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Qualitative structural design education in large cohorts of undergraduate architecture students

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ABSTRACT: While constraints imposed by large cohort sizes and lecture-based teaching are often described as preventing an educational focus on quality and individual thinking, this article presents a mixed method teaching approach for quality-oriented structural design education of large cohorts as implemented in a module on structure and construction of the BEng in Architecture programme at Xi'an Jiaotong-Liverpool University, Suzhou, People's Republic of China. In this approach, lecture-based teaching is extended with open-ended individual and group assignments that emphasise individual qualitative learning. Results from the module show that in large cohorts, structural design education with an emphasis on quality and individual thinking is achievable.

Keywords: Structural design education, architectural design, large cohorts, qualitative education

INTRODUCTION

Architectural education is centred on the design studio, a form of education commonly found in design-related disciplines in which students learn to develop design proposals in tutorial conversation with their tutors [1]. Designing has been characterised by Schön as a form of *reflection in action*, a process of recurrent production, evaluation of, and reflection on, design proposals [2]. Architectural education supports students in learning to engage in this cyclic and applied process, addressing primarily qualitative aspects of both the architectural proposals and students' learning processes. Due to the close collaboration required between tutors and students in the design studio, one tutor will typically supervise no more than 15 students throughout one studio, typically lasting one semester. For this reason, architecture studio cohort sizes rarely exceed 100 students. Besides the applied and quality-focused design studio, architectural education typically also comprises conventional lecture-based modules with much higher student-to-teacher ratios.

In contrast to process- and quality-centred design studio education, lecture-based modules tend to emphasise contents, which students are usually required to memorise and reproduce in some form of written examination. Lecture-based teaching is a teaching approach preferred for its resource efficiency in particular for large cohorts, but has also been criticised for its rigidity and pedagogical ineffectiveness, in particular for design-related learning [3]. With the design studio at the core of architectural learning and production, the question arises of how lecture-based modules may be taught in ways that relate to, and support, designerly modes of thinking and learning even for large cohorts. In the engineering fields, a similar refocusing on more applied forms of learning and teaching has led to problem-based learning [4-6] and active learning [7][8] being adopted in particular for final year projects.

Structural design as a part of architectural education is typically taught in lecture-based modules. Despite the overall focus on the design studio, structural design modules are rarely seen as opportunities to deliver the subject within a framework that integrates architectural design and engineering aspects [9][10]. Instead, they are often conceived as simplified civil engineering modules with a focus on basic statics. The main challenge in structural design education in architecture is thus to enable students to incorporate structural design learning with their applied design skills [11]. Structural design ability in the context of architectural design is thus understood in this article as the ability to develop design proposals that sensibly employ and integrate structural and architectural aspects. This ability - or perhaps more adequately, this structural sensitivity - is usually not learned in lecture-based modules that are modelled on

undergraduate engineering education and focus on numerical structural analysis methods for the purpose of dimensioning structural elements.

The educational approach presented in this article instead pursues the integration of structural and architectural design by teaching students to see buildings as structural systems, to see relationships between structural and material choices, and their implications on architectural design proposals, and to perceive structures as contributing to architectural design. While these qualitative aspects of structural design education may relatively easily be pursued in a design studio setting with small groups of students and close guidance by a tutor, this is increasingly challenging with larger cohort sizes, in particular in lecture-based settings. While design studio and structural design modules are typically taught by different members of staff, the author's involvement in both has resulted in the integrated, quality-focused teaching approach presented here. It forms the basis of a second-year undergraduate module on structure and construction at the Department of Architecture at Xi'an Jiaotong-Liverpool University (XJTLU). Since its first year of teaching in 2011/2012, the Department of Architecture offers its four-year undergraduate BEng in Architecture programme to large first- and second-year cohort sizes of around 200 students. The module discussed here introduces students to both structure and construction basics, and has been taught and coordinated by the author for the past two years. The focus of this discussion is on the above-mentioned integration of quantity and quality in teaching basic structural design to large cohort sizes.

IMPLEMENTING THE EDUCATIONAL APPROACH

To allow for qualitative learning, the teaching approach employed in the structure and construction module is based on the integration of multiple modes of learning and teaching. The following sections introduce and discuss these modes as they relate to the challenge of teaching large cohorts with the aim of qualitative learning. They include conventional lecture-based teaching, drawing-based exercises to engage students actively, hands-on learning, off-campus site visits and module-related voluntary activities. This section further includes a discussion of assessment strategies to support qualitative learning.

INTEGRATING CONVENTIONAL LECTURES WITH ACTIVE STUDENT ENGAGEMENT

The educational approach pursued in the discussed module does not dismiss conventional lecture-based. It integrates it with other modes of learning and teaching to achieve a balanced and applied learning experience. As conventional lectures put students in the position of passive listeners, the primary aim in broadening the scope of teaching methods beyond lectures is to give students a more active role in their learning process. This seemed particularly important in the context of this module since most students entering the architectural BEng programme at XJTLU come from a Chinese educational background.

The Chinese school system focuses on written examinations, such that students are used to - and experts at - providing correct answers to predefined questions through rote learning, but find it difficult to develop individual decisions and proposals. Given this background, lectures are complemented with in-class exercises that encourage students to make diagrammatic structural design proposals based on individual judgment and choice. As architecture students in the initial semesters of undergraduate programmes are learning to express ideas visually through drawings, the exercises developed for the structure and construction module build upon this skill, and take the form of a series of drawing-based exercises focusing specifically on aspects of structure and construction. The emphasis on visual expression is particularly useful in the second-language learning context of XJTLU. The drawing-based exercises developed for and through the module are part of an educational strategy that seeks to encourage student engagement through design-type tasks that do not have predefined, correct answers, but instead require students to provide individual responses that are judged based on coherence and on the degree to which they demonstrate appropriate reasoning.

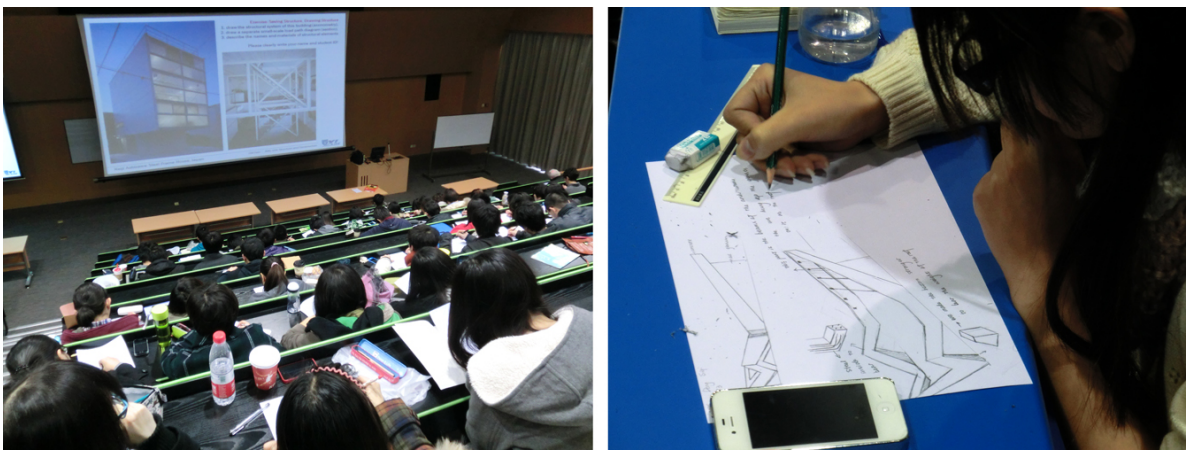

Figure1: Students working on a drawing-based exercise following a conventional lecture.

Drawing-based exercises are conducted as short and un-announced in-class exercises building upon contents taught during preceding regular lectures (Figure 1). Each drawing-based structural design exercise lasts between 20 to 45 minutes depending on the difficulty of the given task. The exercises address three related aspects of learning about structure and construction: analytical appraisal of given structures, providing educated guesses regarding the nature of a partially hidden structure, and providing basic structural design proposals for given architectural forms or intentions. Typically, four to five exercises are conducted over the course of each semester-long module, addressing the three aspects outlined above as three progressive stages in student learning. All exercises are based on photographs of existing structures. The first type of exercise, focusing on the analytical appraisal of a given structure, typically requires students to make drawings, which clearly illustrate the structural systems and elements of a given structure (Figure 2). Alternatively, analytical appraisal can take the form of schematic sketches of the building structure in conjunction with load path diagrams. These exercises primarily aim to teach students to *see* structure within architecture and to articulate structures visually as coherent systems.

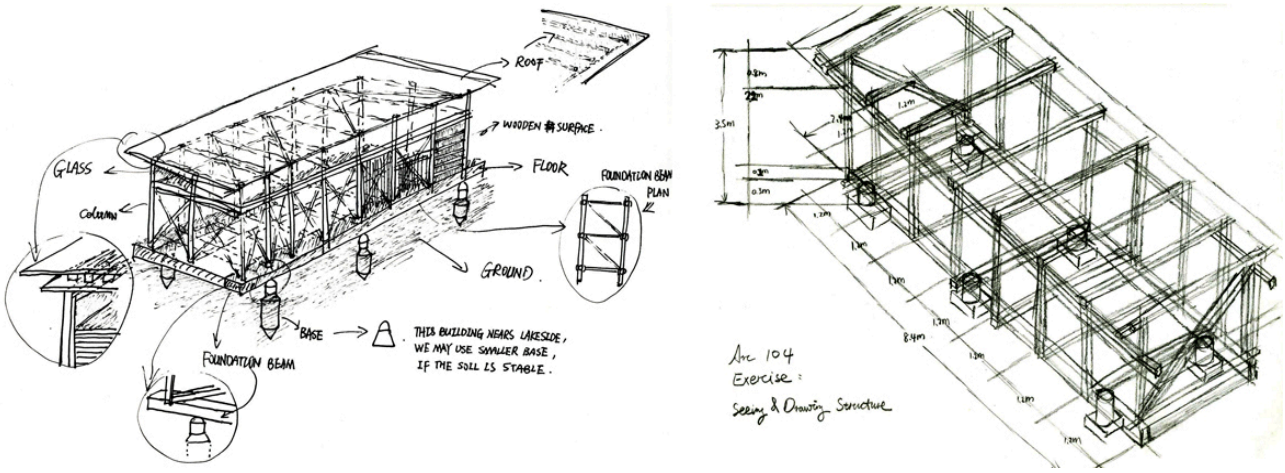

Figure 2: Results of a drawing-based exercise requiring students to analyse the structure of a small timber pavilion.

In the second type of structural drawing-based exercise, students are asked to provide educated guesses about the structure of buildings from photographs in which only parts of the structure are visible. This requires students to form their own understanding of given building structures and encourages independent reasoning (Figure 3). Exercise results are judged based partly on students' ability to recognise and to express the structural systems of shown buildings, but also to a large extent based on students' ability to identify and to visually present a coherent and sensible structural system.

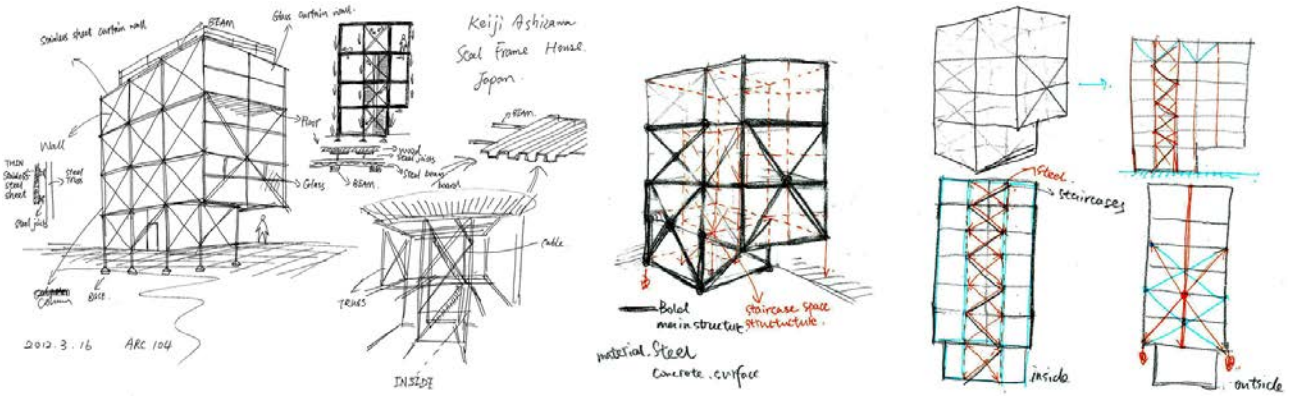

Figure 3: Results of a drawing-based exercise requiring students to guess and visualise a steel frame structure.

The third type of exercise is the most difficult type of drawing-based exercise given in the context of the discussed module and requires students to provide a sketch structural design proposal for a given building form. While students' structural design proposals can only be basic due to students' early stage of learning about structural design, proposals should demonstrate students' ability to understand, transform and integrate what was taught during preceding lectures in the form of individual structural design proposals. This ability, in turn, is intended to enable students to make structurally informed choices in their architectural design studio work. As students become aware of structural proposals potentially complementing or clashing with architectural intentions, this type of exercise further encourages students to think about the relationship between architecture and structure. Together, the three types of drawing-based exercises support a gradual progression in learning about structures and construction, beginning with the conscious seeing and appraisal of existing structures, continuing with the guessing of only partially obvious building structures, and leading to simple and tentative structural design proposals for given architectural forms or intentions.

Since the drawing-based exercises do not have predefined, correct answers, but instead require students to provide individual answers, results from these exercises show students' learning stages as students cannot simply copy or memorise a given solution, but have to develop and illustrate their individual learning and choices. The exercises, however, also have several drawbacks. The workload for involved teaching staff increases significantly as each exercise has to be reviewed qualitatively. As there are no correct solutions to most of these design-type exercises - merely better or worse answers - providing prompt qualitative feedback is essential for students' learning. Given the cohort size of around 200 students, no individual feedback can, however, be given to all drawing exercises. Instead, feedback is given in the lecture setting by showing and discussing typical samples of student work as soon as possible after the exercise. Results of the exercises demonstrate a qualitative gap in learning between the repetition of correct answers as it occurs in conventional written examinations, and students' actual ability to create individual structural design proposals. While it is relatively easy to perform well in the former, the latter is more difficult and often produces initially weak outcomes as students adapt to new ways of engaging with the subject matter, as well as with new modes of individual expression. Over the course of the module, a gradual learning process was observed in most students as they became more confident in making quick individual choices in the in-class drawing exercises. Students further became more attentive to the qualitative feedback given in the discussion of student works in class, and increasingly initiated conversations via email and on social networking Web sites regarding the structural aspects of buildings they found interesting, but did not entirely understand.

HANDS-ON LEARNING

In addition to the drawing-based exercises described above, the structure and construction module includes a more substantial exercise worth 30% of final module marks in which student groups are required to build functional cardboard structures in response to a given brief (Figure 4). In the first year the module was taught, the brief asked students to design cardboard chairs for kindergarten age children (Figure 5). In the second year, it called for the design of cardboard bridges for children (Figure 6). The exercises are teamwork projects of 4-6 students to foster discussion among students, as well as a spirit of experimentation and hands-on learning. During this exercise, students primarily learn from their own experiences made while designing, constructing and, subsequently, analysing and reflecting on the outcomes of the cardboard structure building process. In both years, the structure and construction module has been taught, this exercise included the load testing and qualitative evaluation of the cardboard structures in both an internal interim review (Figure 4) and in a public final review event (Figure 6).

Figure 4: Presentation, load testing and discussion of cardboard bridge models at 1:2 scale during the interim review in a lecture theatre setting.

The inclusion of applied exercises that involve design and construction of functional cardboard structures is based on the observation that students learn effectively from working in teams and directly with materials. In this type of exercise, the material presents constraints that students have to deal with by learning about its physical properties, and by developing and building design proposals that match these properties [12][13]. For the purpose of teaching large cohorts, this type of exercise can provide a learning context in which feedback is given not only by the module tutor, but by the material itself, as well as among peers within the teams. Students can immediately try out and test design ideas, determine and improve the structural viability of their proposals without having to refer to tutor feedback at every stage of the design process. Tutor feedback is given verbally during interim and final reviews, and addresses mainly qualitative aspects of the presented cardboard structures in a fun and encouraging, but also critical manner.

Feedback given by the module tutor and invited guests typically addresses the overall coherence of the chosen structure, the craftsmanship and attention to detail expressed in the cardboard structure, and a discussion of potential alternatives to students' structural choices and detail design. As an additional optional feedback channel during the past two instances of the module, a large number of students in the module used the Renren social networking Web site - the Chinese equivalent of Facebook - to share and discuss their work in progress among themselves, as well as with the tutor. This informal sharing of progress among peers and encouraging tutor feedback helps to create a positive atmosphere that is driven by students' pride in their achievements rather than formal assessment. In their final reports,

students often remarked on the value and importance of discussions among their teams for their learning, and on the value of taking on and sharing of responsibilities within their teams.

The cardboard structure exercise takes place during the earlier half of the semester and is organised around one interim and one final review, with students working on their structural design development by themselves in between reviews. The reviews serve several educational purposes. In the interim reviews, students obtain tutor feedback when presenting their work to the entire class. The semi-public nature of the interim reviews and students' desire to present good work in front of the entire class are a strong motivation for students. Furthermore, seeing the work of other teams provides a rich source of ideas for further development until the final review.

Figure 5: Cardboard chairs for children during the final review and testing at a cooperating kindergarten.

The final reviews are arranged as public events with an external audience to motivate students to present good work and to allow students to obtain a wider range of feedback. In the case of the cardboard bridges for children exercise, this external audience included invited staff and students of the Department of Architecture, as well as other departments of XJTLU. During the final review, children of academic staff also tested and commented on the bridge structures. In the case of the cardboard chairs for children project, the final review included a trip to a cooperating local kindergarten where students presented their works to six year-old children who also tested the chairs. Involving children in the cardboard structure exercises added an additional relevance to the role of structural stability and gives students an acute awareness of responsibility, as well as safety requirements that grading alone cannot achieve in the same manner. In addition, it added the notion of the user to structural considerations, as structures do not only need to function safely, but should also be appreciated by those who use them.

Figure 6: The final review of cardboard bridges for children designed and constructed by students.

OFF-CAMPUS SITE VISITS AND RELATED INITIATIVES

A module on structure and construction ideally includes student visits to construction sites, so students can become aware of and acquainted with the realities of the local construction industry and construction projects. This is particularly relevant to students at XJTLU as the University is situated within a rapidly growing urban environment with plenty of construction sites in close proximity to the campus. In Chinese construction practice, architects are often not involved with site supervision and rarely visit construction sites. Visiting construction sites as part of the module, thus, serves to teach students about construction on site as a first step in raising their awareness of construction quality. For safety reasons, site visits are, however, feasible only for small groups of up to 20 students. As a part of the module, a number of site visits are organised by small groups of student volunteers for other students who apply to take part (Figure 7). After the visits, participating students are required to share their experiences with the entire cohort through

presentations showing and discussing their experiences. The exclusivity of participating results in site visits becoming highly desirable events to students within the context of the module.

Figure 7: Small groups of students on student-organised visits to local construction sites.

Taking advantage of thematically related opportunities, further activities related to the themes of the module are coordinated by the module tutor for interested students. These activities have, so far, included the participation of four volunteering student teams in the 2012 and 2013 international earthquake safety design competition IDEERS (Introducing and Demonstrating Earthquake Engineering Research in Schools) in Taiwan, as well as the participation of a student team in the 2013 Tongji University Construction Festival. Similar to the site visit volunteers, students participating in these activities are asked to report subsequently their experiences back to the entire cohort. These initiatives, although only indirectly related to the module, seek to establish opportunities for those students who are particularly motivated and interested to further pursue their structure and construction interests, and learning beyond the classroom. Cultivating motivation and enthusiasm in this manner, with the backing and support of the Department of Architecture, has led to student teams winning prizes at competitions and increasing awareness of students towards structural design as a worthwhile area of creative architectural exploration.

ASSESSMENT

The main challenge in assessment and marking in the module discussed in this article is to ensure that assessment reflects student learning. Unfortunately, the necessity of assessing the work of large numbers of students within the tight time constraints and quality assurance frameworks set by university administrations tends to emphasise assessment over learning. The module is formally assessed in three components: a final examination (60% of marks), drawing-based exercises (10% of marks) and a final report (30% of marks). These weightings, however, reflect assessment conventions more than they indicate the relevance of these components for qualitative learning. Beyond formal assessment, the educational approach taken for the structure and construction module seeks to establish and encourage students' interest, motivation and enthusiasm. These powerful sources of learning are not directly assessed, but fostered in other ways as outlined in the following. In some aspects of the module, the intentional absence of assessment and the application of alternative means of motivation are strategically used to encourage qualitative learning.

The final examination was carried out as a conventional written test, conforming to the standard assessment procedures of the University. The examination, however, included a qualitative drawing task that corresponds to the drawing-based exercises conducted in class to avoid students relying exclusively on rote memorisation to pass the module. The in-class drawing-based exercises present an assessment challenge for their sheer volume: conducting five drawing exercises per semester in a class of 200 students generates around 1000 individually different drawings to review and to provide feedback on. The reviewing and assessment process is shortened somewhat with the discussion of typical samples of student work in class, and by introducing broader grading categories to indicate below satisfactory, satisfactory, good and excellent work. The cardboard structures exercise is assessed based on an individual final report in which students present an analysis of the cardboard structure they designed and built. In addition, students report and reflect on their design processes and team working. Final reports are assessed based on the quality and appropriateness of the structural design proposals, the quality of students' explanations of structural principles employed, and the extent to which students are able to implement and respond to tutor feedback and what was taught in class. Cardboard structures are evaluated, but not graded on the success or failure during both interim and final reviews, to allow students to focus on qualitative experimentation and analysis in their final reports. The reports form the only graded component for the cardboard structures exercise. With this only indirect assessment strategy, students are motivated primarily through their own ambition and pride in their achievements, and the desire to present good work in front of others.

CONCLUSIONS AND OUTLOOK

This article has introduced and discussed an educational approach developed for teaching structural design with a qualitative focus to large cohorts of undergraduate architecture students at XJTLU. For the purpose of qualitative

structural education, conventional lectures were supplemented with alternative modes of teaching, including in-class drawing-based exercises, hands-on learning, off-campus site visits, module-related voluntary activities, as well as alternative assessment strategies. The article illustrates how structural design can be taught in a way that relates more closely to architectural design studio work than the conventional emphasis on calculation and dimensioning. The structure and construction module discussed in this article aims to foster students' structural design sensitivity by exercising students' ability to analyse, design, build and express structural choices as part of architectural design.

Qualitative learning is supported through design-type tasks that do not have predefined correct solutions but require students to exercise their own judgment and present their own choices. Drawing-based exercises provide a means of qualitative learning by relating more closely to architecture students' tendency to visually understand and express ideas, while hands-on exercises support applied learning. In the assessment of the cardboard structures, grading of success or failure was de-emphasised as a motivational device in favour of encouraging students' pride in individual and team accomplishments.

Among the difficulties encountered in the teaching approach introduced in this article are the increased workload for teaching staff and the difficulty to provide qualitative feedback to each individual student. Overall, the qualitative aspects of the teaching approach discussed in this article have been positively received and will be further developed in future instances of the module.

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BIOGRAPHY

Christiane M. Herr is an architect, researcher and educator focusing on the areas of innovative structural design, cross-cultural studies in design and education, and digitally supported design. Christiane is a German national and has studied and worked in Germany, Australia, Hong Kong, China and Taiwan for more than 12 years. In her PhD work at the University of Hong Kong, Christiane explored cellular automata as a means to establish architectural design support, which led to her strong interest in diagrams and designerly ways of seeing. In her recent teaching and research, Christiane has focused primarily on innovative approaches to structural design education in architecture. Christiane is a board member, as well as member of conference organising and review committees for the American Society for Cybernetics and CAADRIA (Computer-Aided Architectural Design Research in Asia) and a member of review committees of various journals and conferences.