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THE HEADSPACE PROJECT

Computer-Assisted Fabrication as an Introduction to Digital Architectural Design

STANISLAV ROUDAVSKI[1] AND ANNE-MARIE WALSH[2]
The University of Melbourne, Melbourne, Australia,
1. stanislav @stanislavroudavski.net, 2. amwalsh@unimelb.edu.au

Abstract. Written for architectural educators, this paper discusses whether digital fabrication can be usefully employed in early architectural education. The paper uses examples from a course that aims to introduce the fundamentals of digital architectural design to first-year students. To achieve this, the course integrates digital fabrication as the core element of the production workflow. Challenging but rewarding, early adoption of digital fabrication exposes students to the process- and material-based thinking of contemporary architecture at a time when they form lasting attitudes to designing.

Keywords. Architectural education; digital fabrication; digital architectural design; creativity; process-based designing; performance-based designing.

1. Introduction

Architectural education needs to respond to the rapidly increasing utilisation of computation in architectural design. Digital fabrication in particular is gradually gaining prominence as a fundamental shift in design development and construction (e.g., cf. Kieran and Timberlake, 2004; Addington and Schodek, 2005; Kolarevic, 2003; Sass and Oxman, 2006). Being able to fulfil "informed *manufacturing* potentialities [becomes] a principal strategy in realising innovative contemporary architectural design intentions" (Kolarevic and Klinger, 2008, p. 7). The contemporary condition of rapid change and intense experimentation poses a difficult challenge for architectural education because architecture schools have to introduce the new knowledge in parallel with its emergence. Major transitions are difficult for educational institutions that have established curricula, ways of thinking about architecture and employees educated within previous paradigms. It is easier to introduce experimental techniques in smaller graduate courses that attract experienced students already interested in digital creativity. Indeed, the pioneering of new approaches to date has largely occurred in such courses, often lead by influential practitioners (Oxman, 2008, p. 100). This is understandable given that undergraduate courses commonly have larger class sizes and involve students that lack specialist preparation or proven commitment. Utilisation of digital fabrication in foundation courses is particularly unusual. The closest example we could locate is Özkar's (2007) description of a first-year course that introduces learning by making in the context of design computation. Motivated by similar concerns, this implementation still seeks to provide an analytical foundation for future experimentation at the graduate level and does not engage computation for first-year project work, preferring to introduce relevant methods with analogue means. However successful, small studios utilising digital fabrication at the graduate level cannot reach all students or institute an early acquisition of relevant mental and practical habits. When Bauhaus or VHUTEMAS presided over similarly major shifts in design education, the acculturation to the new ways of thinking in the foundational courses was deemed essential (Khan-Magomedov, 2000; Wingler et al, 1969). Engaging with this challenge, this paper discusses a foundation course that introduces the emerging principles of digital architectural design through digital fabrication.

Early design studios

The design studio is an essential device of architectural education. It supports experimental exploration of concepts, representations, materials and processes, introducing students to the designerly ways of thinking. Its usefulness as a place of learning through making is confirmed by the artisan traditions, Dewey's (1916) philosophy of education, Bauhaus's *Vorkurs* and recent research (Temple, 2007).

The role of the first-year studio is particularly important. It helps students to form initial ideas about design and architecture, to establish the foundations of their personal creative practice or – as legitimately – to convince them not to specialise in architecture. These first encounters with designing introduce students to wicked problems and the ways to tackle them. Most new architecture students need to abandon their preconceptions about designing (for a parallel discussion, see Temple, 2009) because their understandings of creativity are often naïve and their knowledge of useful architectural precedents – minimal. Moreover, design studio work typically requires significant transformations in learning behaviour, away from habits formed during pre-architectural education. Such transformations can be challenging and uncomfortable. To minimise their re-occurrence, it is important to initiate students into creative processes able to provide an enduring foundation for their learning and practice.

Digital design thinking

Discussing the challenges for architectural education in his work on design pedagogy, Oxman (2008) persuasively argues that contemporary design teaching needs to be founded on new digital design thinking rather than on templates typical for paper-based workflows. Today's computational capabilities introduce associative and performance-based processes that were not available in the pre-digital era. These new methods change the conventional relationships between such fundamental categories as ideation and making or form and material. Reflecting the new capabilities afforded by computing, recent architectural theory moved away from once dominant notions of formal knowledge, typology and representation to new concepts that prioritize dynamic generation in response to performance criteria and the linking of design development to the affordances of material systems (e.g., see Kipnis, 1993; Eisenman, 1999; Kwinter, 2001; Kwinter, 2008; Lynn, 1999). The need for change can be even greater in foundation courses that typically focus on explorations of shape, colour, rhythm, light and idiosyncratic experimentations with materials (Boucharenc, 2006) rather than on issues of performance, generation and emergence. The new emphasis on processes and materiality requires new vocabulary, new domain knowledge, new practical skills and – consequently – new approaches to teaching.

2. Structure of the course

The paper illustrates its discussion with examples drawn from one course, a constituent of a Bachelor of Environments program at The University of Melbourne. This course, entitled Virtual Environments, is intended as an introduction to the use of representation in architecture, landscape architecture, urban design and other allied disciplines. The course is structured around a practical project – called HEADSPACE – that necessitates learning about design precedents, encourages understanding of digital architectural design theory and convinces students to develop essential skills through practice. The HEADSPACE project asks students to design and build geometrically complex sculptures that can be made from paper and worn on the head (details are available on request, for more, see: http://vimeo.com/13719923).

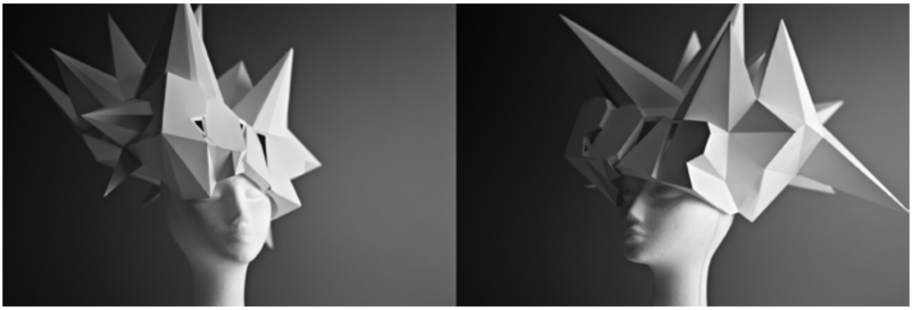

Figure 1. A headpiece design by Laura Ng; semester 1, 2010.

The course consists of four modules. In Module I (*Engender*), students use drawings and physical scale models to develop three-dimensional forms from the analyses of dynamic processes. In Module II (*Digitize & Elaborate*), students use orthographic projections, contouring techniques and/or point clouds to describe their models and convert them into three-dimensional computational representations. These representations are then modified and extended with digital modelling techniques. In Module III (*Fabricate*), students use computer software to unfold their models into two-dimensional components that can be cut out of paper. These components are then used to manufacture self-supporting paper structures, manually or with automated cutting machines. In Module IV (*Reflect & Report*), students produce documents describing their projects. These documents include justifications of design logic, evidence of analyses and precedent studies, precise geometric descriptions, how-to manuals and depictions of headpieces in context.

The course is run in challenging conditions. An iteration of the course can attract up to 400 students specialising in a variety of disciples within and outside of design. For many, this is the first course of their introductory year at a university. The course lasts 12 weeks with one 50-minute lecture and one 2-hour workshop per week. Students attend lectures together and are subdivided into groups of 16 for the workshops. Each group has a tutor who meets the students during these workshops. The course is directed by a coordinator with the help of a senior tutor. Due to pragmatic constraints, the students are not provided with permanent studio space or dedicated computers. All software used in the course is freeware: GIMP, OpenOffice and SketchUp.

Previous versions of this course – coordinated by a different team – involved quasi-architectural project content (such as kiosks) and formal exercises (such as the task to represent a set of geometric shapes in orthogonal projections). Motivated by the ambition to teach representation in relationship to the principles of digital architectural design, two semesters ago Stanislav Roudavski (with the help of John Bleaney, the senior tutor at the time) restructured the course to incorporate digital fabrication as its core technique. We adjudged that the building-scale briefs were a distraction for the new students who lacked previous design education. Predictably, their design proposals were uncritical copies of bland (or kitsch) commercial architecture. The complexity of architectural problems undermined students' ability to focus on heuristic, conditional and iterative development. In a course with the institutional remit to teach representation, there was no time to teach design history. Another solution had to be found. By replacing a series of small quasi-architectural projects with one comparatively abstract theme – the headpiece – we were able to free resources that allowed us to accommodate a challenging conceptual change and move from conventional experimentation with different design media to an exploration of digital architectural design with computer-enabled fabrication at its core. As a result, we were able to give students an opportunity to produce completed objects rather than tentative descriptions of proposals, such as drawings or physical scale models. We also asked students to cope with unfamiliar and unusual processed-based themes that discouraged uncritical adoption of existing design solutions or unthinking importation of conventional building types. To encourage emotional investment and make students feel greater responsibility for their projects we organised for the designs to be demonstrated in a prominent public event during a specially staged "fashion parade". For young people whose creative personality is still in formation and who – many as teenagers – are particularly conscious of their public image, such public exposure can be highly embarrassing or highly rewarding. A public event at the end of the course caps a prolonged development process with a distinct and picturesque resolution reframing a potentially dry project as a socially meaningful and emotive encounter.

3. Learning outcomes

The focus on digital fabrication allowed a move away from outmoded emphasis (cf. Oxman, 2008, p. 106) on typologies, formal representations, visual precedents and arbitrary ideas. Instead, the structure of the course prioritises gradual, iterative development that searches for outcomes by exposing initial concepts to different media, techniques, contingencies and materials.

In addition to emphasizing these new concepts, this digital fabrication ascribes new meaning to the traditional tools of architectural ideation and development, including descriptive geometry, paper sketching, collaging and physical modelling. Working with these media within the framework of digital architectural design, students become accustomed to transferring design content into different representational forms and learning their comparative characteristics. Interpreted "as design thinking through iterative stages of visual formal discovery", sketching in paper (or in clay) can be justifiably seen as "the antithesis of the digital 'matter and material' approach." (Oxman, 2008, p. 110) However, these techniques do not have to be bound by such a narrow conceptualisation. Integrated into the process underpinned by digital fabrication, they can instead by interpreted as devices that aid understanding, analysis and discovery. Indeed, as has already been argued (Garvey, 1997), traditional techniques, for example those borrowed from fine art, can enhance and guide digital experimentation. To illustrate, in the Virtual Environments course, students were asked to base their designs on an existing dynamic event, for example that of ink dissolving in water, plant extending towards light, a match bursting into flame, a sand dune pushed by the wind or a stalagmite rising from a floor. Having made a reasoned selection, they had to utilise several forms of representation for the analysis of the chosen phenomenon. This analysis could be conducted through a variety of sampling techniques ranging from a frame-by-frame review of a video sequence to the staging of a practical sedimentation process.

Forms possible via computer-assisted fabrication are unconventional and directly refer to the current state-of-the-art experimentation in architecture. Exposure to such forms and associated methods encourages students to question their preconceptions of architectural designing and its products. Instead of continuing with a typical romantic image of a designer as an idiosyncratic creator, the students experiment with process-based approaches. Because relevant theory and precedents are less obvious to newcomers, the students cannot rely on existing knowledge and have to engage in independent search for the relevant conceptual context and the existing communities of practice. In our experience, this need has the capability to inspire the students and tutors alike. It can also leave behind weaker students who are unwilling to do independent research. Making them understand and assimilate deeper theoretical implications remains our primary challenge.

Introduction of fabrication allows students to develop ideas in response to the contingencies of making, closer to the way design happens in practice and in extension to the more typical approaches to architectural education that support students through ideation but frequently do not provide opportunities to engage with production. (Lara et al, 2009)

The digital fabrication workflow requires coordination between different media and skill sets. By focusing on a holistic challenge of fabricating a complex form, this approach provides a context that demonstrates how multiple types of media satisfy different pragmatic needs. Working on the project, students acquire skills in physical modelling, sketching, drawing, photographing, digitization, three-dimensional modelling, unfolding, fabrication, writing and desktop publishing.

Engaging with such challenges in the context of digital fabrication is particularly useful because it results in easy-to-perceive successes and failures. If the final paper headpiece does not assemble, it is clear that a geometric mistake has been made. As a result, "[w]orkmanship becomes evident as a category of design decision-making, not simply as a by-product or something that might be spoken of at a designer's whim." (Temple, 2009, p. 220)

The introduction of conceptually and technically challenging content is never without difficulties. We could not supply computers or industry-standard software to all of our students. However, this was overcome with the use of free-to-use software and students' laptops. Such software brings limitations but also teaches students to cope with difficulties and acculturates them into online communities that are vital for digital creativity. Similarly, it is still a challenge to find tutors able to teach digital fabrication and – especially – its conceptual implications. This can be partially offset by carefully prepared course content and should improve with time as ideas and knowledge propagate through the pedagogic community. Another difficulty was brought about by our choice of the headpiece as a design theme. Some students struggled to see the similarities between these abstract structures and the larger scale architectural projects despite our efforts to highlight such similarities in lectures. If history and theory on one hand and mathematics and geometry on the other were supporting the theoretical discussions and practical work on digital architectural design, the conceptual implications would be more obvious. As it was, students struggled with the idea of a process as a design theme but many have overcome this challenge successfully, sometimes in truly innovative ways. Finally, complex fabrication workflows requiring multiple versions and frequent remaking tend to consume a lot of time. Sometimes the best students are left dissatisfied because their proposals cannot be faithfully fabricated within a tight schedule. However, such constraints mimic those typical in design practice and produce learning benefits even when the resulting objects are oversimplified or poorly built. As the next section will demonstrate, these difficulties did not stop our students from appreciating the important aspects of the course, producing spectacular results and learning a great deal.

Qualitative educational benefits of this approach are hard to measure. Instead, we prefer to evaluate the impacts of the course through the students' feedback discussed below and appraisals offered by academic and professional peers. The latter included a congratulatory reception of the local exhibitions by academics and others, coverage in press, exposure in more than a dozen international design blogs and admissions into the programs of two international films festivals on art and design (for more, see: http://www.facebook.com/pages/Headspace-projects/152613348100201). This response confirms that the course provided a large group of first-years students an unusual opportunity to produce publicly acclaimed design work; an outcome that we hope can be classed as a benefit.

4. Student response

Student response in a large and complex course operating under multiple and contradictory constraints is also difficult to evaluate. In order to understand it better, we conducted regular formal surveys using anonymous questionnaires that included multiple-choice questions for the collection of quantitative data, specific questions for qualitative feedback and fields for unstructured comments. We also instituted a mechanism for student representation. Each tutorial group of about 16 selected a representative. The academic staff met these representatives at several occasions that allowed discussion of specific issues and opportunistic feedback. Data from the questionnaires, records of the representatives' meeting and the discussions on the online forums have all contributed to the analysis of the student's response and the learning outcomes.

One theme that emerges from this feedback is that students find the approach based on digital fabrication simultaneously more challenging and more rewarding. The difficulty seems to dissuade the ones who are less committed or lack the aptitude: in the second iteration the course size dropped by 30% in the first two weeks. Given other circumstances the discussion of which is beyond the scope of this paper, the ability to select more suitable students in this way is a reasonable outcome.

Many students agreed that the project meaningfully tied together a number of subfields, as one student noted: "excellent idea to get through the entire process from design to fabrication – very satisfying."

One student reported that the subject "required more time than the others to achieve high marks" and yet that he/she (the response was anonymous) "felt the most motivated to succeed in this subject than any other." This comment expresses a common sentiment, especially in the second iteration of the course. At the same time some students felt that the workload was excessive. It is revealing that the number of students that felt demotivated by the workload has dropped dramatically in the second iteration of the course. This is despite the fact that this generation of students had to cope with more challenging project requirements and that the total amount of work had not changed significantly. We reason that perceptions changed so dramatically because in the second iteration we were able to refer to the examples of student work generated earlier. This has helped to illustrate the expectations by demonstrating different types of geometry, expected levels of craftsmanship, efficient types of workflows and so on. A semester-one common comment stating that the "beginning of the subject was too vague, perhaps an example of what we were aiming for could have been shown early in the semester" has largely disappeared in the second iteration of the course.

Students' comments also confirm that the fabrication of a completed object is a useful and satisfying experience, or as one student put it: "seeing your final finished model was rewarding as it was a challenge to create."

Finally, our decision to present the resulting design in a large public event also worked to motivate and reward the digital fabrication work. The "fashion parade" helped to put individual achievements into perspective by exposing them side by side with other, conceptually or qualitatively differing headpieces. "For the amount of work I did on this subject I was a bit disappointed at the marks I received. However comparing my work to others on the parade night I understood that my final fabricated design was at a lower standard; and I know I am still learning so I am happy with the marks I received."

5. Conclusion

As Özkar (2007, p. 100) states, "how the notion of making in the studio prevails in the age of technology remains to be investigated". Seeking to fill this gap, our paper suggests that design projects structured around digital fabrication can be successfully sustained in the context of early architectural education and result in an integrated learning of theory, techniques and creative practices pertaining to the emerging paradigm of digital architectural design. Unusual at the time of writing, such integration in the context of a foundation course is a pedagogical innovation. The suggested approach is characterised by the following important choices: 1) the design project at the core of the course is simple, abstract and full scale; 2) the course allows the student to follow the design process from inception to completion, focusing on processes and gradual iterative development; and 3) the course concludes with a dramatic public event that brings the students together in an emotionally challenging but rewarding setting. The pedagogy discussed in this paper is significant because it demonstrates how architectural education can begin incorporating the influences of computation. Teaching digital fabrication at the very beginning of architectural education transforms students' understanding of design and moulds them as creators. If their understandings become aligned with the state of the art from the very beginning, they gain a lasting foundation from which to plan their education and careers. These effects should be studied better and this paper invites further experimentation. We would also be grateful for feedback or information on other similar courses run elsewhere, if any.

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