The Re-Engineering Project
Developing Pedagogical Frameworks for Early Stage Collaborative Design between Engineers and Architects

Andrew Maher
Jane Burry
RMIT University

Abstract

We describe a research-based design studio entitled ReEngineering, brought together by two research groups with the aim of further understanding factors that promote conceptual design for interdisciplinary work between architects and engineers. The aim, through a sequence of semi-structured projects, was to reflect upon the students' attempts both at a co-rational (Fischer 2006) approach to design and at the culmination of each stage to return to the beginning albeit with a more sophisticated understanding of the work. Through this process we found that a close-coupled design process was achieved between these disciplines at a conceptual level but when the participants developed a shared understanding supported by a project language and when each eschewed their discipline specific tools a co-rational approach was obtained.

Introduction

In 2003 we published a paper (Maher and Burry 2003) in which we described a project that parametrically linked the architectural design geometry and the engineering analysis of a bridge so that iterations of the design could be optimised or ‘solved’ to produce variations according to the design parameters offered up for change.

This project and several others we have undertaken since offered insights into the development of design schemas required by parametrically defined models in which both the initial conditions and conceptual agenda were well described and often well advanced. With this experience, we were able to engage with constraints often discovered and developed later in the design process; the bridge for example was developed using knowledge garnered about its proposed fabrication methods. New relationships were formed at different stages of a project as fabricators and their processes were engaged with much earlier in the process.

In the intervening period we have been pushing the concept of schema preparation—designing the design—further toward the beginning of a project.
The challenges are non-trivial; the period of a project we are looking at is where the process of defining the problem is itself often undergoing redefinition.

This is when problems are often at their most wicked, when procedures that designers find intuitive are in the process of transference toward declarative knowledge, and before they can be shared between other participants in the design more explicitly. It is here that training, professional education and organisation of a discipline become paramount in our ability to consider new possibilities.

We have been looking at the nexus between architects and engineers, together possibly the most important progenitors of built form. This paper reports on a research-based design studio entitled Re-Engineering, which brought together final year students from architecture and structural engineering to explore conceptual design for the organisation, development and fabrication of built systems in co-rational collaboration.

The expectation of students exploring a co-rational approach to design was explicitly to avoid the situations in which a structural system is the starting point (pre-rational) and in which structure is designed in reaction to formal resolution (post-rational)—or ‘make it stand up please’ (Fischer 2006). The studio provided an opportunity to explore structural systems in synthesis with other design drivers. There was an emphasis on the support systems to conceptual design through structural evolution for parametric digital modelling.

The notion of co-rationality served a dual purpose within the research studio. Its association to a building’s physical structure offered tangibility to the engineering and architecture students and served as a metaphor for the intended process of collaboration.

The research was conducted as part of a RMIT University initiative to promote the bringing together of discipline-based research groups under the banner of Virtual Research and Innovation Institutes (VRII). The authors are members of a VRII project called Dissolving the Boundaries between Architecture and Engineering which serves to link the Spatial Information Architecture Laboratory (SIAL), located within the School of Architecture and Design, and the Innovative Structures Group (ISG) from the School of Civil and Chemical Engineering.

Architects and engineers

Much effort has been expended in describing the differences between engineers and architects. They belong to disciplines that have been distinct for at least two centuries and yet as Tom Peters—who has contributed more than most on the topic—has observed, “it is curious that there should be two fields devoted to the same activity, namely, the ejection of structures.” (Peters 1987)

When interviewed by Edward Robbins, the celebrated engineer Peter Rice offered his insight into one difference between architects and engineers through his observation of each discipline’s preferred mode of representation: architects think through drawing whereas engineers engage with what is not easily drawn:

“As buildings get lighter . . . environmental loads like wind, snow, earthquakes, temperature effects, and such become increasingly important. These kinds of
loads have little to do with the general shape of a building. Unlike a gravity load, which is visible, they are not.” (Robbins 1994)

Voyatzaki and Williams (1996), in their study of the design of non-conventional building structures, noted that the cyclic nature of collaboration between architects and engineers was disrupted by the inadequacy of conventional drawing techniques to describe difficult geometry, either by hand or computer. Replacing drawing with computational modelling does not automatically guarantee a coherence of information. When dealing with wind for example, engineers still rely on wind tunnels for results, in some circumstances “even the most advanced CFD (Computational Fluid Dynamics) process cannot calculate the wind-induced flow … with sufficient precision.” (Gerhardt 2003)

The absurdity is that for most of their professional lives these two disciplines form the closest of working relationships which is usually conducted in a post-rational manner, as described earlier. Changing this situation by encouraging engineers and architects to design together earlier in the process is not trivial nor is it solved with technology alone. (Achten 2002; Steele et al. 1999) However, the differences between architects and engineers are an exemplar of the many disciplinary divisions encountered in the design of buildings, and studying the possibility of collaboration in the early stages of design stakes an interest in the development and acquisition of cross-disciplinary skills through project-based work.

The difference between disciplines can often be reinforced on university campuses. Our university is not uncommon in its structure where architecture and engineering students are found in separate schools located in different faculties. Divisions are easily established and then maintained as courses are accredited by their respective professional bodies (to which there is strict adherence) and the students (and most of the faculty for that matter) do not interact.

This situation is of course not limited to any one country, but is replicated many times throughout the world. There are exceptions, however, albeit in specialist programs. One is the joint degree program offered at Sheffield University in the UK, which has the recognition of both the Royal Institute of British Architects and the Institute of Structural Engineers. (Popovic 2002) Another is the course on Collaborative Design taught at Eindhoven University of Technology. (van Leeuwen 2005)

**Teaching across disciplines**

The Spatial Information Architecture Laboratory, or SIAL, is a research centre located within a school composed of five programmes: architecture, interior design, industrial design, landscape architecture and fashion. Our teaching both informs our research and serves as a platform for interaction between these design disciplines at a primary level, and between other programs throughout the university. As such, we have gained experience teaching interdisciplinary courses using different methods of delivery and support systems. (Burry et al. 2003)

As a general consideration we want to note that the teaching demands are much higher under these circumstances as each
individual discipline needs to be addressed at the same that the bridging between them needs to occur. These challenges also hold true for the students. We have also found that when working at a School level the barriers between disciplines with similar training and approaches can be completely transgressed—landscape architects become architects and vice versa. In fact, between such disciplines we have found little evidence that individual contributions remain completely discipline specific.

The Course

Research Aims

The aim of the research was to identify points at which the students would begin to experience shared understandings, either using conceptual devices and aids or through communication. Co-rationality was held as a beacon between the prevailing conditions as described, to effectively promote joint authorship. We were equally interested in making out the shape, metaphorically, that the disciplines had already formed around these students. At what points, if any, would they connect?

Planning for the research included investing effort in understanding the respective programs, locating subjects with the potential to collaborate between each of the disciplines’ existing courses, and establishing support systems for the students.

Course Structure

In contemplating the appropriate structure for this research, we had to negotiate the divergence in the two program structures, the requirements of each discipline and the expectations of the students. The engineering program follows a horizontal year-long structure, whereas in architecture the main focus of the programme is the vertically integrated thematic design studio, each of a semester-long duration. Architecture students have the license to 'curate' their own course, selecting subjects that often inform their themed studio work; the engineering students cover many aspects of their discipline from geology to material science to transport.

For this research we chose a studio-based research course taken by final year architecture students and an investigation project undertaken by final year engineering students. Equivalence in students' course loadings is one of the issues we have faced with collaborative studios, whether they be remote, intra-school or, as in this case, between schools. We have observed that this directly translates to the effort they will place in the work, their attentiveness, and then the quality of the collaboration. Our chosen structure allowed the students to approach the course from within their own domains although the architecture students’ load was double that of the engineers, and yet the engineers participated in both the studio and completed reports for their respective subjects.

Support systems to promote collaboration

An ethnographic study of the computational affordances that support design collaboration in professional design
practice noted that commercially available collaborative and computer-aided design software tools "have limited coverage when it comes to exploring social structures and surrounding interactions across everyday practice beyond the computer." (Simpson and Viller 2004)

Our computer-support systems in these courses tend to focus on communication rather than data or filing structures. In earlier efforts to promote collaboration, we initially gave primacy to visual and aural forms of communication; for example, we joined three remotely located sites with a proprietary 'always on' system and supplied students with web cameras, tele- and video-conferencing. We observed though that students often preferred email and text based messaging software for communication. Email provides an interesting case for collaboration as it is both asynchronous and dispersed. It can provide an incomplete picture to any one participant as not all members of a project may be included in all exchanges.

We surmised from an investigation into the email archive of a design project with many participants from multiple disciplines that the quality of communication was not significantly affected by the ontological differences between disciplines. (Burry, Burrow & Burry 2005) In fact, we found that through text-based exchange a project language developed that was inclusive to all members.

Latterly we have been using wikis as a primary means for communication. A wiki is a hypertext linked collection of online editable pages (Wikipedia, "the free encyclopaedia that anyone can edit," being one of the most well known). Like email a wiki is also asynchronous, but unlike email it collects the communication in one place. Editing and structuring is also possible, as is the opportunity to build lexicons by creating wiki-words that become navigable hyperlinks.

Wikis have proven to be immensely popular, and we have been both observing how they are used and developing newer versions to promote emergent activities that may support collaboration. The wiki in ReEngineering was used by the students to write journals, organise and structure their work, chat, store presentations and communicate the research when seeking support outside the university.

**Project-based research**

**Project rationale**

We divided the semester into three projects and monitored the use of digital tools carefully. Initially students worked with a severely restricted palette which was later expanded but then restricted again when issues of discipline specificity appeared, such as interoperability between software or exclusivity to one discipline. The first project aimed to test conceptual design practice in each discipline through a series of set exercises that matched form finding with contemporary structural systems. The second focused on a particular example in a more detailed manner to test a close-coupled design process as an identifier of collaboration, after Kvan (2000). The third added siting and location issues. The intention of the tripartite was to force a return to a beginning point, albeit with a more developed focus at each stage.

A feedback loop was created so that at
the culmination of each project tutors and members of an external panel evaluated student progress, and then changes were incorporated into the subsequent project.

The Projects

The first project required the students to work in partnerships representing both disciplines and to evaluate programmatic forms with related structural concepts as a series of exercises on a weekly basis. In this project students explored a range of structural, site, programmatic and formal situations and evaluated something about the potential for 'defining a compositional' (and structural)'system alongside and so some extent through the process of designing a form.' (Fischer 2006) In other words, the potential for co-rationality. For example, the students were introduced to conceptual digital tools sourced from our research VRIL, such as Evolutionary Structural Optimisation (ESO), a method originally developed for progressively removing the most redundant material from a structure. (Xie and Steven 1997) Each week, we required students to represent outcomes with physical models of their preferred structural systems, which included folding trusses, catenary structures, tensile cables and shells.

Evidence of the disciplinary boundaries appeared early in the research. From the outset it was clear that one discipline did not necessarily empathise with the other:

"I really struggled to understand what was being said for at least the first two weeks of the project. The most telling misunderstandings were clearly evident when an engineer tried to use the terms or phrases used by the architects, or vice versa ... It became clear very quickly that understanding the language and terminology used was to play a very large part in the success of any co-rational design work." (Engineering Student 01)

The architecture students quickly settled into the familiar studio process, hopping from idea to idea. And, it was interesting to hear the engineers' perplexity emerge when, in the second week, they declared they believed the experience revealed that they had not previously been taught design at such an early stage in a project.

"As engineering students we have been taught to keep our designs as simple as possible, and most of the time that means designing square structures. While they may be easier for an engineer to design, they are not as aesthetically pleasing as the more complex structures." (Engineering Student 02)

The second project aimed to capitalize on the students' first experiences, directing them to focus on one particular strategy for an extended period. At this point, they expanded the tool set to include a mathematical visualization program. We had observed the students discussing the potential of mathematics as a point of departure. They embraced a program with the following features; it had an existing library of mathematical objects, it could offer a process to customize equations and edit the controlling parameters of the resultant surfaces, and it could export the geometry.

Figure 1 illustrates one outcome, entitled the Hybrid Cathedral where mathematical surfaces were used to
generate a shell structure which delineated the building’s two functions: cathedral and multi level apartments.

The disparity between approaches in software became apparent during the second project. With a longer period to investigate, the students began developing their work in their software of choice, using discipline targeted programs with which they were familiar. Transferring files became an issue, as did the restrictive nature of engineering software which, in imposing boundaries to manage the serious potential legal liabilities of structural design, discourages speculation, in contrast to the laissez faire push and pull of architectural software. The locations of computer laboratories with specialist software also failed to support the partners working in close proximity, and the students noted, or rather complained, that this was the major consideration limiting their ability to work together in a synchronous manner.

At the end of the second project one student reflected,

"I realised that I don’t understand what the architectural supervisors expect from me as an engineer. After presenting several structural schemes from Space Gass for project two I was told that they were too detailed for these projects. To me, this is conceptual design because

\[ x(u,v) = cn(v) + (u) \\
\[ y(u,v) = sn(u) - v \\
\[ z(u,v) = cn(u) \cosh(v) \]

Figure 1. An equation combining the Jacobi elliptic function and the hyperbolic cosine function was harnessed in the creation of a shell structure and arbitrating surface for the ‘Hybrid cathedral’. The surface mediates between two divergent programs.
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otherwise I can have little input into the design process apart from commenting structurally on the form. Therefore, my ownership of the design is minimal in comparison to the architect who will actually develop the form. This would be the first time in the project that I have started to question what co-rational design really is. The further that I get through the project, the more I think that in reality it is very difficult to develop or even define a formal co-rational design approach.” (Engineering Student 02)

The third project aimed to extend the second by introducing a new starting point through the context of the siting and location of built form. We proposed the students investigate a bridge—another metaphor—by investigating and eliciting mathematical parameters which could then be transferred into design schemas for the project.

The students were discouraged in this project from resorting to discipline specific tools, and encouraged to address communication issues even if they believed some ideas may only come to fruition at a later stage in the project. Students worked to identify project parameters of both structural and architectural interest and then authored the coding of an equation that would satisfy both disciplines and the programme at hand. At one point this approach necessitated their decampment to a mathematics department to give further functionality to their equation.

A number of mathematical parameters were developed in the equation for the bridge including those to control the curve of the bridge, the number and height of its piers, the width and length

![Diagram](image_url)

**Arching Gird Bridge Iteration - bottom chord Formula**

\[
\begin{align*}
\delta x(i) &= 20x(i) \cdot (0.275) + 0.75x(i) \\
\delta y(i) &= 20x(i)
\end{align*}
\]

![Diagram](image_url)

**Arching Gird Bridge Iteration**

The depth of the box beam increases where it is necessary

**Cantilever Bridge Iteration - bottom chord Formula**

\[
\begin{align*}
\delta x(i) &= 20x(i) \cdot (0.275) + 0.75x(i) \\
\delta y(i) &= 20x(i)
\end{align*}
\]

![Diagram](image_url)

**Cantilever Bridge Iteration**

Figure 2. A schema for an inhabitable bridge. Mathematical parameters were identified to control the structure and multiple structural iterations were produced for the main span.
of the road. Figure 2 shows the structural variables the students agreed upon for form manipulation of the main span between an arch and a cantilever, and Figure 3 shows alternative iterations of the bridge illustrating the power of the parameters in the mathematical equation to rapidly respond to changes in the brief. In this case, the students formed an iterative process between the architect and engineer through a set of skills they developed together and through the use of a project language, the mathematical parameters, for both the structure and form.

Figure 3. Iterations of the form through the manipulation of parameters.

Figure 4. A view of the bridge showing a cantilevered section designed to span a shipping channel.
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Discussion

Mapping relationships

During our interdisciplinary studios students are encouraged to take a critical position both to understand their relationships in class as well as to perceive the differences between their undertakings and to project these experiences to potential professional relationships. The engineering students were contributing in this regard via their journals, and during the projects the architecture students were asked to make maps of the relationship and workflow as they discerned it. In this research, formal design frameworks to suggest ways of working were not presented to the students. Steele et al. (1999) suggest that predefined mapping encourages participants' adherence to a method during conceptual design without demonstrable benefit. The students in ReEngineering were also asked to identify the software they were using at the time.

Figures 5 and 6 show one mapped relationship between an architect and engineer during the second and third projects respectively. Observe that the nature of the interaction changes from one project to the next. Through the second project the architect and the engineer worked in a close coupled manner only for a relatively short period, first discussing the forms that had been generated by the architect and later alongside one another using separate software.

At the end of the third project, when the working relationships had had time to develop, the architect and engineer students performed a context analysis of the site together. From this they formed a schema with mathematical parameters. They sought help from a mathematician with parametizing the surface equations to conform to this schema. Then an iterative process between the architect and engineer began—not being identified with either discipline—where they both took ownership of the equation and were able to manipulate its form and outcomes beyond mere parameter values. Evident in these students' work, as Kvan has suggested, is "collaborative design consisting of parallel expert actions, each of short duration, bracketed by joint activity of negotiation and evaluation." (Kvan 2000)

![Diagram of architectural mapping](image)

Figure 5. Mapping the relationship between architect and engineer during second project.
Future work

Education across disciplines requires direction from each discipline involved and this seems inevitably to multiply the workload of studio directors. Accordingly, the differing expectations from each student's backgrounds must also be managed.

We found that by the final years of a student's program of study disciplinary structures and attitudes were well formed. This developed in the absence of any interaction between the student populations during their entire undergraduate studies, through instruction in their respective disciplines, and during any work placement that had been undertaken. This research studio served to engender a sense of understanding between the students, a respect for each other's creativity and a willingness to work together.

In this case a strategy to encourage students to work with tools that were not discipline specific (the mathematical software) finally served to frustrate a divergence and retreat to either discipline during conceptual design. The ReEngineering studio provided an interesting insight into the potential for the use of mathematical expression as a design support for schema generation for both engineers and architects working in co-rational collaboration. It would be relatively simple to transfer a schema such as the one we have shown for further development in the design process.

We have begun to develop our support tools for charting and mapping the social structures that evolve during a project. We are working on a graphical view of a wiki so that we can observe in real-time the links, via wiki-words (the project language), as they are created. This has yielded some interesting preliminary results including views of extraordinary activity interspersed with areas of relative isolation. A further wiki development project separates the online chatting from the page structure to a discussion list on each page.

One successful outcome from the ReEngineering studio has been that the School of Civil and Chemical Engineering has invited students of architecture to join a core engineering subject—High-rise and Long-span structures.

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