 8** Senan Naamo’s early concept for the park structure. Interlocking discs of metal and acrylic simulate the dappled shade of a tree canopy. (Source: Kirsten Orr)

The second architectural design studio, *11505 Material Technologies*, succeeded in getting students to recognise they were engaging in research through a focus on material experimentation. As a result they strongly identified with their role as practice-based researchers, one observing that,

‘I think we’ve actually gone beyond what some professionals probably do … We’ve jumped into this really open-minded and we’ve taken on the scientific methods of research.’ (Student comment, IML focus group, 2011)

The iterative processes in which they were engaged were very clear as they applied their theoretical knowledge to creating physical prototypes in precast concrete, which were then evaluated against digital models, performance criteria and aesthetic frameworks (Figure 9). Upon reflection about the successes and failures the process was modified and repeated. One student observed that,

‘We were going back and forth. So you did your physical experiment, then you went in to do digital. You realised once you hit the wall in your digital you [should] go back to your physical and then you hit the wall with the physical. They’re interactive with each other for me.’ (Student comment, IML focus group, 2011)

The precast concrete prototypes were not an end in themselves but were regarded as a small step in a long-term research process shaping architecture’s future.

‘I guess we’ve learnt design and construction processes in terms of the material. How can we design with this material? How can we make concrete more of a design element rather than just a structural thing?’ (Student comment, IML focus group, 2011)
The process of devising the innovative casting method was of primary importance and was significant because the students recognised its role in forging the links between teaching, research and learning (Figure 10).

![Diagram showing the process of devising the innovative casting method](image)

**Figure 9** Kara Gurney developed a Grasshopper® script that allowed exploration of the geometry of concrete components cast in laser cut polyethylene terephthalate formwork. (Source: Kirsten Orr)

## Student awareness of prototyping as a research activity

All of the UTS case studies involved prototyping activities as a form of research. However, students appreciated the research dimension more strongly in some situations than in others. The 11505 Material Technologies studio was most successful in terms of student identification with a research process. In the other three courses, the simulation of real architectural practice appears to have dominated. The differences can be attributed to variations in course structure, community of practice and the degree to which practice-based research was openly discussed with the students. Spronken-Smith and Walker (2010) have identified a strong research-teaching nexus existing in situations in which students are aware of their role as apprentice researchers (p.734). This was borne out in 11505, where the students started as apprentices learning casting techniques and progressed to a status more akin to that of a research assistant, working alongside their tutor, a PhD student. In contrast, in the 11506 Fabrication Technologies studio, although students could see their iterative process as moving between theory and practice, they
did not recognise it as a form of practice-based research. This is partly because the teachers did not speak of these processes as being a research investigation that could contribute to knowledge.

![Figure 10 Mette Fast devised an ingenious system of re-usable formwork closely related to conventional jump-formwork. (Source: Kirsten Orr)](image)

It is evident that students need to be given clear information about what constitutes research in a particular discipline and how they might be engaging in it. This becomes particularly important in a creative discipline like architecture where the nature of research is contested. Even the most speculative design inquiry can contribute to knowledge and be thought of as research if it is evaluated within a theoretical or practice framework. Edmonds and Candy (2010) examine art practice as research and trace the relationships and trajectories in several PhD projects between theory, practice and evaluation. For art practice to qualify as PhD research they argue, the outcomes must be accessible to other people and be available in a documented public form so that they can be evaluated and considered for their contribution to knowledge. Often without recognising it, the system of architecture design studio teaching tends towards art practice as research because the students are engaged in a research and learning process, the outcomes of which are publicly evaluated. Knowledge is made public through assessment by external juries, exhibitions of student work, installations in public places and publications ranging from catalogues to more scholarly articles such as this one. As Wortham (2007) notes, ‘the public nature of these investigations allows knowledge to be disseminated, challenged and developed in a collective and comprehensive way. Studio, then, is an opportunity for architectural faculty to engage in public and collective research’ (p.49).

**Conclusion**

Prototyping is a form of inquiry-based learning that is frequently integrated with live projects that incorporate a design/build component. As such it is well placed to contribute to the research-teaching nexus but must be carefully structured if it is to be as effective as possible in engaging all students in a deep learning experience. Reflection on the UTS case studies supported by a review of the literature, points to a number of key considerations that may enable or limit the stimulation of creativity, the development of higher-order thinking and the optimisation of a link between teaching and research.
The case studies integrated a live project involving cutting edge CAD/CAM technologies and innovative materials as a catalyst to progress the theories and practice of architecture in an era of digital mass-customisation. They supported prototyping activities as a research activity for a client who was ‘curious and open-minded’. For Froud the testing of ideas in this context provides ideal conditions for research to occur, allowing ‘everyone to learn together, with social and spatial implications tightly intertwined’ (Harriss & Widder, 2014, pp.193-194).

Because prototyping is modelled on sophisticated processes drawn from the practice of experienced architects, ‘scaffolding’ must be provided to support students with the relevant knowledge and skills at each stage of the process. Of particular importance is the establishment of a community of practice that ideally includes academic researchers in their own field of expertise, representatives of the architectural profession and construction industry, and an engaged client. The cross-fertilisation of ideas made possible in this environment stimulates both creativity and the production of new knowledge. The timescale limitations imposed by semester structured university teaching must be kept in mind, for otherwise goals will not be reached, sufficient resolution of designs will not be attained to justify the effort of constructing a prototype and students will not be rewarded with the physical outcome they were expecting.

One of the benefits for students of engaging in prototyping in the context of a live project is that they experience the difficulties and complexities associated with the physical act of construction first hand. Widder (2014) claims that ‘They value empirical learning for the inevitable failures it includes; they are able to learn to transpose architectural ideas into their constructed forms’ (p.31). However the greater benefit takes place when prototyping is conceived as a research activity. When prototyping emphasises iterative processes and reflection upon each stage, students learn a method of producing creative outcomes through a research-based process. It is imperative that students be made aware that prototyping is fundamentally a research-based activity and that it is just one of many research activities common to the discipline of architecture.

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