INTRODUCING ARCHITECTURE & ENGINEERING TO PROSPECTIVE UNDERGRADUATE STUDENTS

through a design activity supported by digital design media

STYLIANOS DRITSAS¹ and SAWAKO KAIJIMA²
¹,² Singapore University of Technology and Design, Singapore
stylianosdritsas@sutd.edu.sg, sawakokaijima@sutd.edu.sg

Abstract. We present a design activity offered as part of an open-house event conducted at the Singapore University of Technology and Design to attract prospective undergraduate students of architecture and engineering. We examine the role of digital design media in their potential of bridging the gap between disciplines in education.

Keywords. Education; Design Computation.

1. Introduction

The Singapore University of Technology and Design (SUTD) is an institution of higher learning comprised of the schools of Architecture and Sustainable Design (ASD), Engineering Product Development (EPD), Information Systems and Technologies Design (ISTD) and Engineering Systems Design (ESD) established in 2010 in collaboration with the Massachusetts Institute of Technology (MIT). Part of its pedagogical framework aims at introducing students, independent of preferred discipline, to methods employed among different fields of design to seed interdisciplinary awareness from the very early stages of academic scholarship. Computer science and engineering systems students, for instance, have the opportunity to learn about design in the physical world through the architecture and product design disciplines, and vice-versa, in a unified foundation year in design education. As a preview to these interdisciplinary courses we developed and offered a series of design workshops during on-campus open-house events to demonstrate to prospective undergraduate students the curriculum of SUTD (Wood et al. 2012).
1.1. OBJECTIVES

In this paper we present the skyscraper workshop: a design challenge combining learning experiences from the domains of architectural and structural engineering design supported by design-computation. Our challenge was to create a condensed but indicative experience of the considerations and processes involved in building design in an intellectually engaging, fast-paced, hands-on, highly collaborative and most importantly fun activity. We developed and deployed design-computation to create a contemporary design experience its participants wouldn’t have the opportunity to be exposed to a decade or two ago. In this paper we will touch on subjects of design education and we focus on the development of contemporary design media for education across disciplines.

1.2. BACKGROUND

The workshop was informed from such precedents as the architectural design studio, engineering exercises of project-based learning and design of experiment, one-to-one design-built workshops and the popular spaghetti & marshmallow challenge (an informal exercise typically conducted with participants with no prior design training). Since we targeted prospective architecture and engineering students we made effort to be indicative of the modalities of university education yet independent of discipline.

Teaching across disciplines raises some very difficult questions such as: (a) What can be taught, in other words, what is shared, unique and essential to introduce in each discipline; (b) How can it be best taught and what is the pedagogical framework behind a design activity; and (c) What one can really learn in a short timeframe given no prior exposure to design education.

The skyscraper workshop was developed with the guidance of Professor Frey (MIT); derived from a previous team-based design activity conducted at the Franklin W. Olin College for prospective engineering students (Frey et al, 2002). In addition, we advised with Professor Dym who has also extensive experience in project-based learning education which is the equivalent to studio based design education in architecture. In fact, introducing design early in the undergraduate engineering education is not common but its merits have been discussed in the past (Dym, 1994; Duston et al, 1997; Kuhn, 2001; Dym et al, 2005).

Following this inquiry we organized the workshop on the principles of (a) Prioritizing teamwork through the design-development of an artefact that no participant could create alone due to its sheer scale; (b) Heavily reducing the size of the design space while retaining the open-ended opportunities for experimentation and expression; (c) Combining quantitative and qualitative
methods and evaluation criteria to borrow some of the best pedagogical paradigms from both disciplines; and (d) Compressing technical aspects such as calculation, drawing, fabrication and construction to retain the entire design to production spectrum of activities and emphasize design as a coupled thinking + making process rather than reducing the scope of the workshop to a concept/ideation session.

Beyond learning objectives and measurable outcomes, a workshop with a demographic as such, offers an opportunity to investigate the role of media in design. The introduction of digital tools for design has been extensively discussed in the past few decades (Mitchell, 1977; Mitchell, 1990; Gross and Do, 1999; Kolarevic, 2003; Kalay, 2004) highlighting the different characteristics and affordances in the design thinking and making processes (Do and Gross, 1996; Alvarado and Davis, 2001). Our motivation for developing a bespoke design-computation system for the purposes of the workshop were driven by: (a) Time limitations by which we employed computation as a unifying and effective design to production platform; (b) The desire to offer an outlook in the contemporary modes of how practicing architects and engineers work today rather than entertain cultural biases assumed by entry level students pertaining dualities such as the notions of sketching and calculation; and (c) Investigate the behaviour of students with no prior training in paper-based or computer-based sketching.

Our contribution in extending the framework of introductory design activities by Frey and Dym was by: (a) Merging the architectural notion of context-aware perspective in design with the fundamental engineering design methods; (b) Introducing current design technologies by developing a simplified computer aided design, finite element analysis, resource take-off simulation, construction and building information modelling application tailored to a prefabricated erector-set type design-build system; and (c) Offer insights for the development of cross-disciplinary design activities.

2. Workshop Structure

The workshop introduced architectural and engineering design through a design-built activity of a large scale massing + structure concept prototype for a tall building. Students were divided into teams and called to design, analyse, evaluate and construct "the tallest and most spectacular skyscraper" with respect to constraints such as budget, time, materials and footprint area. Over the course of three days we run five workshops with more than twenty-five teams of approximately five people each (Figure 1).
The scope of a fast-paced exercise cannot encompass the numerous design considerations involved in the design of a tall building. We thus limited the scope to the overall building shape, commonly known as the massing study, which is conveniently compatible with the phase of mega-structure engineering design. We guided students to design a building form, evocative of spatial qualities in terms of scale, proportion and enclosure while considering fundamental principles of structural performance and resource utilization. The workshop brief called for not merely an objectively evaluated tall structure but also an inspiring one. The best design by standing height and tutors vote was awarded with a symbolic design excellence trophy.

The workshop was organized in three segments: (a) Lecture and training; (b) Design and review; and (c) Fabrication and assembly. The initial allocation of time ratios assumed that 10:20:30 minutes as sufficient under the assumption that visitors, parents and students, would prefer to not attend an event longer than an hour. However, after iterations with currently enrolled students we concluded that at minimum an hour and a half was required and optimally the ratios would need to double to 20:40:60 minutes.

3.1. BRIEFING

An introductory presentation on tall building design offered historical background on the evolution of the typology and its relevance today through a series of successful case studies with the goal of adding perspective as well as a lightweight formalization of architectural/engineering design processes. The theoretical component introduced fundamental concepts of loading and static determinacy of triangulated spatial lattices. An interactive training session followed introducing students to our design-computation application. The design brief explained the aforementioned design goals and set the constraint of five thousand virtual dollars spent on building components and real
estate, that is, gross footprint area. Students were provided with workgroup desks, sketch boards and stationary, and a desktop computer with a drawable wall projection surface.

3.2. DESIGN, ANALYSIS, REVIEW

During design and review students discussed their design goals, communicated by sketching, modelled and analysed their designs. Each team was supported by a tutor that offered feedback and assisted with technical questions. The goal of this segment was to challenge the participants into tackling a mildly ill-defined problem bound by multiple and conflicting considerations in provision of the implications of design action from the concept and schematic phases of design to fabrication and construction. Teams were encouraged to form a strategy for whether they would address the design challenge quantitatively, that is attempt to maximize building height; qualitatively, that is attempt to design the most impressive tower, or to find a balance.

3.3. FABRICATION AND ASSEMBLY

In the final segment students were challenged with the physical production of their designs. Their tasks were multiple: (a) Size and cut foam members; (b) Weld multiple parts together into long beams and mount joints; and (c) Coordinate the production, assemble and erect a spatial lattice using ball-joint connectors. Those tasks require role specialization, tight teamwork and strong coordination. Tutors assisted by demonstrating the necessary procedures and taking care of safety.

A ball-and-stick construction system (Figure 2) was developed along with the simulation tool. It was comprised of partially prefabricated components: (a) Extruded polystyrene foam beams sized to 50x50x1200mm; (b) Floor-balls drilled at various angles serving as nodes; (c) PET bottles used for joinery whereby the nozzles were heat shrunk onto the end of the beams such that a member would screw directly onto the nodes using the bottle caps (already attached on the balls). Longer elements could be produced by heat welding two or more beams using the middle portion from a PET bottle, while shorter elements could be cut to size via supplied hot wire cutters. Cable ties between the ball-joints and bottle caps where used as tolerance buffer in case of fabrication errors. Effectively the students had to follow a building scheduling information sheet produced by our software, fabricate the members, weld end-joints and assemble their structure.
4. Design-Computation

The software was developed with interactivity as a key priority such that geometric, structural and resource simulations would be integrated into a limited in scope but comprehensive design workflow. The application was derived from previous work of Kaijima & Michalatos (2008, 2012) and integrates computer aided design, finite elements analysis and building information modeling. The challenge of designing the application to enable novices not merely to rapidly acquire the skills required and interact with the tool but most critically to think, analyze, evaluate, build and assemble their designs. This required a subtle balance of simplifying processes and hiding technical details without removing the opportunity to acquire intuitive understanding of the underlying principles and also provision of design actions and their repercussions in both quantitative, such as structures, and qualitative, such as spatial and formal sophistication.

The software is comprised of a number of design perspectives: (a) Idea Sketching: where students modelled a design in three dimensions; (b) Statics: where the structural behaviour of the construct can be evaluated in terms of deflection due to self-weight; (c) Stability Test: where the tower can be tested under lateral loading, (d) Visual Simulation: a perspective where the final artefact can be visualized; (e) Construction: where information about fabrication and assembly are displayed to hint of the construction effort and complexity of a design (Figure 3).
4.1. COMPUTER AIDED DESIGN

The user interface was designed such that students could rapidly acquire 3D drawing skills. The modelling perspective supported only three actions: (a) Creation of beam element assisted by automatic node generation and coordinate fusion; (b) Transformation of elements which restricted manipulation to translation in three directions; and (c) Disposal of nodes and beams. Beyond those operations students had to familiarize themselves with typical CAD camera/view operations such as pan, zoom and orbit.

4.2. FINITE ELEMENTS ANALYSIS

Skyscrapers were modelled as networks of elements and nodes and FEA was performed to observe the structural behaviour towards self-weight and pseudo wind-load scenarios which are important for tall buildings. Prior physical tests were conducted in order to calibrate the physical behaviour that is, the polystyrene beams and the simulation tool. The joints were calibrated to take approximately 30% of the moment in the structural analysis. The limited number of elements allowed for real-time analysis of stress information at interactive speeds. In order to simplify interpretation of the structural behaviour and ensure that students would not build structurally unsound towers we incorporated a safety standard, displayed as a traffic light, signalling the green for deflections of no more than 3cm, yellow for less than 5cm and red for over 8cm.
4.3. BUILDING INFORMATION MODELING

Design metrics such as buildings height, gross area, material resources consumption, number of parts, virtual cost information where updated in realtime to provide direct metric design feedback. The notion of virtual cost was pre-calibrated to retain the overall design complexity to manageable levels and serve as a composite feasibility indicator. In addition the construction perspective displayed geometric data such as the beam member lengths and topological information such as the node and element adjacency numbers, to simplify fabrication and assembly respectively.

5. Evaluation

In the skyscraper workshop, students with no prior architecture or engineering background were called to design and construct a large scale skyscraper mock-up, with results as high as six meters tall, in a short period of time of no more than two hours. Construction exceeded the time requirement due to geometric complexity which signals the need for further assistance and time-compression via perhaps rationalization and automated generation of assembly instructions. Even though no student left the workshop due to time constraints, we feel that it would be more beneficial to expand the design time. The cost and preparation time of prefabricated parts could also be improved in order to reduce material waste and simplify pre-fabrication efforts.

Overall, students expressed their excitement and a sense of achievement for the learning experience, using a sophisticated design tools, even though they didn’t necessarily understood its underlying complexity, and constructing hands-on artefacts as sketched on-screen. This is true for teams comprised of boys, girls and a mixture thereof. For many it was the first time to engage in building physical prototypes and/or performing an intellectual + physical activity as part of a learning experience. The scale of the model as mentioned was instrumental in fostering collaboration. Students found design evaluation by peer review surprising as their prior educational experiences were based on standardized tests the validity of result was never within the subjective opinion of an expert but rather impersonal or objective.

All teams produced a unique design, some of which were quite surprising even though the quite limited problem space. Students relatively quickly understood the benefits of a prismatic structures, a series of connected triangular plans arrayed vertically, as efficient in material use and stability, yet they persisted in achieving designs which were not archetypal by deforming the geometry to achieve a gestural design; increased the complexity of their designs by adding structurally extraneous members; or by incorporating decorative elements, such as flags and spires to differentiate their designs. We al-
so noted teams that attempted to bypass the design process by moving onto construction with no clear design plan. This was with both successful but generally unsuccessful consequences. In a particularly interesting case a team did not design, measure or cut any element but built a purely canonical modular tower using the provided elements. Many others in similar fashion and without any encouragement from the tutors towards that direction attempted to optimize the expended effort.

6. Conclusions

The role of computer aided analysis and design tools offers certain interesting observations. Interactive media allowed high school graduates with no prior experience in sketching to effectively communicate and coordinate. Students attempted to express ideas using the sketching material but given their limited skills to convey those ideas via drawings they quickly moved to 3D modelling. In fact the experience of modelling using the limited repertoire of add, move and remove element, was simpler or no more complex than any human-computer interaction they already familiar through mobile devices or computer games. Interestingly, the level of direct feedback offered by simulation was rather not surprising to them but expected.

Structural simulation paired by our explanation of the principles of rigidity ensured a small number of tower collapsed due to flawed structural design. Those were predicted but students felt ambitious to attempt challenging the results in hope of achieving higher designs. The most interesting challenge was the difficulty of correlating digital and physical reality in terms of fabrication complexity. Their structures required substantial effort in construction: using irregular or long members, with no attempt of rationalization, multi-element node joints and designs that had no concept or plan for their erection. The complexity thereof was only realized during assembly. The notion of virtual cost as an aggregate design constraint criterion was relatively helpful to the degree it was used as an optimization metric to achieve the largest design minimizing material resources. However we observed limited cases where the presence of a notional monetary quantity distracted students from exploring what their design was trying to achieve qualitatively.

To the degree that we can convey but a mere glimpse, a low resolution version of the design process, through a two-hour long exercise we find that we successfully managed to expose students to a range of design activities which capture the broad spectrum of the design from its inception, development and realization. The degree students internalized some or more of those aspects is unclear; they did express various degrees of comfort and excitement in the creative conceptual phase, communication and coordination, pro-
totyping and assembly processes and combinations thereof; however the end result, a product larger than an individual, in both terms of collective effort and physical size, that transformed itself from virtual to physical seemed to be highly rewarding. In this context and demographic perhaps the most valuable lesson a student can gain through this type of learning experience is the idea of design is a creative process that engages ones all senses while being structured, methodical and constructive.

Acknowledgements

We would like to thank the SUTD-MIT International Design Centre for supporting the Sky-scraper Designette and the staff of the Office of Education for the effort in coordinating.

References

Frey, D. D, Horton, A and Somerville, M. 2002, Breaking the ice with prospective students: A team-based design activity to introduce active learning, In the Proceedings of the American Society for Engineering Education, Boston, MA, USA.