Enriching architecture courses with Engineering knowledge

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Structured abstract

BACKGROUND

Designing sustainable structures is a shared responsibility among architects, engineers, planners and contractors. While the process requires good communication between engineers and architects, professional bodies often identify this as an aspect that still needs improvement. A claim is often made that architecture students are not adequately equipped with the basic engineering knowledge, which enables them to be component and conversant in the technical jargon that engineers use. Therefore, to initiate such an improvement at the university level is relevant. Basic engineering knowledge includes, among others, being able to assess the structural, thermal and environmental aspects of a design from an engineering perspective. The course "Advanced Architecture Studio 2" is offered for the first time at Griffith University in Semester 2, 2013, and is designed to enhance engineering knowledge into the architectural program and exposes architecture students to principles of sustainable designs.

PURPOSE

Expose architecture students to basic engineering knowledge and enhance the students' multi-discipline competencies to prepare them for their future career.

APPROACH

This innovative approach were conducted during the first six weeks of the second semester of 2013 and involved postgraduate students from the architecture program (Griffith School of Environment), and three academic members from architecture, structural and environmental engineering. This course is convened and taught by the academic member in architecture, and was therefore architecturally orientated. Each academic member from engineering delivered a workshop on his area of expertise and assisted students in key points of their design. The workshops introduced students to the use of timber (to be used in the project) in structural designs and Life Cycle Analysis (LCA). Assessment focused on the process of incorporating sustainable design as an architect rather than engineering knowledge. After each workshop, students were surveyed to obtain feedback on (i) the effectiveness of the engineer in communicating his ideas to the architects, (ii) how to best communicate engineering principles to architects and (iii) if students thought that the ideas introduced were useful to their future profession as architects. Additionally, at the start and completion of the project, the revised two-factor study process questionnaire (R-SPQ_2F) (Biggs et. al. (2001)) mapped students' initial and change in approaches to learning, therefore quantifying if students engaged with the course.

RESULTS

At the end of the teaching period, architecture students acquired better understanding of engineering basic knowledge and engineering technical jargon, and were able to incorporate the skills learnt into their designs. Consequently, it is believed that students are now better equipped to communicate effectively with engineers.

CONCLUSIONS

Better communication between architects, civil and environmental engineers is essential to design sustainable structures. This innovative approach is designed to better prepare architects for their professional career through increasing their exposure to engineering principles, usually lacking in architecture programs. It is recommended that the course be offered by both the Griffith School of Environment (Architecture) and School of Engineering to expose engineering students to architectural principles.

KEYWORDS
Deep learning, student engagement, cross-disciplinary learning

Introduction

The quest and awareness for a better environment and quality of life has considerably increased with the rising of sustainability, as a driving force and form of development. Agendas, programs and legislation have strengthened goals and incentives to move towards sustainability at a faster pace. There are strategies and methods to develop the wide variety of issues. However, there still remains a need to develop sustainability not only as a technical concept, but also as a fundamentally human-related challenge.

In the construction sector, designing sustainable structures is a shared responsibility among architects, engineers, planners and contractors. While the process requires good communication between engineers and architects, professional bodies often identify this as an aspect that still needs improvement. More broadly, it suggests that partition in work, which is inherited from Fordism, may not be the best approach (Dupre et al., 2008). Thus, sustainable development should be seen as one opportunity to transform some cultural systems that show evident limits. As such, the training of future architects and engineers needs to be questioned, not only to break boundaries but also to encourage innovative cooperation.

Construction, structure, technical performance and physical properties of a building are usually taught as part of the architecture training in Australia. Nevertheless, program structures, courses contents and their weightings vary significantly among teaching institutions. This inconsistency leads to discrepancy among architects' competency in engineering skills and the technical jargon that engineers use. Hence, it limits the efficiency of the communication between architects and engineers. Because Architecture at Griffith University is a new program, offered only since 2008, it is still very open to changes and improvements. Interested to find out how a better communication between architects and engineers could be initiated at the university level, the authors have decided to conduct an experiment within an architecture course at Griffith University. This paper offers the first presentation of this study, with its methodology, results and conclusions.

Background

General

At the undergraduate level, students in architecture at Griffith University have to complete a minimum of three courses (worth 30 credit points, out of 240 for the Bachelor curriculum) in the "Documentation and technical studies" subject area. They are the 'Introduction to structures', 'Construction material and practices' and 'Building construction and services'. Only the first course is taught by an engineer, the other two are taught by a professional builder and an architect. At the Master level, only one course (worth 10 credit points out of 170 for the Master curriculum) needs to be completed in the "Documentation and technical studies" subject area: 'Advanced integrated technologies'. This course is taught by an architect. Although, while no specific rules prevent the intervention of an engineer in the remaining courses of the curriculum, and specifically for the design studios, it is done quite sporadically. 'Design studios' are a form of courses, in which the student is presented with an architectural project to design and document. Over several weeks, the student consults with tutors, academics and professionals, who provide assistance and guidance to the development of the final design.

Because the master course "Advanced Architecture Studio 2" was offered for the first time at Griffith University in Semester 2, 2013, it presented an opportunity to design it following student-focused research led teaching approach (Brew, 2002). Particularly, to enrich the architectural program with engineering knowledge and expose architecture students to sustainable designs through (i) working on an actual architectural project, (ii) a series of guest lectures in structural and environmental engineering, (iii) using innovative timber structural products and (iv) assessing sustainability of design options using life cycle assessment methodology.

Practically, during the first six weeks of the second semester of 2013, postgraduate students were asked to design a structure. Their brief outlined the fact that they should use a timber product currently under development at Griffith University (Underhill et. el., 2013; Gilbert et. al., 2013), "investigate [it], test, innovate and make a design proposal". Furthermore, the brief required the proposal "to be innovative in its use of materials and construction techniques enabling it to be realised with awareness of its sustainable character and minimum cost for maximum impact". From the architecture point of view, it meant not only to address conceptual design ideas and their resolution (to summarise it) but also to evidence some deeper competencies in building (structural knowledge and understanding, data analysis and bottom up and top down reasoning). Three academic members from architecture, structural and environmental engineering were involved in teaching the course to provide students with the required technical skills to successfully complete their project. Furthermore, having architecture students working on products currently researched and developed at the Griffith School of Engineering, allowed to (i) find new applications for the products, (ii) promote their potential uses in architectural buildings and (iii) increase the collaborations between the Engineering and Architecture disciplines at Griffith University.

While this course was convened and taught by the academic member in architecture, and therefore is architecturally orientated, each academic member from engineering were equally involved in the brief outline, delivered a workshop on her/his area of expertise and assisted students in key points of their design. An inductive teaching approach which is more aligned with teaching courses in architecture was adopted by the engineering academics instead of the traditional deductive approach which is common in engineering (Prince & Felder, 2006). The teaching team agreed that what should be assessed in the study is the learning process to develop a sustainable design for future architects rather than the acquisition of engineering knowledge. The small number of students enrolled in the course (15) has also offered a good opportunity to provide detailed qualitative analysis of each student's performance.

After each workshop, students were surveyed to obtain feedback on (i) the effectiveness of the engineer to communicate his ideas to the architects, (ii) how to best communicate engineering to architects and (iii) if students thought that the ideas introduced are useful to their future profession as architects. Additionally, at the start and completion of the project, the revised two-factor study process questionnaire (R-SPQ_2F) (Biggs et. al. (2001)) mapped students' initial and change in approaches to learning, therefore quantifying if students engaged with the course.

Innovative timber products used

In hardwood plantations grown for high-quality sawn timber, an average of 1,000 stems per hectare is planted. However, only high quality trees are allowed to mature, with the lower quality trees (for instance, those that are crooked, smaller or have too many branches) removed in operations referred to as "thinning". Around 300 trees are cut in the second thinning operation at 10-15 years before the plantation is finally clear-felled at 25-35 years. The trees cut during the second thinning operation have a breast-high diameter (BHD) of about 20-30 cm, and are deemed of little or no commercial value.

Various Veneer Based Composite (VBC) structural applications using thinning veneers are currently being developed at Griffith University (Underhill et. el., 2013; Gilbert et. al., 2013) (see Figure 1) in an effort to develop high value end-uses for these low quality logs. In addition to being manufactured from waste material, advantages of the new products over sawn timber sections lie with the products having efficient cross-sectional shapes, (i.e. hollow, Cee or I shapes) and being able to be manufactured in large sizes currently not available in timber. Additionally, thin-walled timber products are also currently being developed at Griffith University (Gilbert et. al., 2013).

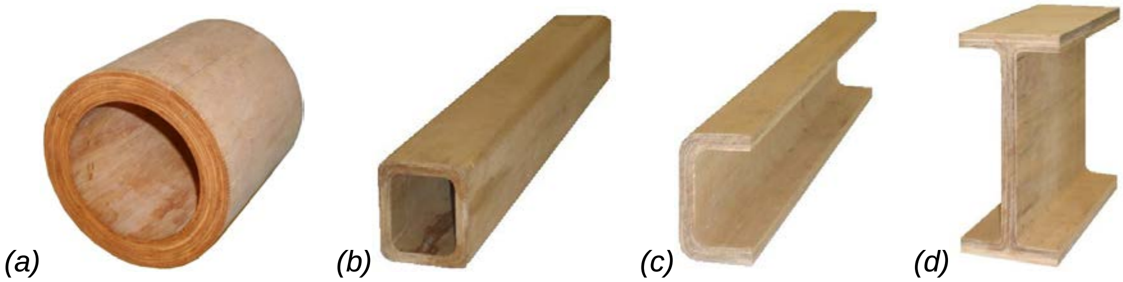

Figure 1: VBC structure developed at Griffith University (a) Circular hollow section; (b) Rectangular hollow section; (c) Cee-section; and (d) I-section

Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a comprehensive and standardized method to evaluate the environmental impacts of a product or a service throughout its life cycle including all stages of the product system from material acquisition all the way to final disposal (ISO, 2006). LCA ensures that all environmental burdens are accounted for and prevents the shifting of the burdens from one stage of the life cycle to another. According to ISO 14040:2006, LCA comprises 4 phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation. Due to the comprehensive nature of LCA, it requires extensive details about the product or service being evaluated and the processes associated with it. As such, specialised software which simplifies the process of implementing LCA is deemed essential to successfully conduct these studies. Eco-calculator published by the Athena Sustainable Materials Institute, is specialised software for the construction industry (Athena Sustainable Materials Institute, 2013). It contains a large inventory of construction materials as well as a life cycle impact assessment method. It allows the user to easily evaluate the emissions and the environmental impacts associated with their selection of different construction materials for their design. It also presents the results in easy to understand visual display. The software was introduced to the students, as it is a user-friendly tool to demonstrate the LCA method in a classroom setting or simply to get an initial estimate of the environmental impacts to compare different designs or evaluate modifications to a given design.

Methodology

Course structure

The course was designed for students to interact with the engineers at key points during the six weeks of the project, either through lectures/workshops or during studio sessions, where engineers assisted students in further developing their design. Table 1 indicates when students were interacting with the academics in engineering. All in all, the course was covered up to 66% with engineers and 100% with architects.

As shown in Table 1, during the first week of the project, each of the academics in engineering gave a two hours lecture/workshop. Specifically, the structural engineering lecture aimed at (i) briefly introducing the sustainable advantages of timber, (ii) explaining where is the waste timber material (thinning) coming from, (iii) presenting the products currently developed at Griffith University (mainly manufacturing, advantages/disadvantages and preliminary test results), and (iv) the vision for the future (including enhancing a multi-discipline group of architects and engineers). The environmental engineering workshop aimed to make students aware of the environmental impacts of their design, especially, how material selection can alter the environmental impact outcomes of the design. Furthermore, the use of life cycle was promoted to encourage students to think beyond the immediate end of pipe emissions and to incorporate other environmental benefits (such as avoiding emissions) when selecting alternative materials. The three academics attended the Master's final presentation and evaluated it.

Table 1: Weeks where students interacted with engineers

Activity	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Lecture in structural engineering	X					
Lecture/Workshop in environmental engineering	X					
Academic in structural engineering attending studio		X		X		X
Academic in environmental engineering attending studio						X

Surveys

Students were surveyed on five occasions at key points during the six weeks duration of the project. The aims of the survey were to:

1. Collect data of initial students' approaches to learning, as well as the change in their approaches to learning after completion of the project. The revised two-factor study process questionnaire (R-SPQ_2F) developed by Biggs et. al. (2001) was used for this purpose. Students were first surveyed during the first lecture, after the introduction of the project by the academic in architecture, but before the first engineering lecture/workshop. The second and last surveys were conducted at the end of the project, just before the final presentation (that is before the final assessment item of the project).
2. Obtain feedback on (i) the effectiveness of the engineers to communicate their ideas to the architects, (ii) how to best communicate engineering to architects and (iii) if students believed that the ideas introduced were useful to their project and future profession as architects. Students were surveyed immediately after each of the two engineering lecture/workshops. Each of the surveys was tailored to the specific engineering topic covered during the lecture/workshop and included (i) one "scaled" and "open" question on the effectiveness of the engineer to communicate his ideas (both surveys), (ii) one "scaled" and "open" question on the motivation of the architect students to work on product currently in a research stage (structural engineering survey only) and (iii) three to four "scaled" questions on if students believed the workshop increased their general engineering knowledge and will significantly influence their project and professional life after graduation (both surveys). For the "scaled" questions, five different answers were possible, ranging from *Not at all important* to *Extremely important*. Students were able to write comments in the "open" questions.
3. Collect data on students' initial thought on the qualities/competencies important for succeeding as a professional architect, as the change in these beliefs after completion of the project. Students were surveyed twice, at the same time as the approaches to learning in item 1. Each academic staff asked four to six "scaled" questions on the qualities/competencies, in relation to his/her discipline, s/he believed important for the students to acquire as future professional architects. In total fourteen "scaled" questions were asked. Similar to item 2, each "scaled" question offered five different answers, ranging from *Not important at all* to *Extremely important*. The students also had the possibility to add their own qualities/competencies and rate them from *Not important at all* to *Extremely important*.

Data Analysis

Microsoft Excel™ with the Analysis Toolpak add-in was used to analyse the data. Although data were collected at an ordinal scale, the underlying meaning of the data can be treated as interval/ratio. Therefore, it was deemed appropriate to use descriptive statistics to summarise the data. Furthermore, to determine if significant change has occurred between students' responses to questions in repeated surveys, non-parametric ANOVA (Kruskal-Wallis one-way analysis of the variance) tests were conducted. ANOVA was also used in conjunction with the Kruskal-Wallis test, especially, in cases where the data exhibited some degree of normality but appeared to not have satisfied the Kruskal-Wallis assumption that both sets came from similar distributions (i.e. the sign of the skewness of the dataset was not the same and the kurtosis values were far). In case, where the ANOVA suggested a difference, F-test of the variance and t-test of the mean were also conducted to determine the direction of the change (if any). In interpreting the results, the Kurskal-Wallis test was given higher value due to the nature of the collected data. Correlation analysis was also used to discover dependencies between students' responses to different questions in the survey.

Results and Discussion

Approach to learning

Out of 15 students, 12 and 10 students answered the revised two-factor study process questionnaire (R-SPQ_2F) (Biggs et. al. (2001)) at the start and end of the project, respectively. All students, but one, showed a deep approach (DA) to learning, with a trend towards a deep motive (DM) approach. The one student neither showed a deep or surface approach to learning.

A significant change in students attitude towards deep learning was observed in their answers to Q3 ("My aim is to pass the course while doing as little work as possible") as confirmed by the t-test (p=0.015). Although, the Kurskal-Wallis test suggested no difference, its results was just marginally outside the 5% significance level (p=0.06). Nevertheless, the change in attitude was further noticed in student responses to Q10 ("I test myself on important topics until I understand them fully") with both the t-test (p=0.01) and Kurskal-Wallis (p=0.02) confirming the change. Since at Griffith University, a minimum GPA of 5 is required to enrol in the Master program in architecture, this deep approach to learning strategy was therefore expected. This approach to learning may have also contributed to the students being receptive to the project, as outlined in following Sections.

Structural engineering

12 students answered the survey focused on structural engineering (item 2. in previous Section *Surveys*). Giving a score of 1 point for *Not at all important* to 5 points for *Extremely important*. All respondents (100%) found that the "engineer effectively communicated the importance of using timber to achieve sustainable architectural design"- Q1, with an average score of 4.8 (CoV of 0.1). This high score is believed to be attributed to the lecture being more general than technical (contrary to conventional engineering lectures) and therefore better adapted to architecture students with limited technical background. Specifically, the philosophy behind the lecture was to briefly show the potential of timber in architectural buildings and the sustainability of the material, then further talk about the innovative timber products (both architecturally and structurally) to be used in the project.

Majority of students (92%) engaged with the concept of using a timber product at a research stage and thought "that working on an engineering/architectural product at a research stage was rewarding"- Q3, with an average score of 4.3 (CoV of 0.2). Students felt a real sense of purpose to the project and had the feeling of being involved in an actual process, not a pure academic exercise. When asked why working on this concept is rewarding, comments includes "*Because we can start from scratch and we can help to develop the product and find out solutions and new uses*", "*Very existing to be involved in the development of a new product, benefit construction + waste*", "*Existing to be exposed to alternative materials"* or *"New technologies and materials change architecture*".

Likely due to the lecture being general, students did not find "that their general engineering knowledge improved after the lecture" – Q5, with an average score of 3.1 (CoV of 0.4). Yet, students clearly agreed (91%) that "the ideas/knowledge introduced during the lecture will influence their design" (average score of 4.5, CoV of 0.2) while 73% indicated that it will influence "their professional life" (average score of 4.3, CoV of 0.2), Q6 and 7, respectively.

Further analysis also showed strong correlations between students answers to Q6 and 7 (r=0.9) and Q5 and 7 (r=0.8). This could be explained as willingness of students to incorporate their engineering skills into their designs and translate these skills to their professional practice.

Environmental engineering

Out of the 12 students who attended the workshop on life cycle assessment, 11 valid responses were returned. In response to Q1, 91% of the students agreed that the engineer was highly effective (average score of 4.2, CoV of 0.14) in communicating his ideas to an audience of architects. Seven (7) out of the 11 respondents gave feedback (Q2) on why they gave the rating in Q1. The comments revolved around four (4) axis: (i) The workshop used hands on approach to demonstrate the ideas (4 comments) (ii) The workshop made them aware of material selection impact on the environment and human health (3 comments); (iii) The software used in the workshop was easy to use and effective to demonstrate the idea (3 comments) and (iv) The lecturer explained the capabilities and limitations of the LCA method (1 comment). Hence, it can be concluded that the combination of theoretical knowledge with hands on exercises while at the same time contextualising the idea was very effective in getting the point across despite the technical nature of the topic. In response to the following question in the survey regarding whether the workshop helped them increase their engineering knowledge (Q3), 55% of the students agreed that the workshop was *Very important* or *Extremely important* with a average score of 3.5 (CoV of 0.36). Nevertheless, students' responses to Q3 exhibited moderate correlation (r=0.63) to their responses to Q1. The reason for this lower rating could be that the students did not regard LCA as pure engineering knowledge rather an inter-disciplinary application. This correlation followed on between students' responses to Q3 and Q4, Q5 and Q6 with correlation factors of 0.63, 0.62 and 0.66, respectively. This indicates that students' perception of their engineering knowledge may play a role in their willingness to change their current practices (Q4 & 5) especially with regards to applying new methods such as adopting non-traditional materials (Q6).

The majority of students (73%) rated the ideas presented in the workshop as '*Very important* or *Extremely important* in influencing their design for the purpose of course assessment (Q4) and their professional career (Q5). Further analysis revealed high correlation between students' responses to Q4 and Q5 (r = 0.86). This high correlation may be interpreted as willingness, on part of the students, to incorporate the skills they learn in class into their professional practice.

Just under half (45%) of the students who responded to the survey indicated that they are more likely to adopt non-traditional materials in their design after attending the workshop (Q6). Nevertheless, high correlations were observed between students' responses to Q6 and Q4 (r=0.90) as well as Q5 (r=0.76). This may indicate that the students interpreted the adoption of non-traditional material in their designs as only one way in which the ideas introduced in the workshop can influence their design. This is a healthy sign as the students did not limit their thinking of improving the environmental performance of the design to a narrow interpretation.

Students' willingness to incorporate LCA into their designs was evident in their final poster submissions. Several students (40%) used the Eco-calculator software to evaluate the environmental impacts of their final design. However, none of the students used LCA as a tool to improve the environmental performance of their design and most of them did not provide meaningful interpretations of the LCA results. This is perhaps due to the way the workshop was conducted. Because of time and logistics limitations, the workshop focused on giving students brief theoretical background and showing them how to use the software but not explicitly telling them how it can be used to improve the design or how to interpret the results meaningfully. Furthermore, the workshop was conducted during the first teaching week with no follow up communication between the environmental engineering academic and the students. This may have given the students the impression that the skills taught was casual. Nevertheless, the mere fact that many of the students attempted to incorporate LCA into their design is in fact a very good sign and is consistent with the survey results as discussed earlier (Q4 and Q5).

Attitude toward engineering

Quantitatively, the attitude toward engineering revealed by the surveys shows an uniformity of answers with 100% of the students being convinced that basic engineering knowledge and ability to communicate with engineers were *Important* if not *Extremely important*. Yet, design proposals did not reflect exactly the same engagement during the final presentation. Although 94% of the students dutifully drew construction details and sections or/and elevations at a scale that permit structural understanding of the project (from 1:50 to 1:20), only 40% addressed the question of LCA and none explained how it might have influenced the proposed design. This result is also corroborated by the absence of concern displayed during the studio sessions: the topic of LCA was rarely raised outside the LCA workshop.

Further qualitatively, the proposed designs were not always structurally right thus evidencing the fact that understanding the need for engineering doesn't necessary mean the acquisition of the knowledge itself. Admittedly, students actively requested the engineer tutors but obviously, for some of them, competencies were not acquired during the six-week project.

Conclusion and future plans

The purpose of this study was to evaluate the exposure of architecture students to basic engineering knowledge and enhance the students' multi-discipline competencies to prepare them for their future career. Interestingly, the results evidence that architecture students are in majority demanding and convinced by this type of initiative, but not always ready to apply them. As such, it indicates that students are fully aware of the challenges brought by sustainable development and consider themselves as potential actors of change. Yet, the gap between what one thinks and what one does also shows that there are many areas for improvement.

Since structural and environmental engineering did not receive the same level of engagement within the project (with a clear disadvantage for the later), future studies aim at evaluating the criteria that can modify this engagement. For instance, the duration of the project and the project type could be some criteria worth focusing on. The curriculum background of the students is also worth investigating.

The enthusiasm of the students to be involved in the development of a real product (here VBC timber products) is also a sign that, even during their architecture training, they envision their current activity within a professional scope. This down-to-earth approach might also explain their maturity towards learning. A following up of these students for the next five years would also complement the current research and provide indications whether this course had an impact on the long-term and students' professional career. However, it seems important at first to replicate the study with another cohort with some adjustments to answer the above-mentioned questions.

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