UTILISING DIGITAL DESIGN AND RAPID PROTOTYPING TOOLS IN DESIGN EDUCATION

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Abstract. This paper presents a formal framework for utilising different digital design and rapid prototyping technologies in design education. The framework has been applied in a studio created for a mixed cohort of tertiary students from architecture and industrial design. A comprehensive survey was conducted at the end of the course as a means for evaluation, and for student self-reflection. This paper reports the experiences in conducting the studio and the student perceptions of their design processes and outcomes whilst confronting these tools. The paper provides insight into the application of digital design and rapid prototyping tools in design education, supported by a qualitative analysis of the survey result.

Keywords. Student perceptions; digital design; rapid prototyping.

1. Introduction

The increasing adoption of computational design technologies and methods has been significantly changing the way design is perceived, conducted and constructed. The use of leading-edge digital design and rapid prototyping tools has presented opportunities for supporting creative processes across the whole design life cycle (Sass and Oxman, 2005; Kolarevic, 2003). As witnessed in the latest development, they have radically changed design and design education, resulting in innovative design with new forms and processes as well as design theory and pedagogy that support such practices (Oxman, 2007). A wide range of digital design and rapid prototyping tools have been applied in design education over the past decade, and we have witnessed a diverse range of creative outcomes resultant from the processes. Although
the accumulated experiences of applying such technologies has been reported by many design researchers and educators alike, there is a general lack of formal studies that systematically address the application and evaluation of such technologies. As pointed out by Oxman (2007), most educational cases of such, for example, Stavric et al. (2007) were inspiring, yet they were often motivated and influenced by “individuals”, without adequate considerations for a theoretical and pedagogical basis. This paper presents and evaluates a formal framework for utilising different digital design and rapid prototyping tools in design education. The framework has been applied to a design studio for a multi-disciplinary class of tertiary students. The paper will contribute to a greater understanding of digital design and rapid prototyping technologies in design education.

Firstly the paper presents the developed framework: a project roadmap that utilises three main categories of tools involved in a typical digital design and rapid prototyping project life cycle. The framework is applied and demonstrated through the design and implementation of a design studio conducted in 2009 for a mixed cohort of 3rd year architecture and industrial design students. The paper then discusses the evaluation of the tools through a qualitative study that investigates students’ perceptions of applying the tools. A comprehensive questionnaire was designed and distributed at the end of the studio to document and reflect students’ design experiences using the tools. The study specially focuses on two sets of questions: (1) Has the use of the technologies changed the processes and outcomes of their designs, and how? (2) What design and technological factors have the students considered in choosing tools and processes from the project roadmap for design development? Supported by a qualitative analysis of the survey result, the paper aims to provide insight into the application of digital design and rapid prototyping tools in design education, from students’ perspective.

2. The digital design and rapid prototyping project roadmap

The digital design and rapid prototyping project roadmap has been applied as a course framework for the design and implementation of a 13-week design studio, in the School of Architecture and Built Environment at the University of Newcastle, Australia. The inaugural studio was attended by 14 3rd year students from the architecture and industrial design programs. All students had an expected intermediate skill level of applying conventional Computer-Aided Design (CAD) systems such as ArchiCAD and SolidWorks. The aim of the studio is to introduce senior-year design students to the creative and exploratory practice of digital design and rapid prototyping, and to equip the students with the start-of-the-art design knowledge and technical skills that
reflect the contemporary digital design culture. In order to achieve the aim, the syllabus was divided into two main parts. The first half of the studio comprised of dedicated lectures of digital design theories and group discussions on key literature and case studies. The second half of the studio emphasised on the introduction and technical skill development of different digital design and rapid prototyping tools. The weekly studio includes a one-hour lecture / instruction and a two-hour design development / discussion. The assessment items include a design project, and a report that reflect on students’ digital design and rapid prototyping processes.

The roadmap utilises three main categories of tools involved in a typical digital design and rapid prototyping project life cycle. The roadmap also provides a base for students to identify the suitable tools and techniques to form their own “path” for project development, according to their needs. The roadmap as illustrated in figure 1 comprises of three main components: *input tools*, tools that support the development and digitisation of design representations; *design interaction tools*, tools that support digital design interactions for conceptual and detailed design; and *output tools*, tools that support rapid prototyping design representations. Depending on the complexity and the timeframe of the project, the roadmap is recursive enabling further design development, evaluation and refinement.

Common physical *input tools* such as sketching devices and clay models were mirrored with virtual options by utilising digitising devices such as 3D scanners and haptic pen devices to generate the creative forms students desire, without being compromised by their (lack of) abilities in applying particular digital tools. The acquisition of the scanner and haptic pen provides the students with alternative means of generating their digital representations, with an emphasis to support their freeform designs. Sculpted physical models from clay or foam can be scanned into a 3D virtual model. The similar practice can also be conducted solely in the virtual domain by using a haptic pen device that offers clay-like form creation through a digital tactile interaction. 3D freeform design representations generated with conventional CAD software can be challenging and time-consuming in comparison to more geometrically based models, often resulting in restricted creativity and unfulfilled representations of the designers’ intentions. The integration of the scanner and the haptic pen device would, in theory, increase creativity and realisation of intent. However studies into design with haptic devices, and their applications in design education, are particularly limited. Research such as Garcia (1999) centres on sensory evaluation rather than using the functionality in form creation. The outcomes of the design project and students’ perceptions on the particular matter will provide valuable evidence in this respect.
**Output tools** such as rapid prototyping (RP) devices have long been used in industrial design circles and are growing to be a major force within the architectural design process. Prototyping processes such as Computer Numeric Controlled (CNC) machinery and Stereolithographic techniques are enabling designers to accurately realise their concepts developed during their design interactions. Adbullah et al. (2006) comments from an industrial viewpoint that a physical model can help people understand a complex design instantly, which supports the use of RP as a fast, cost-effective solution for representing and evaluating more complex and intricate designs. Successful RP outcomes require suitable CAD strategies as a pre-requisite, which suggests that within the roadmap a process skill graduation must occur for the next design phase to begin.

![Figure 1. The digital design and rapid prototyping project roadmap.](image)

The roadmap is inclusive, which enables students to explore and alternate between the physical and the virtual domains, following the suitable path and finding the appropriate tools for their design needs. It is essential to balance and blend the tools from both domains to ensure that the design process was to operate efficiently but not to be biased to any particular elements or pathways. The roadmap is provided for the students to understand different alternatives and to choose their individualised path through the roadmap in order to suit their needs and preferences. Schnabel (2004) comments that virtuality can become its own reality to compliment the physical realms. This supports the objective of design exploration and creation using varying realities, whereas the roadmap can be served as a structured framework for creating proven pathways that support such practices. Through tutorials, students are guided to master the tools. Through design exploration, they further understand the advantages and limitations of the tools, gradually refine the design
concepts, and make informed decisions about their own individualised path on the project roadmap.

Introducing advanced technologies in a short timeframe has been identified as a challenge, consequently specific training and support were provided as intensive tutorials. As a result, some high-end digital design tools such as those for parametric and generative design were reserved for the future agenda. Among the technologies listed in the roadmap, focus was given to advanced tools including the 3D scanner, the haptic pen device, the CNC RP machine, the laser cutter and the Fused Deposition Modeller (FDM) RP machine. The tutorials adopt the “learning by doing” principle to familiarise the students with the new hardware and software. In our case, to aid a student’s understanding, learning, selection and application of suitable tools for project development without feeling overwhelmed by the new tools is the key to a successful outcome, within the short given timeframe.

3. The design project and selected outcomes

The studio is exploratory in nature. The design project enables students to explore creativity in design form marking through the introduction and application of leading-edge digital design and rapid prototyping technologies and techniques. Students were asked to design and decorate a dining space as an installation piece to be exhibited at the Watt Space gallery in Newcastle, Australia, creating discussions on contemporary design culture among the design community and the general public. Each student were asked to design and present a prototype of a functional object within the dining space, with a new form that challenges our common perceptions about the object. The rationale of the project topic selection is based on the following: For all designers including architects and industrial designers, form making is an inseparable part of the integrated design process. Forms as an important part of the design vocabulary and the necessity of having designers mastering the arts of form making has always been emphasised in practice and echoed by scholars such as Ching (2007). Therefore an important part of design education is the process of enabling students to explore and exercise form making. This given brief is general and yet provocative, with which we aim to encourage the students to push the boundaries with the newly gained theories and techniques.

In-class competition. The detailed requirements of the design brief were developed through an in-class competition during a gallery visit. The winning design, voted by all participate students, provides a conceptual framework that combines both the eastern and western traditions of dinning and identifies 14 functional areas within the dinning space for individual project development. The setup of the competition increases students’ sense of “ownerships”
of the project and has greatly motivated them.

**Project process.** The students, developed their own selected areas, and collectively formed the dining space in the gallery. Each area is filled with a list of familiar objects. Each student then selected a particular object from the list, and applied suitable digital design and rapid prototyping tools and techniques from the roadmap to transform the selected object, and produce a prototype with a new form that challenges the common perceptions. The generated new form was to critically reflect the digital design theories they have researched; and demonstrate their understanding and technical skills in digital design and rapid prototyping. Post-project, the students collectively constructed the dining space for the exhibition with both the original objects and the new designs presented to show the transformation. Their project progress was managed and evaluated through two minor assessment items: an initial project proposal and a mid-term design review.

**Selected project outcomes.** The 14 designs emerged from the studio have been very refreshing, ranging from forms translated from sound waves, to forms influenced by 4D space, to forms that transforms traditional patterns. The stimulus of the new theories and technologies and the opportunities of the gallery exhibition have been proven effective. Students’ “usual” ways of conceptual development and project implementation have been largely challenged. Although further studies are needed in order to understand the impact of the roadmap on students’ creative development, nevertheless they were able to create a new form for a functional object in a dining space that challenges our common perceptions as required by the brief. The selected projects below showcase some of the works developed in the studio and demonstrate three different approaches to supporting the creative process: (1) by physical design interactions; (2) between physical and digital interactions; and (3) by digital design interactions. Each of which adopt a different path on the project roadmap. Students were able to explore the opportunities presented in different approaches and alternated between the physical and the virtual according to their design needs.

![Figure 2. Physical working model of an origami influenced plate by Henrike Parkhouse.](image)

The first example is a dinner plate design created with the influence of the origami folding techniques. The student was fascinated by the arts of origami and applied for form creation to reflect the eastern theme. Figure 2 shows
three working models for her project development. Here the creative process is largely supported through her physical interactions with the papers and her interpretations of the origami folding techniques. The student then digitised a final version using the 3D scanner to create a digital model, the 3D model was optimised and refined with additional details, and finally a prototype was produced using the FDM RP machine for submission.

The second example is the design of a central display piece for the dinning space, with a reflection on deconstructivism. The student selected a Buddha sculpture as a base for form creation. Firstly she digitised a physical sculpture to develop a digital model (fig. 3 left). The student then explored various techniques in order to deconstruct the digital model. The slicing technique (fig. 3 middle) was selected as the mean to deconstruct the model into horizontal and vertical profiles. The developed profiles were then rapid prototyped in the laser cutter to develop the final outcome (fig. 3 right). In this case, the creative process was supported between physical and digital interactions, through the digital profiling and the physical assembling.

The third example presents a form for a bowl design that was transformed from sound waves of a music piece. The student’s conceptual development started with the reflection on cultural significance through music. He highlighted the standout frequencies in a visual sense, namely their individual waveforms, and blended them in a 3D space for form creation. The three main stages identified are audio sampling to create sound waves (fig. 4 left);
algorithmic interpretation to create the desired 3D form (fig. 4 middle); and the final rapid prototyping to develop the output (fig. 4 right). The creative process is largely supported in the digital process of algorithmic interpretation from the sound waves to the functional 3D form. The student explored different theories and applications in order to develop a set of constraints for controlling the form transformation.

4. Survey result and discussion

As evident in the designs emerged from the studio, the application of the roadmap as a course framework has enable the students to critically evaluate, explore and select the suitable digital design and rapid prototyping tools to suit their projects and design preferences. Three approaches for supporting the creative process as by physical design interactions, between physical and digital interactions, and by digital design interactions, have been discussed above. To further our understandings of the effectiveness of the tools and the application of the roadmap, a comprehensive survey was conducted at the end of the studio as a means for evaluation of the framework, and for student self-reflection of their experiences. The paper concludes with a general discussion of the survey result, and issues identified for future works.

The questionnaire has three parts including 15 questions. The first part aims to reveal students' perceptions on the effectiveness of the tools and their experiences in applying the roadmap for selecting input tools. The second part aims to study the same issues for selecting output tools. The third part is general open questions that aim to invite more detailed discussions on the issues. Although the survey result is limited due to the small size (14 students) of the studio, nevertheless students' responses and commentaries provide very valuable evidences for evaluating the roadmap and the tools. We synthesised the result in the following two categories with a focus on two specific issues: (1) Has the use of the technologies changed the processes and outcomes of their designs? (2) What design and technological factors have the students considered in choosing tools and processes from the roadmap for developing the design?

Students' perceptions on the input tools. Among the six types of input tools as listed in figure 1, most of the students have adopted more than one type in their project. The selected tools were evenly distributed among physical 3D; physical 2D; virtual 3D – direct; and virtual 3D – free-form modelling. The other two categories of virtual 2D tools have a significantly low preference. It was interesting to note that many students indicated hand sketching (physical 2D) as an important means for conceptual design, yet the majority of students have not used any 2D digital tools.
The main rationales for the tool and process selection were identified as the ability of the tools to support the conceptual development of the project; to support complex or unique form marking, to complete the project more efficiently; and to learn about the new technologies. Students' previous experiences, and existing knowledge and technical skills were identified as less important in influencing their selections. A small group of students indicated that the complexity and technical difficulties of certain tools have influenced their decisions in not selecting those tools.

Among all the input tools, the haptic pen device has been identified as most effective. All 10 students who have adopted the tool in their project commented that the haptic pen device has enabled them to explore different design options, to develop design in a different way from their normal process and practice; and to develop a more interesting / creative design. Students commented positively regarding the capability and flexibility of the tool especially in modelling and form making. The 3D scanner has been identified as least effective as students commented that the scanning process was long and the outcome was not ideal, for which they would have preferred direct 3D modeling with other CAD applications.

**Students' perceptions on the output tools.** Among the five types of output tools as listed in figure 1, over half of the students have chosen the FDM RP machine (physical 3D – rapid prototyping – additive). The rest of the selections were evenly distributed among physical 3D – rapid prototyping – subtractive; physical 2D – standard documentation; and virtual 3D – static documentation. Students who have adopted the FDM RP machine all agreed that the device has enabled them to explore different design options. However, the opinions were largely divided in terms of the abilities of tools to enable them to develop design in a different way from their normal practice; and to develop a more interesting / creative design. The reason can well be that due to the constrains of time and cost, most students considered the prototype produced from the FDM RP machine as their final outcome, and therefore did not experience the full potentials of the rapid prototyping process for evaluating, refining and improving their designs.

The main rationales for the tool and process selection were identified as the tool ability to support complex or unique form marking; and to complete the project more efficiently. A small group of students also indicated that to support the conceptual development of the project and to learn about the new technologies also contributed to their selection processes.

Based on the survey result and reflecting on our own experience in applying the project roadmap for planning and conducting the studio, we conclude the paper with a list of issues for future improvement.
To further explore design interaction. This part of the roadmap was largely unexplored in the current studio. In the survey, students commented positively regarding the introduction and exploration of new digital design theories in the studio, yet there were inadequate conceptual design tools available. Therefore the future plan will include the introduction and tutorial of conceptual design technologies such as those for parametric and generative design. Due to the complexity of the tools, a supporting unit may be required outside the studio to serve as a pre-requisite for the studio.

The cycle of the roadmap is not recursive. Due to the constrains of time and cost, most students considered the prototype produced as their final outcome, and therefore did not fully explore the potentials of rapid prototyping in design. This is an open question for further works in the field.

To explore deeper and more complex architectural issues. The inaugural studio has successfully adopted the digital design and rapid prototyping tools to challenge students in design form making. We aim to further challenge the students with deeper and more complex architectural issues. The future integration of more advanced conceptual design tools will contribute greatly in this regard.

Challenges for large classes. The design outcomes and the exhibition resultant from the studio have attracted greater attention from the student body. We expect a significant increase of student number next semester. While all is positive, the challenges for offering the studio to a large number of students are very great, imposing many pressures on the academics especially in accommodating technical tutorials; on the institutions in providing adequate high-end technologies; and on the laboratory technicians who must ensure and assist the delivery of the prototypes in a timely fashion.

References