# *Teaching Lightweight Structures*

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## INTRODUCTION.

The use of lightweight structures by human kind pre–dates history. The ease of construction of found materials of timber and grasses could be quickly fabricated into shelters and structures with the minimum of conversion, unlike their counterparts, stone and mud which require hewing and moulding to provide a useable structure. The exquisite material nature of the lightweight dwellings using these systems is seen in many parts of the world from the east in Japan, South East Asia and American (Hyde R.A. and Lucky D.,1996 forthcoming). The development of these indigenous building techniques seems to come from a tradition of building based on thousands of years of unconscious research and development. The basis of this tradition lies both in nature and in the spirit of human invention and innovation. It provides the foundation for future development of these types of systems and our methods of understanding and teaching methods. The purpose of this paper is describe broadly the architectural aspects of these systems and expore issues that have arisen in teaching this area of architectural design.

This will include first the broad intrinsic characteristics of lightweight structures that are of interest to architectural designers and some of the problems faced by architects using these systems in design.

Second, the intrinsic nature of lightweight systems has led to the development of specific teaching initiatives for architectural students in the design and use of tension structures. Moreover, these initiatives have focussed on the formation of student architects and engineers into teams to solve problems. These teaching initiatives have led to a wider reflection of architectural theory and practice of architecture. Some of the issues arising from this reflection have led to a fundamental re–evaluation of architectural tectonics and open up the area of professional relationships between architects and engineers as an area of concern.

The third area of the paper outlines these issues and some steps taken to address the problems encountered.

Finally the present direction of teaching is placed in the changing education context. It is argued this change could provide the framework for more effective and relevant teaching of students provided it has a sound educational basis.

## CHARACTERISTICS OF LIGHTWEIGHT MATERIALS AND STRUCTURAL SYSTEMS.

The aspects of lightweight materials and structures that are of interest to architects are many. It is beyond the scope of this paper to innumerate all, it is perhaps sufficient to select a few that are relevant to the local context and provide the background to teaching in the area of lightweight systems.

### *MATERIALS TYPES*

Materials that are considered lightweight are those of relatively low mass although this definition is not mutually exclusive since many high density materials can be manufactured into lightweight components. Indeed with the advent of mechanical lifting devices, what constitutes lightweight is clearly difficult to define since reinforced concrete panels upto 20–30 tonnes can be prefabricated and lifted into place. Convention seems to be that materials such as steel, timber and fabrics form the primary lightweight materials with components of allied composite materials such as fibre cement and laminated glass also considered.

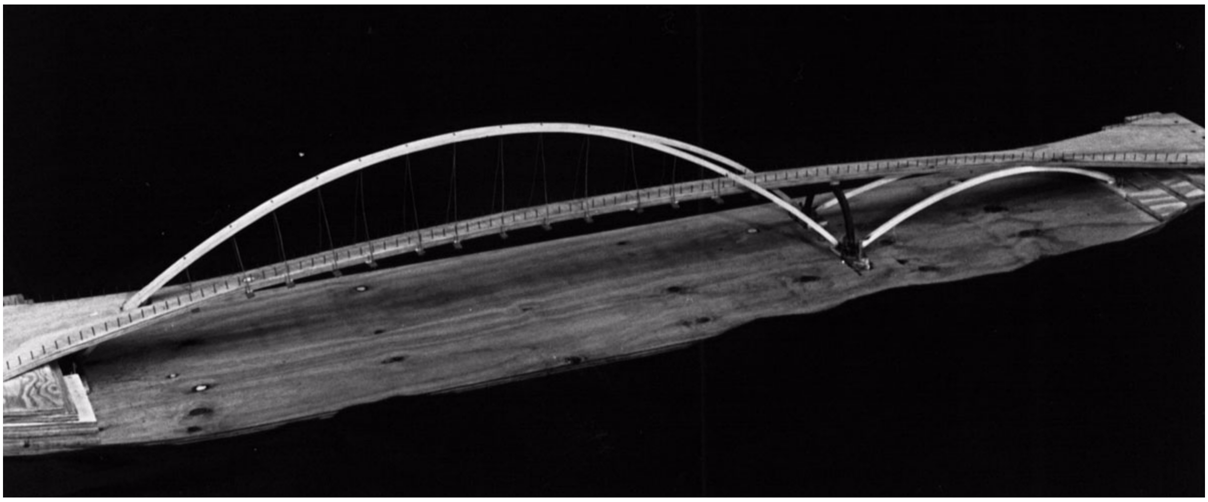

**Figure 1 – Simone de Sousa Roque, Shane Ince, David Kane and Chris Melville**



The potential for these materials in Queensland is important– the nature and diversity of climate, topography, low population density and lifestyle seem to provide considerable opportunities for the use of these materials. In particular the use of steel, timber, fabrics and fibre cement are assisting in the development of alternatives to the notions of dwelling and indeed the form of a contemporary Queensland House. In early years the dominancy of the Queenslander, the colonial bungalow, an imported concept, gave way to the ubiquitous slab on ground brick veneer home from the south. A number of Queensland architects and engineers have examined alternatives to these approaches principally using lightweight materials. Illustrative of this is the work of Gabriel Pool with his famous Quadrapod and ”tent house” which use steel and tensile fabrics. Also Lindsay Clare with his Buderim House, made of timber and fibre cement; elevating the status of these materials with a climatically approriate building. Further more research work at the Department of Architecture, the University of Queensland, into portal frame timber houses using new engineered timber products has led to the development of environmetally oriented buildings. (Hyde R.A 1995, Skinner, P., 1996 and Mc Bryde, K. 1995).

Closer analysis of these buildings reveals not so much a standard house form as with the brick veneer home or the Queenslander but a set of ideas about using lightweight materials which respond to the needs of users, site and climate. It is the flexibility and diversity in design that gives this approach its capacity to provide appropriate architectural and environmental solutions as well as spur innovation in structural and building form.

*STRUCTURAL SYSTEMS AND ARCHITECTURAL FORM.*

The opportunities for incorporating lightweight materials to form structural systems and innovative forms is witnessed by the proliferation of these systems worldwide and in Queensland. Two particular issues seem apparent from examination of these structural systems, first the need for approriate technical synthesis and second formal synthesis.

With formal synthesis, this centres primarilty on the design approach used. Particular problems seem to exist where tension structures are required to intergate with conventional building forms. The standard orthagonal geometry of these forms seem to conflict with shape vocabularies offered by membranes. Tension structures seem to be succesful as stand–alone buildings where the structural form plays a simple utilitatian function (Hong Kong Avery) or has deeper cultural and meterphorical meaning (Haj Terminal, King Abdulaziz Internationla Airport, Jedhah deigned by Skidmore Owens and Merrill).

Technical synthesis becomes a major issue in complex buildings were services, lighting and structure require an intergrated approach. Successful solutions seem to require a transformation of the structural types underlying the lightweight systems to make them place specific. The Menil Gallery by Renzo Piano is a useful example, where enclosure, lighting, services and structure are meshed requiring a transformation of the space frame system.

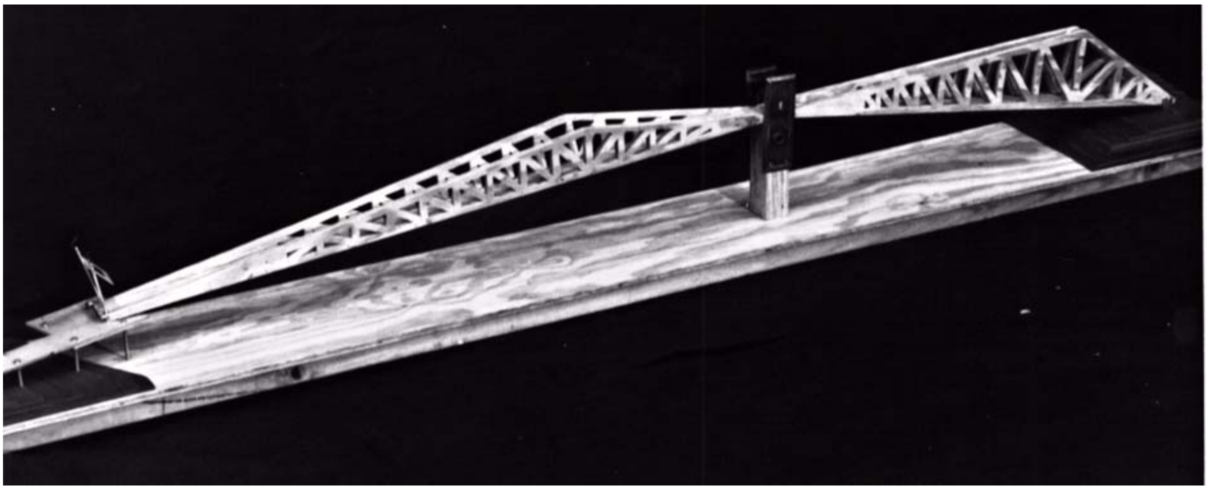

**Figure 2 – Robin Hewitt, Stephanie Lee, Vivienne Duffy and Amanda Ament**

Examples found in Brisbane include the Convention Centre – the roof form derived from hypar geometry to give a unique form.

Finally perhaps the potential for these kind of lightweight systems lies less in the formal geometry that they provide, the cones, hyperbolic and free form vocabularies. The lightness and transparency of the materials seem to give a unique experiential quality due to the facility of these materials to manipulate light. The Imagination Headquarters by Herron Associates is a useful case. The membranes are used to give enclosure between two existing buildings creating a new and dynamic atrium space. The use of tensegrity principles by Burro Happold mean that the high tensile forces are resolved with the atrium roof and not transferred to the existing buildings. The lightness of structure contributes to the play of light both during the day and enables successful artifical lighting at night.

Overall therefore the key issues of the nature of shape vocabularies offered by lightweight systems, the need for technical synthesis, and the experiential qualities provided by these materials and systems, form key points of departure for many of the teaching methodology and educational exercises described further in the paper.

## TEACHING METHODOLOGY

### *KINAESTHETIC LEARNING.*

Kinaesthetic learning is derived from Dewy's education theory of "learning by doing". The principle argument behind his work was that the concretisation of knowledge is achieved best through the physical involvement in the use of knowledge (Hyde R.A 1982). In the applied subjects such as architecture, in particular in the technology area, this translates into a teaching philosophy of learning through building. Underpinning this is the axiom that students learn best by manipulation materials and building systems in a creative and purposeful way. This provides a kinaesthetic understanding where the relationship of individual perception and handling of materials combine to provide meaningful and indeed a memorable experiential learning environment.

This approach was taken with a number of projects at fourth year level based on the use of timber materials to provide alternative framing systems for housing. Half full size models of bays of the framing system proposed were built by teams of students to test ideas concerning buildability, jointing and structural stability. These projects complemented research work in the department and was augmented by representatives from the timber industry who provided materials and expertise. Lightweight materials such as timber are ideal for this type of teaching approach since they can easily be manipulated using hand–tools and do not require sophisticated jointing techniques.

The use of kinaesthetic learning in this way is not just limited to making large prototypes. The approach can also be used for exploring the design of membrane structural systems through model making.

**Figure 3 – John Larrazabel, Max Brewer, Andrew Leung, Eric Gubter, Michael Tuiloff**

*STRUCTURAL TYPOLOGY'S.*

The uses of structural typology's are particularly important in the teaching of tension structures. In a limited objective design exercise for fourth year student , the use of precedents as a way of understanding the typology has been achieved. The aims are four fold,

- To develop awareness of the precedents in the design of membrane structures.
- Gain experience in the analysis of precedents which relate to the structural typology of membrane structures.
- Develop experience in the various form finding techniques that are appropriate for developing conceptual ideas for design.
- Gain experience of the load implications and technical problems in resolving the detail design of tension structures.

Particular emphasis is placed on the idiosyncrasies of the design of membrane structures. It is stressed that the design of this type of a building defies the normal plan/ section mode of working because of the three dimensional nature of the structure and the way the structural action of the surface of the membrane acts to achieve structural stability. So, to design of this form of structure ,the need for stability and the need to achieve an appropriate form that meets the needs of the brief, have to be synthesised at the same time.

To satisfy these two, what are often thought, irreconcilable needs, a method of working has been devised that helps the designer come to some expeditious reconciliation of the stability, form, shape and need of the brief. The method of work will follow a conjectural and analysis procedure.

- First, experiments are carried out with some soap film models using wire and soaped water to develop an idea of the primary shape of the structure.

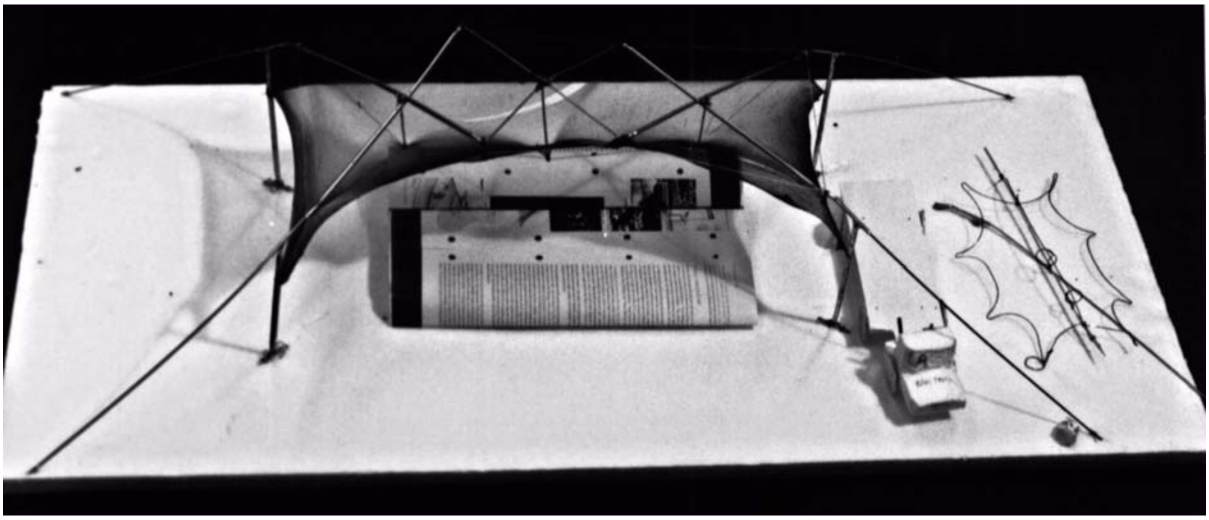

**Figure 4 – Chris Lee, Robyn Hewitt, Adrian Spence, Stephanie Lee**

- Second, another model that firms up intentions regarding supports and fabric is made. This is to scale and uses stretch fabric and Licra to simulate the fabric. Simulation of compression supports using timber dowels and cotton or twine for tension elements is carried out.
- On completion of the second model examine load path and restraints is made. Futher comparative analysis of the structure to the structural typology is used to establish which type it most closely related..
- Further focus is them placed on a particular precedent within the typology and use made of this as a guide to detailing joints and fixings.

The use of this approach has led to the development of a form finding method which allows students to work from design objectives to technical resolution in an effective process. It is clear at the relevant stages where deficiencies in both the desired form and structural stability are found.

*PROBLEM SOLVING.*

The use of simple tension structures exercise helps prepare students for more complex problem solving projects.

Efforts have been made to expand the professional integration aspects of the earlier hands–on courses. At fourth year students require some preparation for the professional involvement on graduation. In the technical area this usually means liaison with consultants– structural engineers, mechanical and electrical engineers and manufacturers. To make learning more relevant to future profession working practice attempts have been made to integrate these specialists in the program. The technical detailing area of facades is one area where this is most relevant. The use of lightweight facades in the form of curtain walls and suspended glazing systems presents a challenge to architects to resolve both design, climatic and technical factors in the resolution of a problem.

This exercise is called a Component Study. With the high levels of prefabrication of these types of system issues such as tolerance, clearance, dimensional coordination are examined amongst other factors as durability, structural integrity and assembly sequence

Again the students work out of a project that has been developed in the design studio. Students engage in research into the types of component and systems available that meet design needs. Consultants are invited to the studio to assist with the resolution of the study.

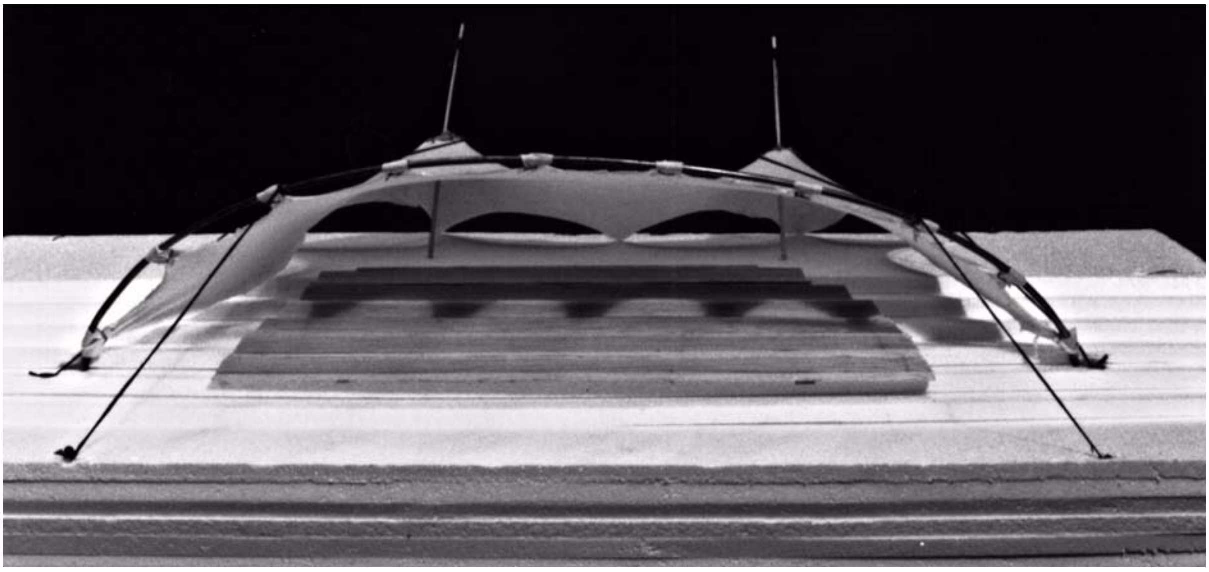

**Figure 5 – Jim Lau, Fred Hsu, Frankie Cheng and Jeff Hsung**

*ACTION LEARNING.*

This type of detailing study has been complemented by broader conceptually orientated projects of a structural nature. This type of project has been carried out in conjunction with fourth year students in the Department of Civil Engineering. It normally involves the design of a bridge or tower as part of work in the architectural design studio. A pilot project was run last year for a bridge design

The bridge project focussed on how structural forms integrate with the landscape. The proposed pedestrian bridge linking the University across the Brisbane River to the south was used. The brief was developed by the Properties and Facilities Department of The University of Queensland. The aims were as follows.

- To explore the relationship between human artefacts and the natural landscape.
- To establish sensible and sensitive aims regarding large scale interventions in the landscape.
- To establish a synergy of design and technical thinking to achieve these aims.
- Develop a cogent and supportable argument for the feasibility of the realisation of these aims.

Students worked in groups comprising civil engineering students and architectural students. A number of tasks were set to assist with resolution of the design and to test it structural integrity. To facilitate group work the tasks involved extensive use of graphic and modelling techniques as a way of externalising the design process to facilitate discussion. It also provided a means of testing the visual and structural integrity of the design.

The tasks used include site concepts, photomontage, conceptual model making, experimental model making and computer model making. The extensive use of model making

Implicit in this design work where architects and engineers work together essentially involves an action learning type process (Zuber–Skerritt 1992). Participants in the group have to plan, act and reflect on their actions. Although the project was well received, particular issues arose which seemed to suggest the different ”design cultures” of the two groups was preventing this kind of learning from being achieved. This generated particular pedagogic and theoretical issues which were investigated as part of an Action Learning Program with the Tertiary Education Institute this year.

## THEORETICAL DEVELOPMENT

*SYNERGY.*

One of the under estimated aspects the pilot program was the relationship between the working practice of architects and the engineering students. Educational principles were used in the develop of groups but this belied a fundamental problem of the significant differences in working practice. This was examined by investigation of the working practice of architectures and engineers, in particular that of outstanding engineers in the field. The rational used was that their model of practice may be exemplar and provide insight into the mechanics of best practice. As yet only one engineer has been examined, Peter Rice, famous for his work on the Sydney Opera House, Pompidou Centre and other large projects. It is clear from his work that he clearly defines the role of both architect and engineer separately,, the former being more conceptually ”creative”, the later being more conceptually ”inventive”. It appears also that this separation of roles in the process of design can result in the fracturing of the design process. It seems also that this process is not simply collaborative but more synergistic where there is a sharing of both structural and engineering conceptual ideas (Hyde. R. A. and Peel J. 1996 forth coming).

Interesting synergistic is a term which has several related meanings. It can be generally described as the combined effect of several agents working together in such a way that the result of their cooperation is greater than that which could be achieved by the individual parts. Another common usage of synergy is for medical phenomena, its definition being;

> ”A cooperative action of discrete agencies (as drugs or muscles) such that the total effect is greater than the sum of the two or more effects taken independently”[3]

More important, this word also has a theological definition which suggests that in regeneration of the soul there is *cooperation* of divine grace and human activity.

Synergy has therefore been used here to define an inter–disciplinary collaborative working method for the design of structures which involves some form of sharing in the conceptual framework of the design. The result is not just cumulative in relation to both technical and aesthetic concepts but transformational giving a dual or even multiple meanings to the structure of the building.

*STRUCTURAL DUALISM*

Attempts to define the nature of this dualism have been made. This dual meaning is perhaps best understood by the work of Sandaker and Eggen in their book ”The Structural Basis of Architecture”. They define structural dualism as the functions shared by structural elements. with regard to the technical and aesthetic aspects of the building. The first is generated by concepts in the body of knowledge concerning statics and the other in the area of visual aesthetics. Whilst the former is self explanatory, the second is more illusive. In this case it is suggested that the building structure acts also as a ”meaningful visual vehicle” which can become a ”convincing and

[3]”Webster’s Third New International Dictionary of the English Language”, P. Babcock Grove ed. in chief., C&G Merriam Company, Massachusetts, 1971.

recognisable medium for architectural expression" (Sandaker and Eggen 1992). The author has some reservations with this definition since many architects and indeed engineers do not necessarily use structure for expressive purposes. For example, compare the Eiffel tower to the Statue of Liberty (Salvadori. M.,1980). In the former a clear expressive role is found in the structure whilst the later is clearly not expressed. Yet it is important to recognise that in each case the structure still plays a crucial conceptual role in the "visual" aspects of the design of building.

The exploration of structural dualism is being carried out through the development of a data base called "Duality". This examines case studies of buildings which are exemplary in design both structurally and architecturally. Analysis of these projects will give insight into this area. Moreover it will be used as a teaching tool, students will be asked to examine precedents and enter their designs into the database as examples. In this way both architects and engineers can become more aquatinted with the different conceptual aspects of the respective professions. The data base becomes not a tool for integration of structure in the design process but a guidebook for exploration of the differences in the two fields. It is hoped that through greater understanding of these differences or the duality of the design arena will come a better working practice will emerge. A prototype of the data base has been developed as part of the Action Learning Project.

## FUTURE RESEARCH AND TEACHING CONTEXT

The themes from the first two parts of the argument can now be put into context. The opportunities provided by lightweight materials and systems are apparent particularly in Queensland. An indigenous culture that used and still uses a lightweight systems of building, A climate that is "beautiful one day perfect the next" provides a benevolence that can be exploited by lightweight materials. A distinct Queensland vernacular that is based on lightweight materials. It would seem that there is the basis here for a contemporary regional architecture. Cases point to considerable conceptual, formal and technical advantages of these systems to architects and engineers.

The effective teaching of these kind of systems to both architectural and engineering students has gone some way to embody this particular philosophy. Teaching methods that focus on kinaesthetic leaning, problem solving and action learning provide the basis for more meaningful and memorable experiences by students. The value of this experience is largely a measure of the future of the professions of both architecture and engineering. Hopefully it will enable them to leave our institution with skills in advance of practice as agents of change in our rapidly evolving State.

This kind of direction has provoked perhaps more questions than answers both in terms of the aesthetic place of structure in the design of buildings and the working practice of architects and engineers which at present seems to be particularly polarised. These issues will need to be resolved if progress is to be made in realising a regional architecture and indeed a cohesive industry. Further more this resolution is further necessary given the present pedagogic and structural changes proposed in education which seem to stress more interdisciplinary integration. At The University of Queensland the proposed integration of Architecture, Engineering and Planning into a super faculty, if initiated, will provide the academic foundation to this kind of direction.

The way forward is perhaps for architects to move from their more artistic base to a technical orientation in their course whilst engineers should move from the technical to the artistic. This is not to say that architects become engineers or visa versa. More that the design skills learnt prioritise a more holist resolution of building design problems. This is a "big ask" both groups will need to move out of the comfort zones of their professions and begin to engage in a broader discourse that forms out of mutual respect and understanding.

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