A Preliminary Study for a Teaching Framework that Incorporates CAD/CAM Media into the Basic Design Studio

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Abstract. The objective of this research is to apply the teaching of CAD/CAM media to basic design studios for 1~2 year undergraduate students. The research consequently concludes a framework of “e-basic design studio” based on literature analysis and design studio observations, which including the new tectonics thinking and the operation of traditional 2D/3D design media and CAD/CAM digital tools.

Keywords. Design Education; Basic Design Studio; CAD/CAM design media; digital thinking.

Introduction

In the eighties, the digital medium flourished and began to be applied to the architectural field. Since 2000, researchers have been discussing how to apply the digital medium to architectural education and especially how to include CAD/CAM media into the content of design studio and courses, particularly those of MIT, Harvard, AA, Columbia, ETH, etcetera. (Campbell, 2006; Garber and Jabi, 2006; Kalay, 2006; Schoch, 2006). Meanwhile, many researchers start to discuss CAD/CAM digital media from these courses and offer suggestions for architectural design teaching courses (Ceccato, 2004). Through hands-on operation in CAD/CAM design studio, CAD/CAM case studies, and experimental studies of courses, researchers have proposed teaching frameworks which apply CAD/CAM digital media-aided design and manufacturing process (Larsen, et al, 2008). In addition, Barrow (2006) and Iordanova (2007) indicate that the design studios where CAD/CAM media have been applied must contain two-stage teaching; that is, basic skill training courses and advanced digital design creation. As for the teaching in skill courses, researchers also discuss how to incorporate professional systems such as Gehry Technologies or Generative Components (GC) into the teaching framework of digital design studios (Hanna & Turner, 2006).

It is learned, from the above research development, that the current CAD/CAM digital technology has become an important design medium in design and manufacturing process in the digital era. Moreover, how to apply the CAD/CAM technology to designing the studio teaching framework is also a major development in architectural education and research fields domestically and internationally.

These CAD/CAM courses were usually planned for advanced design students (4~5 year undergraduate and graduate students) because of their highly-technical content. In recent years, however, they have become increasingly popular in the architectural design process and education programs that use the digital medium and some researchers have
started to study how to apply digital tools to the basic design studio (Shih, 1996; Chien, 2007). In 1996, Naai-Jung Shih already started to discuss how to use CAD in basic design studios, and offered suggestions for CABD (computer-aided basic design) studios (Shih, 1996). Through case studies and teaching experiments, Sheng-Fen Chien et al. (2007) plan a series of applied CAD digital media-aided design studios according to various levels. These researchers apply the CAD digital media to basic design studios, extend the application of CAD which was used only for presentation in early days, and allow novices to start the application of 3D digital modeling.

**Problem and Objective**

From the courses and researches, it showed that the role of CAD/CAM media in digital age was popularizing and the threshold of learning has gradually decreased. Consequently, it has become critical to include CAD/CAM media and digital thinking into the planning of basic design studio.

The objective of this research is to apply the teaching of CAD/CAM media to basic design studios for 1~2 year undergraduate students. First, the authors will observe some aspects of design thinking and processes using CAD/CAM media by novices. Then, the research will be placed in a framework of “e-basic design studio” based on earlier observations, including the new tectonics thinking and the operation of traditional 2D/3D design media and CAD/CAM digital tools.

**Methodology and Steps**

This research comes in two parts: 1. a literature review, and 2. participant observations on how to shape a teaching framework for an “e-basic design studio”.

**Step 1: Literature review**

In the first step, we integrated “teaching purposes”, “the training of media operations” and “design thinking” into the traditional basic design studio format from collected research data. This included literature analysis and case observations from basic design courses. Then, we integrated the digital media operation and digital tectonics thinking based on the research of Iwamoto (2009) and Liu and Lim (2006). Based on these analyses, we defined “the training of media operations” and “design thinking” in both the traditional and digital design studios, in order to establish a preliminary framework for the “e-basic design studio”.

**Step 2: Participant observations**

As the purpose of this research hopes to propose a teaching framework for a basic design studio, it applies the preliminary teaching framework of “e-basic design studio” to a real course (second year undergraduate basic design studio at Department of Art and Design, YuanZe University) for two design projects. By using participant observations we obtained the data we needed for analysis. From the studio observations in the first design project, we determined the teaching effectiveness and noted some aspects of design in the students’ design outcomes. The teaching framework was modified according to the analysis and applied again in the second design project to validate its feasibility. Finally, we integrated an executable preliminary teaching framework for an “e-basic design studio” for design novices, which included the new tectonics thinking and the operation of traditional 2D/3D design media (2D drawing, 3D modeling) and CAD/CAM digital media.

**Analysis**

**A preliminary framework for the “e-basic design studio”**

**Traditional basic design studio**

**“Teaching purposes”**

The current design education, which offers fundamental “basic design studios” for lower level, originates from the design education in Bauhaus
founded by Walter Gropius. At that time, six-month “elementary courses” were offered. They mainly integrated art, architecture, crafts, science and so on, to offer basic knowledge, techniques, and concepts. They mainly contain “fundamental studies on form”, “fundamental studies on materials”, and “studies on composition” (Wang, 2003). And the teaching goal in these courses focuses on the concept and operation, the development of students’ creative thinking, as well as all kinds of early stage professional training (Ni, 2009). Due to basic design studios nowadays tending to continue and value the teaching meaning of Bauhaus, this research will focus the teaching purposes of traditional (non-digital) basic design studios on the following three points:
1. **Design concepts and operation training.**
2. **Development of creative potentiality.**
3. **Early stage professional design training.**

“The training of media operations”
Design media used in traditional basic design studios are mainly sketches, handcrafted models, and photography. The tools for sketches include pencil, watercolor, charcoal and so on. And more materials are used in model making. Major materials generalized by Naomi Asakura (1992) about the materials used in 3D composition contain paper board, clay, wood, metal, plastic, ceramics, and light. The schools in Taiwan tend to use Styrofoam and pearl board, both of which are easily cut, and resin which is easily shaped. In order to train students to apply various materials to make models, especially the woodworking and metalworking in which special equipments are needed or specific technologies are required, many design departments set up woodwork factories or metalwork factories to offer hands-on operation and teaching. In addition, in traditional basic design education, it is also very often to see students present their design ideas with photography or pictures. As they are still not trained with digital drawing, their photographic works are the easiest and most direct way to present the tableaus. Hence, this research concludes the media application training of traditional (non-digital) basic design studios into the following three items:
1. **Sketch:** sketches drawn with drawing tools such as pencil, watercolor, and charcoal.
2. **Handcrafted model:** models made with materials such as paper board, clay, wood, metal, plastic, ceramics, light, Styrofoam, pearl board, and resin.
3. **Photography:** an easy presentation way to select and cut tableaus, and to be the medium to present design ideas.

“Design thinking”
Shun-Chen Ni (2009) integrates several important operational practices in traditional basic design studios, including simplification, 2D composition, 3D composition, and material studies, in his research. These practices are all based on basic training emphasized in Bauhaus education, which are basic knowledge, skills and concepts of “form”, “materials” and “composition”. In these operational processes, “form” design thinking training is mainly to transform abstract conceptual thinking into thinking (simplification, 2D composition) presented with 2D drawings, and then further transform it into thinking (3D composition) presented with 3D model. Especially for operational practices in departments like architecture and industrial design, 2D thinking will be developed into 2.5D first, and finally transformed into 3D thinking. For example, the most common design topic “transformation of 2D graphics into 3D” in architecture basic design studios. Besides, as for the media used in design presentation, students are trained to know and study characteristics of different materials. Therefore, it is necessary to include the selection and understanding of materials in design thinking. Meanwhile, in design presentation, no matter it is 2D drawings or 3D models, students are trained to creatively compose different graphics or materials based on basic elements of composition: point, line, plane, solid, and space. In the process of composition, especially in 3D composition, the construction methods of materials and structure
relationships will be taken into consideration. “Operation and regeneration of objects”, a most common design topic in architecture design studios, is to train students to magnify small objects in their lives and re-compose them with their own interpretation of composition and construction methods. Therefore, this research concludes the design thinking training of traditional (non-digital) basic design studios into the following four items:

**Form**: abstract concepts à 2D sketches à 2.5D models à 3D models.

**Materials**: thinking about characteristics of materials and how to apply.

**Composition**: thinking about different graphics and materials composition based on composition elements, including point, line, plane, solid, and space.

**Structure**: thinking about structure of form and materials in 3D composition.

**Construction**: thinking about construction of different materials in 3D composition.

Digital basic design studio

*“Teaching purposes”*

This study attempts to train design novice familiar with digital design process. So it’s essential to teach the operation of digital tools in basic design studios. At the same time, design novices are trained to familiar with the integration of using traditional and digital design media in their design process. The digital basic design studio will extend the teaching purposes of traditional (non-digital) basic design studios, as it will adding the digital media training associate with computer courses or workshops. It contains the following two points of teaching purposes:

1. **Digital design concepts and operation training.**
2. **Integration of using traditional and digital design media.**

*“Digital media operation”*

In the digital design process, there are software and hardware being used as design media, such as 2D image processing software: Photoshop, illustrator etc.; CAD software: AutoCAD, Sketchup, 3dMax, Rhino, Maya, CATIA etc.; CAM machine: laser cutter, Rapid prototyping (RP), CNC, 3D scanner etc. The operation of these CAD/CAM design media enable to produce 2D/3D drawings and 3D physical models. CAD only used to represent 2D drawings and 3D modeling before. However, the applications of CAD/CAM design media enable to fabricate physical models from the complicated 3D model data precisely. This digitized model making or manufacture process called digital fabrication. The process of digital fabrication is first build 3D design form using CAD software with different modeling method: surface control point editing or parametric design. Then, transfer the 3D model to readable file for CAM machine. Finally the physical design components or model will be fabricated by CAM machine. As this operation is different with traditional model making process, lمامة (2009) concludes 5 types of digital fabrication techniques: sectioning, tessellating, folding, contouring, and forming. These operations only teach in higher grades’ computer courses in many schools at present. The aim of this study attempts to train design novices the basic operation of digital CAD/CAM media. Hence, this research concludes the media application training of digital basic design studios into the following three items:

1. **Digital 2D drawings:**
   a. 2D image editing: using software such as Photoshop, illustrator etc.
   b. 2D plan, elevation drawing: using CAD software such as AutoCAD.
2. **Digital 3D model:**
   a. Use surface control point editing as modeling method: CAD software such as AutoCAD 3D, Sketchup, 3dMax, Rhino, Maya, CATIA etc.
   b. Use parametric as modeling method: CAD software such as Rhino Grasshopper, Maya Mel, 3dMax script etc. This operation able to build complicated freeform model.
3. **3D CAM physical model:**
   a. Laser cutting model: Decompose 3D model to
2D components, transfer the 2D data file to laser cutter machine for cutting. Then assemble the cutting components to 3D physical model. The cut materials are cardboard, acrylic, wood etc. Fabrication techniques include sectioning, tessellating and folding.
b. RP model: Export 3D model to .iges file and sent to RP machine, then physical model are fabricated layer by layer precisely. Materials used are ABS, resin etc. Fabrication techniques include tessellating.
c. CNC model: Fabricate the physical model by subtract the material. The mostly used materials are wood block, acrylic, ABS, PU foam, aluminum etc. Fabrication techniques include contouring and forming.
d. 3D scanned model: Physical model is scanned to become point cloud, and export to 3D model.

“Digital tectonics thinking”
The using of different design media will change the design thinking in the design process (Lim, 2003). The author conducted protocol analysis to compare design thinking of using hand-drawn sketches and computer pen-based sketches, and consequently concluded that digital pen-based sketches have more visual feedback to affect designer’s design thinking (Lim, 2003). Some researchers also analyzed the comparison of design thinking in using traditional handcrafted model and digital 3D model. They pointed out that 3D modeling easy to modify and the “zooming” operation can aid the design detail and scale controlling. However, 3D model lack of physical characteristic. Hence, the applications of CAD/CAM design media are becoming general at present in order to fabricate the physical model through the 3D model data. Meanwhile, the evolution of modeling method from intuitively control point editing to mutative parametric modeling provide the liberty of form generation. In order to explore the tectonic thinking of using CAD/CAM media in design process, Liu & Lim (2006) analyzed 15 digital design cases and integrated a preliminary framework of new tectonics involving classic and digital thinking. It includes 7 traditional tectonics factors: joint, detail, material, structure, construction, and 4 digital tectonics factors: animation, generation, information, fabrication. Furthermore, in order to understand deeply how CAD/CAM media aid design thinking, the author concluded design thinking using different CAD/CAM media (laser cutter and RP) by conducted cognitive experiment (Lim, 2006):

Laser cutter: The fabrication of physical model is based on 2D cutting process. A complicated or free-form 3D CAD model is decomposed to 2D skin and structure elements which can fabricate by laser cutter. Then, the output physical elements are assembled to a complete model. It is more realistic to the real life construction method. It is able to facilitate the design thinking of structure.

Rapid prototyping: The fabrication of physical model is based on 3D manufacture process. A complicated or free form 3D CAD model is produce directly to a complete 3D physical model layer by layer. Designer need not worry about the difficulty of making the complicated forms. It is able to facilitate the design thinking of form.

It can be understand that design thinking in using digital media different from the traditional design process based on the research results mentioned. Especially the digital form generation aided by CAD operation, model fabrication aided by CAM machine, and the accurate characteristic of digital tools enable designer to consider detail, dimension and scale aspect. Therefore, this research concludes the design thinking training of digital basic design studios into the following three items:

4. Digital form:
   a. Abstract conceptsàpoint editing controlà3D digital modelà3D CAM physical model (RP).
   b. Abstract conceptsàparametric settingà3D digital modelà3D CAM physical model (RP).

5. Digital tectonics:
   a. (Laser cutter) 3D digital modelà2D dismantlingà3D assembly. It is able to facilitate the design thinking of material, structure and construc-
b. (Rapid prototyping & CNC) 3D digital model: 3D CAM physical model. It is able to facilitate the design thinking of form.

6. **Digital accuracy:**
The “zooming” operation in CAD modeling can aid the design thinking of detail. The output of CAM physical model aids the design thinking of scale.

**A preliminary framework for the “e-basic design studio”**

Based on the previous analysis of traditional and digital basic design studio, this study conducts a four modules teaching framework which emphasize the four design stages: conceptual design, preliminary design, detail design and manufacture. In the early stage, especially conceptual and preliminary design, apply the training of traditional design media. In addition, the training of using digital CAD/CAM media applies to the model making, detail considering, and manufacturing modules. A preliminary framework for the “e-basic design studio” which integrates the using of traditional 2D/3D design media and digital CAD/CAM media is concluded as Figure 1.

**Participant observations**
The “e-basic design studio” framework integrated in Step 1 was applied to a real design studio (second year undergraduate) at Department of Art and Design, YuanZe University, which have 17 students in the studio. By using participant observations, we obtained the data we needed for analysis from two different design projects during a semester (18 weeks). We determined the teaching effectiveness and noted some aspects of design in the students’ design outcomes. The teaching framework was modified according to the analysis and applied again in the second design project to validate its feasibility. This study chooses 5 students’ results for analyze according to the completeness and evaluation from teacher. The following describes the design process and results.

**Design Project 1: Transformer furniture design**

1. **Aim:** Training students to transform 2D graphic to 3D thinking. Meanwhile, teaching the integration of using traditional design media and digital CAD/CAM media (laser cutter).

2. **Design topic:** Find the natural pattern from nature, develop three kinds of continuous 2D pattern, and then transform to 3D design of deformable multi-functional furniture. Complete the design in 1:1 physical model using acrylic and wood materials.

3. **Design media:** Traditional design media (sketch, handcrafted paper model); digital CAD/CAM media (AutoCAD 2D, laser cutter)

4. **Design outcomes:**
   Module1 (1 week): Conceptual design

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<thead>
<tr>
<th>Module1 (Conceptual Design)</th>
<th>Media operation</th>
<th>Design thinking</th>
<th>Media operation</th>
<th>Design thinking</th>
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<tr>
<td>Traditional 2D/3D media</td>
<td>Photography</td>
<td>Design concept</td>
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<td>Sketch</td>
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<td>Digital CAD/CAM media</td>
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<td>CAD model</td>
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<td>Digital accuracy (detail, scale)</td>
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<tr>
<th>Module2 (Preliminary Design)</th>
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<th>Design thinking</th>
<th>Media operation</th>
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<tr>
<td>Traditional 2D/3D media</td>
<td>Sketch</td>
<td>Form</td>
<td>CAD drawing</td>
<td>Accuracy (detail, scale)</td>
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<td></td>
<td>Handcrafted model</td>
<td>Material</td>
<td>CAD model</td>
<td>Digital Form</td>
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<td>Composition</td>
<td>CAM physical model</td>
<td>Digital tectonics</td>
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<th>Module3 (Detail Design)</th>
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<th>Module4 (Manufacture)</th>
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<th>Design thinking</th>
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<td>Traditional 2D/3D media</td>
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<td>CAM physical model</td>
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*Figure 1: A preliminary teaching framework of “e-basic design studio”*
Figure 2 (left) Figure 3 (right)

Figure 4 (left) Figure 5 (right)

Figure 6

5. **Summary:**
From the design outcomes, it shows that the students thinking start from 2D transform to 3D by using drawings and models representation. Some students used digital tool (Photoshop) in Module 1 to transform (copy, rotate, scale) the patterns. As they are just start being trained in using CAD/CAM media, they still used many handcrafted models in Module 3 instead of making CAM models. Based on these aspects, the framework was modified as following:

*Modify 1:* Add “digital 2D drawing” in Module 1.
*Modify 2:* Add “3D CAM physical model” in Module 2, to train the using of CAD/CAM media ahead.

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Figure 2 shows the designs presented by hand drawings, photographs, and Photoshop drawings.

**Module2 (4 weeks): Preliminary design**
Figure 3 shows the designs presented by hand drawings and handcrafted model (2.5D→3D model).

**Module3 (2 weeks): Detail design**
Figure 4 shows the designs presented by CAD drawings and handcrafted model.

**Module4 (2 week): Manufacture**
Figure 5 shows the manufacture process. Students used laser cutter to cut the design components and assemble, worked in the woodwork factory. Figure 6 shows the final 1:1 acrylic deformable multi-functional furniture design.
Design Project 2: Personal reading space design

1. **Aim:** Training students to interpret 1D text (Literature) and develop to 3D spatial design. Familiar with their body and spatial relationship, consider the structural design thinking. Meanwhile, teaching the integration of using traditional design media and digital CAD/CAM media (Styrofoam cutter).

2. **Design topic:** Interpret 1D text (description of the space) into 3D space design through reading short essays. Develop 3D personal reading space design based on the body posture and text strokes. Complete the design in 1:1 physical model using Styrofoam materials.

3. **Design media:** Traditional design media (sketch, handcrafted Styrofoam model); digital CAD/CAM media (AutoCAD 3D, Styrofoam cutter)

4. **Design outcomes:**
   - **Module 1 (1 week):** Conceptual design
   - **Figure 7** shows the designs presented by hand drawings, photographs, Photoshop drawings and CAD dimension drawing.
   - **Module 2 (3 weeks):** Preliminary design
   - **Figure 8** shows the designs presented by CAD drawings, handcrafted models, 3D models, CAM physical study models (Styrofoam cutter).
   - **Module 3 (2 weeks):** Detail design
   - **Figure 9** shows the designs presented by 3D simulations, 3D models (sectioning model) and CAD drawings (components and units).
   - **Module 4 (3 week):** Manufacture
   - **Figure 10** shows the manufacture process. Students used Styrofoam cutter to cut the design components and assemble them. **Figure 11** shows the final 1:1 Styrofoam personal reading space design.

5. **Summary:**
   From the design outcomes, it shows that the students thinking start from 1D text transform to 3D spatial by using drawings and models rep
presentation. In this project, students are more familiar in using CAD/CAM media; they fabricated their study models (CAM models) in Module 2 with the aid of Styrofoam cutter a lot. As they can easily modify their design in 3D model, they rely on digital tools in Module 3 to prepare the drawings for fabrication. Based on these aspects, the framework was modified again as following: Modify 3: The use of traditional design media in Module 3 become optional.

Results

From the analysis of design outcomes, it is clear that after applied the “e-basic design studio” teaching in the two design projects, the students (design novices) were trained well to be familiar with the implementation of both traditional 2D/3D media and digital CAD/CAM media in their design projects.

This research produced an executable teaching framework suitable for the “e-basic design studio” (Figure 12). We propose a new teaching method for design novices in the design studio that integrates both traditional design media and digital CAD/CAM media in the design process. In addition, this research draws some conclusions regarding the design outcomes and processes for the “e-basic design studio”:

1. Design novices are more focused on their design concept development when using traditional media but more attentive to the scale, material, structure and construction procedure when using CAD/CAM media.
2. Design novices are able to think about the construction procedure during the assembly process.
3. Design novices are more familiar with the conversion of 2D/3D design thinking in the process of integration of traditional and digital media.
4. The design outcomes can be more precise in any scale models; and can even produce works at a scale of 1:1.

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