

AN INVESTIGATION OF STRUCTURAL ENGINEER-ARCHITECT COLLABORATION

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ABSTRACT

The importance of collaboration between structural engineers and architects has long been recognized. Collaboration leads to buildings possessing good seismic configuration and structure and architecture being well-integrated. However, sometimes relationships between these two professional groups are strained. Anecdotes of poor collaboration are recounted when individual architects and engineers are prompted.

A survey of practicing engineers and architects was undertaken in Wellington. Individual practitioners were interviewed to explore the quality of their inter-disciplinary relationships and their perceptions of their professional collaborators. Findings indicate that while there is little if any antagonism, and indeed an overall culture of respect between professions, there is plenty of room for improving the quality of collaboration. Structural engineers' main concerns focus upon the following: architects' lack of structural understanding; architects seeking structural advice too late for optimal structural solutions, and the need for architects in general to improve their focus upon collaboration. On the other hand architects are disappointed by engineers' lack of both innovation and engagement with architectural design ideas. The paper concludes by discussing a range of approaches to engender better collaboration, stimulated in part by comments from a subsequent and less formal survey of practitioners.

1.0 INTRODUCTION

Given the different aptitudes and roles of engineers and architects it is not surprising that successful collaboration is a challenge. Tensions between the professions of engineering and architecture take root even before tertiary education. During secondary education students tend to choose between the arts or sciences and may bring preconceptions regarding the two professions with them to university. Stansfield (2003) notes that 'the idea that first year engineering students must be able to record structures by sketching and drawing has yielded such misconceptions as "sketching is for architects".'

Salvadori (1991), a Professor of Civil Engineering, notes how in his experience engineering students are so different from architectural students. He describes engineering students as 'not ambitious enough to aspire to scientists: they are willing to accept the dictates of science and apply them to the practical problems of our culture.' He states that they 'do not develop much of a critical mind' and 'are socially and politically conservative.' In contrast, he considers architecture students 'open-minded, adventurous, critical, curious, and independent.' He believes they are 'interested less in the practicalities of life and more in the infinitely varied and complex problems of their society ... and more gregarious and eager to understand their

fellow human beings.' Although these generalisations are one person's views of student life about twenty years ago there still appear to be some elements of truth.

Tertiary education provides limited preparation for young professionals to learn how to collaborate across disciplines. While architecture students are usually exposed to at least one structural engineer, collaboration is not explicitly emphasised within their curricula (my experience suggests that architecture students are better than most disciplines at collaborating within the design studio). Civil engineering students have minimal if any exposure to architects and architecture.

1.1 Different modes of thought

One of the biggest challenges to collaboration, yet potentially one of its greatest strengths, lies in the different modes of thought that engineers and architects possess. Members of each discipline tend to have different perceptions of the same reality. Peters (1991) generalizes how engineers use the notion of mathematics and translate what they see into an abstract model or diagram. In contrast, architects use a visual language and look for logic in a visual pattern. He believes engineers use a vertically stacked analytical or hierarchical system whereas architects use a lateral system which is non-categorical. The

PAPER CLASS & TYPE: GENERAL . REFEREED

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hierarchical system used by the engineers allows for the systematic derivation of an answer. In contrast the non-hierarchical system of architects' thought processes allows for infinite possibilities.

Pfammatter (2000) touches upon another difference between the professionals: 'For an engineer, most design effort involves analysis. For an architect, design is the process of synthesis.' The harnessing and integration of these two opposing approaches is the aim of collaboration and the source of its value.

Some architects feel strongly the effects that these different modes of thinking have on their architectural aspirations. Felix Candela, the Mexican engineer famous for his innovative concrete shell structures comments: 'The second design phase...consists of a tremendous battle between the structural engineer and the architect... The result of the struggle is always the same: science prevails and the final design has generally lost the eventual charm and finesse of detail dreamed by the architect.' (Holgate, 1986). Jørn Utzon would probably use similar words reflecting upon his experience of attempting to realize his design of the thin concrete shell roofs for the Sydney Opera House that eventually had to be completely reconfigured structurally. The reality is though that architects' dreams ultimately do have to accept the laws of physics and the analytical engineering skills available at a given time in history. (I reject this dichotomy and especially putting these words into Utzon's mouth when, as I understand it, it was the inability of engineering to analyse shell structures, though their stability was self evident, that caused problems).

1.2 Timing of engineering involvement

At the early stages of designs, architects require design flexibility and freedom. That is why they are concerned that if a structural engineer is involved too early, he or she can prematurely stifle their design explorations. Architect Arthur Erickson states: 'Structure is the strongest and most powerful element of form, so much so that if it is not the last consideration in the long series of decisions determining form, it distorts or modifies all other determinants of a building. One finds in fact, that the structure has dictated all the other aspects of the design. The inhabitants should not behave as the columns dictate—the contrary should surely be the case... As with all my buildings the structure was not even considered until the main premises of the design – the shape of the spaces and the form of the building had been determined. Thus, the structure did not preclude but followed the design intent.' (Suckle, 1980). It is worth noting that although Erickson says he postpones structural decisions until after the early design stages, his architecture is notable for its rational and clearly expressed structure. His buildings lack any evidence of conceptual structural design decisions being left too late in the design process resulting in structure poorly integrated with building function and aesthetics. Perhaps he has a particularly well-developed intuitive grasp of structural concepts and requirements.

In contrast, Schlaich (1991), a leading European engineer argues for earlier engineer involvement, before the architect constrains the design: 'Good solutions will emerge if both professionals know their job, share the same goals, respect each other, and, most importantly, if the involvement of the engineer starts early in the architect's programmatic and conceptual phase. The architect will not get the best results by demanding a structure from the engineer under already fixed and constraining boundary conditions.'

In summary, architects want the freedom to explore their designs and involve the engineer when they have settled on a design. Conversely, the engineer wants to be involved before major architectural decisions have been made. Only then can he or she pre-empt decisions that might irreparably affect structural options and lead to an inferior option in terms of cost and quality of structure-architecture integration. These two positions on the timing of structural engineering advice appear irreconcilable. Clearly, the timing of structural input has to be a personal decision each architect makes. The initial period in the architectural development of a project is delicate and sensitive to disruption by over-bearing engineering advice. Exemplary collaboration requires the meeting of the minds of experienced professionals who possess high levels of technical and design skills and with well-developed personal qualities and communication skills. Engineers need to steer a path that is respectful of architects' need to explore alternatives and realize their design aspirations, yet provide guidance on what is technically feasible and appropriate.

2.0 PRIMARY SURVEY

The primary survey was conducted in Wellington during May 2004. Fourth-year architecture students administered the questionnaires. Each student interviewed an architect and an engineer in person. Students selected whom to interview from comprehensive lists of Wellington structural engineers and architects. Thirty-five structural engineers from approximately 160 Wellington members of the Structural Engineering Society New Zealand Inc. were interviewed. Thirty-nine architects from approximately 400 Wellington-based members of the New Zealand Institute of Architects participated. A copy of one of the questionnaires is provided in Appendix A.

2.1 Responses from structural engineers

The first four questions elicited information about the engineers' professional experience and the type of work they were involved in:

- On average, each structural engineer has been practicing for 18 years. Fifty-five percent of the engineers have spent more than 10 years in practice.
- Over the past twelve months 89% of their time has been spent on buildings less than or equal to eight-storeys high. Eighty-nine percent of their workload consisted of non-residential buildings.

- On average each engineer has worked with 16 architects. Forty-four percent of the engineers estimate they have worked with more than 21 architects.
- The engineers estimate they spend 30% of their time on conceptual design, 50% on developed design and 20% on construction observation.

These results indicate that this sample of engineers is relatively experienced. As a group they have had considerable professional experience during which they have worked with numerous architects.

The next group of questions explored engineers' perceptions and experience of working with architects. The engineers rated the statements in Table 1 according to how strongly they agreed with them.

Apart from the less than enthusiastic response to the first statement, responses to the remaining statements are relatively consistent. The engineers rated these statements rather more positively than "moderately true", which although a positive

response indicates that they perceive significant room for improvement in these areas.

The interview concluded with a final group of four open-ended questions. The technique of assessing the responses which allowed multiple responses to each question, was to note each response and to report on those most prevalent.

To the first question "What do you perceive to be the weaknesses in architects' structural approaches or knowledge?" Fifty-four percent of the responses mentioned a lack of structural understanding while 15% raised the issue of the late involvement of engineers in design projects.

The engineers' responses to another question regarding the structural education of architects are summarised in Table 2.

The results of Table 2 indicate that structural engineers are somewhat divided on the issue of the structural education of architects. Although almost a majority of responses indicates architect's structural education is adequate, a desire for improved conceptual understanding also comes through clearly.

Table 1. Structural engineers' responses to statements about architects

Statement	Average response out of a maximum score of 9 points. (1 point for 'Not at all true', 5 for 'Moderately true' and 9 for 'Definitely true')
Architects have an adequate understanding of structural behaviour.	5.2
Architects seek structural advice before they have tried to finalise the structural configuration of a building.	6
Architects are generally receptive to structural requirements.	6.5
Architects appreciate the general structural requirements of seismic design	6
Architects are aware of architectural implications of seismic design, such as separations of buildings from boundaries and separations of non-structural elements like partition walls etc.	6

Table 2. Engineers' perceptions of the structural education of architects

Responses	Percentage of responses (%)
Architects have an adequate structural understanding	43
Architects need better a conceptual understanding of structures	32
More emphasis needed upon the importance of collaboration	10
Architects' structural education should emphasise basic concepts	10

When invited to suggest what messages, if any, they as structural engineers would like architects to hear, 35% said architects should consult structural engineers earlier, 16 % requested that architects' structural understanding be improved, and a final 10% suggested that architects could collaborate better.

No significant themes arose from the final question which invited structural engineers to make any concluding remarks.

2.2 Responses from architects

As with the structural engineers' questionnaire, the first few questions for architects investigated their experience and type of work:

- On average each architect has been practicing for 18 years. Sixty-nine percent have had more than 10 years in practice.
- Over the past twelve months 95% of their time has been spent on buildings less than or equal to eight-storeys high. Fifty percent of their workload has consisted of residential buildings.
- On average, each architect has worked with 10 structural engineers. Ten percent of the architects have worked with more than 21 structural engineers.
- The architects estimate they spend 30% of their time on conceptual design, 50% on developed design and 20% on observation.
- The architects surveyed have an equally high degree of experience as the structural engineers. On average, architects spend far more time on residential scale projects (50%) as compared to the structural engineers (11%).

The architects' perceptions and experience of structural engineers are summarised in Table 3.

These responses indicate that architects view structural engineers' contributions to design projects positively. Architects certainly believe that the existing levels of collaboration with engineers are more than satisfactory. Architects are positive about structural engineers' appreciation of design ideas and requirements and how they communicate structural requirements. The architects also agreed, albeit with some reservation, on the importance of early structural engineering input into design projects.

In the first of the final group of four open-ended questions, the architects were asked what they perceived to be the weaknesses in structural engineers' approaches or knowledge? This invitation to be critical resulted in 33% of the total responses noting engineers' lack of innovative and lateral thinking; 27% stated that structural engineers lack appreciation of architectural design intent, and 10% said that engineers are too conservative in sizing members. Typical comments regarding engineers' lack of innovation included:

- "Apply lateral thinking",
- "Develop creative options", and
- "There can be more than one solution to a structural problem".

Typical comments about engineers lacking appreciation of architectural design intent included:

- "The engineer should come up with a solution that enhances or follows design",
- "Lack of appreciation of architecture. Narrow focus", and
- "Think about the architectural solution".

Table 3. Architects' responses to statements about structural engineers

Statement	Response out of a maximum score of 9 points (1 for 'Not at all true', 5 for 'Moderately true' and 9 for 'Definitely true')
Structural engineers and I collaborate well together	7.6
Structural engineers produce structural solutions in keeping with my design ideas	6.8
Structural engineers generally appreciate architectural requirements	6.8
Structural engineers communicate structural requirements clearly	6.7
The most critical phase of structural engineers' input into a design is during the preliminary design phase when structural layout or configuration is finalised.	6.9

When responding to the next question where the architects were invited to give messages they would like structural engineers to hear, a resounding 42% of the responses were a plea for greater innovation. Also, fifteen percent expressed a desire that engineers be more aware of design concepts and 10% requested that engineers be involved earlier in projects.

The responses to these first two open-ended questions consistently identify architects' perception of engineers' lack of innovation and engagement with architectural design concepts.

In response to a question about architects' own structural engineering education, 43% believe that they had an adequate or better structural education. Thirty-five percent believe theirs' was too technical or theoretical while 10% commented on how they had primarily learnt about structure as they practiced architecture.

In the concluding question, the architects were asked if they had any final comments. Twenty-four percent of the responses stated that collaboration is very important and another 24% affirmed structural engineers as being valuable design team members.

3.0 SECOND SURVEY

Subsequent to the primary survey in 2004, a presentation of its findings was made in November 2007 to Wellington architects and structural engineers. Approximately 10 architects and 25 structural engineers attended a well-advertised function. After the presentation and a brief discussion of ways to improve collaboration between the professions the attendees were invited to make written comments under three headings:

- Suggestions for improving perceived deficiencies in my profession,
- Suggestions for improving collaboration between our disciplines, and
- Final comments.

Although only seven engineers and four architects responded to this invitation some of their comments point to possible ways forward.

Three themes emerged from the engineers' comments. Firstly, they expressed a desire to be more fully briefed by the architect as to his or her design intent or design concept. Secondly, they suggested that collaboration would improve with more inter-professional activities. At an individual level this could take the form of an individual engineer reading architectural books and journals or attending architects' conferences. At a communal level, some joint professional meetings could be held, perhaps consisting of case-study presentations with collaboration being on the agenda. Finally, it was suggested that structural engineers should learn more about architecture at university. Chrisp (2003) describes such a programme to increase architectural awareness.

Very similar themes emerged from the architects' comments. They realised the need to more fully explain their design concepts to engineers. They also noted the value of inter-professional activities like meetings or conferences and thought that architectural students would benefit from more interaction with structural engineers during their university training.

4.0 DISCUSSION

The findings of the primary survey show that each profession has a generally positive respect for the other even though some mutual criticism emerged. Architects are positive about the role engineers play in the design process although they are frustrated with what they perceive as engineers' lack of innovation and awareness of architectural issues. The engineers believe architects are both weak in terms of their lack of structural understanding and seek engineering advice too late in a project. In spite of the perceived weaknesses of each discipline the underlying positive attitudes can be built upon in order to improve the quality of collaboration, but both disciplines need to engage in some self-reflection.

4.1 Ways forward for engineers

Engineers need to identify and reflect on any barriers to their innovation. If, as noted in the introduction to this paper, lack of innovation originates from the type of person commencing an engineering education and subsequently reinforced by the narrow and detailed technical training received, what can be done about it? Although no more than a mention was made by participants about how architects commission structural engineers and how professional fee levels and structures might detract from collaboration, perhaps this aspect needs consideration? Is the relatively late involvement of engineers in some projects the reason for a perceived lack of innovative solutions? Engineers certainly need to take a more proactive approach in enquiring about the architectural aspirations of a given project before immersing themselves in calculations. Perhaps the client will be prepared to pay extra for a more interesting non-standard structural solution? These are some of the questions to be addressed.

There are several ways engineers can increase their sensitivity to architectural concepts and ideas and therefore will be less likely to just offer standard solutions. Firstly, engineers should spend more time discussing the architects' aspirations with them as mentioned above, and secondly they could read more widely. Apart from architectural journals, two books on the relationship of structure to architecture are helpful (Balmond, 2002 and Charleson, 2005). Reading such material can be rightfully considered a CPD activity. Engineers should also consider attending meetings or conferences where architectural issues are discussed.

4.2 Ways forward for architects

Architects can improve their structural understanding by availing themselves of their CPD programme offerings. For

example, The New Zealand Society for Earthquake Engineering offer CPD points for studying a publication on the seismic design of non-structural elements (Massey, 2007) and this opportunity will be extended when a new publication is added to this programme (Charleson, 2008).

Architects need to consider what contractual steps they can take regarding their commissioning of structural engineers to facilitate earlier structural engineering involvement. Perhaps they also need to reconsider their initial or feasibility design process so it can benefit more significantly from timely engineering advice?

Another way for architects to improve collaboration is for them to always explain their design aspirations and concepts to structural engineers at the commencement of design projects. Unfortunately, architects are infrequently attracted into attending typical structural engineering meetings and conferences due to their typically highly technical nature.

The engineers, and to a lesser extent the architects themselves, are concerned about the extent and quality of architects' structural education. Improvements in its coverage and delivery within the schools of architecture certainly deserve attention. Although New Zealand schools, in a positive move, shy away from calculation-intensive approaches, the numbers of lectures on structural topics are being eroded away. Too much faith is placed in teaching structural concepts in design studio environments.

4.3 Ways forward for both professions acting together

Structural groups and NZIA local branches should consider organising a minimum of one combined meeting annually where collaboration issues are discussed in joint presentations. Perhaps several case-studies could be presented with a focus on collaboration.

If the Structural Engineering Society New Zealand Inc. considers there is a need to add or strengthen architectural content in the structural engineering curriculum it should make submissions to the relevant tertiary institutions. Similarly, if the NZIA sees the importance of providing architectural students with some explicit experience of or teaching about collaboration it could enter into dialogue with schools of architecture.

5.0 CONCLUSIONS

After a brief and general exploration of some of the differences between engineers and architects the results of a survey of Wellington structural engineers and architects are presented. They indicate that an underlying positive attitude exists between the professions. However there are areas where each profession is critical of the other. Structural engineers are critical of architects' lack of structural understanding, their seeking structural advice too late for optimal structural solutions, and

request that architects in general improve their standards of collaboration. Architects are disappointed by engineers' lack of innovation and poor engagement with architectural design ideas. The paper suggests how each of these perceptions might be dealt with on individual and organisational levels to improve engineer-architect collaboration.

6.0 ACKNOWLEDGEMENTS

Morten Gjerde and Geoff Thomas are thanked for their comments.

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APPENDIX A

QUESTIONNAIRE FOR ARCHITECTS ON RELATIONSHIPS BETWEEN ARCHITECTS
AND STRUCTURAL ENGINEERS

Information notes

1. This questionnaire has two purposes. First, it provides Fourth Year Architectural Students an opportunity to learn about the relationship between the professions as part of their Arch 451 Structures course. Secondly, results from the questionnaire will be used by the lecturer responsible to produce a report to the professions on the relationships between architects and engineers. The report will take the form of a journal article or a conference paper.
2. The questionnaire is anonymous and the forms, which can not be traced back to you, will be destroyed after the research is completed.
3. If you have any questions or further comments please contact Andrew Charleson, School of Architecture, Victoria University of Wellington, P O Box 600, Wellington, ph. 463 6222 or Andrew.charleson@vuw.ac.nz.

1. How many years have you been practising architecture since graduation? ... years.

2. Over the last twelve months, approximately what percentage of your time have you spent on the following construction types?

Low-rise (<= 4 storeys)	...
Medium-rise (<=8 storeys)	...
High-rise (> 8 storeys)	...
Total	100%

3. Over the past twelve months, what types of buildings have you been involved with?

Housing	...
Commercial	...
Industrial	...
Public	...
Educational	...
Other
Total	100%

4. Approximately how many structural engineers have you worked with since graduation?
(tick box) 1-5 , 6-10 , 11-20 , over 21 .

5. What percentage of your time spent working with structural engineers is spent on the following stages of construction?

Feasibility/concept	...
Detailed design	...
Supervision/observation	...
Total	100%

Based on the scale below please answer the following questions:

1 2 3 4 5 6 7 8 9
Not at all true Moderately true Definitely true

6. Structural engineers (SEs) and I collaborate well together 1 2 3 4 5 6 7 8 9

7. SEs produce structural solutions in keeping with my design ideas 1 2 3 4 5 6 7 8 9

8. SEs generally appreciate architectural requirements 1 2 3 4 5 6 7 8 9

9. SEs communicate structural requirements clearly 1 2 3 4 5 6 7 8 9

10. The most critical phase of SEs input into a design is during the preliminary design phase when structural layout or configuration is finalised. 1 2 3 4 5 6 7 8 9

11. What do you perceive to be the weaknesses in SEs' approaches or knowledge?
.....

12. What messages, if any, would you as an architect like structural engineers to hear?
.....

13. Do you have any comments regarding your own structural engineering education?
.....

14. Any final comments?
.....

Thank you for your time in completing this questionnaire.