Strategic Thinking on the Redesign of a Foundational CAAD Course:

Towards comprehensive training on digital design

Antonieta Angulo[1], Joshua Vermillion[2]
[1,2]Ball State University, Department of Architecture, United States of America
[1,2]http://arch263bsu.wordpress.com
[1]aangulo@bsu.edu, [2]jdvermillion@bsu.edu

Abstract. *The paper describes a new implementation of an existing course on digital design and its contribution to the curriculum of the undergraduate pre-professional architecture program at Ball State University. The strategic thinking behind the re-design of this course reflects not only the need to update its content to reflect the state-of-the art in the domain but also responds to a diversified context that exhibitschanging trends due to digital culture, use of digital media in learning and practice, and educational policy. The paper elaborates on these larger contextual elements and describes the new instructional methods implemented through a modular framework of assignments and a multi-layered delivery system. The paper concludes with a series of recommendations for the future improvement, constant assessment, and further development of the digital design course.*
Keywords. *Digital Design; Instructional Methods; Parametric Thinking; CAAD; Fabrication.*

BACKGROUND

The paper describes the new implementation of an existing course on digital design (ARCH263) and its contribution to the curriculum of the undergraduate pre-professional architecture program at the Department of Architecture in Ball State University. This course was and continues to be the only required regular course directly related to digital design in the curriculum. The ARCH263 is offered every fall semester to sophomore students and also to career-change students aspiring to continue into the master of architecture program. The new implementation of the ARCH263 was deployed during the last academic semester (2011) for a population of 80 students distributed in three sections in the sophomore level and one section in the career change level. Each section had an instructor who was also supported by a teaching assistant. The classes met two times a week for one hour and 45 minutes in each class.

The main reason that triggered the initial impulse to re-design the course resided in the need to update its content to reflect the state-of-the-art in the domain. We are aware that digital design is a domain that closely relies on information technology and that dependency drives constant change in the content and the format through which the teaching and learning of digital design conventionally happens. Accordingly we have revised the as-

signments on a yearly basis and have introduced major modifications every three years. In the last revision of the course during the summer of 2011, we realized that the changes in information technology were only part of a larger context that was also changing and required a strategic response. The larger context is diversified and exhibits changing trends due to digital culture, use of digital media in academia and practice, and educational policy. The contextual elements that were taken into account to determine the instructional methods implemented in the course are described below.

Digital culture: who do we teach?

Manovich (2001) stated that *"today we are in the middle of a new media revolution -the shift of all culture to computer-mediated forms of production, distribution, and communication."* Our students are the so called college millennials (Strauss and Howe, 1991) who have grown up with digital technologies integrated as an everyday feature of their lives: for school, work and entertainment (*Pew Research*, 2010). Our college millennials are natives (Prensky, 2006) in the digital world. They are used to receiving information very fast, do parallel processing and multitasking, they prefer graphics over text, they prefer random access to information instead of a set order, and they are used to networking and working in groups. They are usually more eager to try out a new software program before reading the manual. They are users of all the different types of social media (i.e. Facebook, Twitter, etc.); they are experts at distinguishing the relevant facts from information pollution and usually take a critical stance towards their sources. Our college millennials exhibit basic digital literacy that involves more than the mere ability to use software or operate a digital device; it includes a large variety of complex cognitive, motor, sociological, and emotional skills, which users need in order to function effectively in digital environments. Accordingly, the ARCH263 reflects the student's ability to speedily and successfully achieve computer aided architectural design (CAAD) literacy and dedicate more time and effort to exploring digital methods to undertake project-specific designs. The ultimate goal of this course is to install in the students the ability of learning how to learn to use the ever-evolving digital resources and to understand its significance in their design projects.

Use of digital media in academia and practice: what should be taught?

Historically a CAAD course had as primary goal to instruct on how to produce drawings. Through time we saw that by producing 3-dimensional digital models it became easy to generate not only the visualization documents but also the construction and analysis information. Nowadays, most progressive practice and academia would agree that the goal is not only learning software to produce building information; it is about learning to design with the digital media in every stage of the project. In learning to design with digital media the emphasis mainly gravitates on exploration and validity of design principles and design processes (representing alternative solutions and diagrams of interdependency) and less in the attainment of a design product (producing final building documents).

The area of concentration in our foundational course is the "digital expression of the building form" (Szalapaj, 2005) designed during conceptual stages of a project. By borrowing this concept from Szalapajon the three core aspects of the application of information technologies to design practice, we are interested in the ways in which computer modelling systems can be used to manipulate shape during the design process. We specifically teach how to create geometries that resemble the form of architectural objects and we instruct about the parameters, variables, constraints and basic aesthetic and performance-oriented objectives that concern the creation of form. To fulfil these teaching objectives we have selected 9 commercially available applications (including plug-ins). This group includes the categories of 3D computer graphic software, vector graphic editors, video-editing software, raster graphic editors, computer aided design editors, and html editors, mainly from McNeel, Autodesk,

and Adobe software houses (Rhino, Grasshopper, Panelling Tools, 3DS Max, Architectural Review, Photoshop, Illustrator, Dreamweaver and Premiere). We have chosen these applications because they cover a broad spectrum of skills, they are compatible with our peripherals (printers, plotters, etc.), have easy inter operability, and because we have seen them successfully used in conceptual stages of design.

On operability terms, we see that in academia and practice there is a gradual shift towards implementing collaborative, open environments where screens, printers and other peripherals stand ubiquitous and are available to accessing the information and communicate with design partners via digital networks. Since our department has a strong emphasis on digital fabrication, we also strengthen the relationships between digital design and digital fabrication. We instruct students on how to use laser cutters and 3D printers. We give only 11 main lectures for the whole student body and implement working sessions in smaller groups per section. The students have cold desks elsewhere to work with their personal laptops through wireless networks that connect them to peripherals distributed throughout the building.

Educational policy: how it is delivered?

Educational institutions in general and public institutions in particular are pressed to articulate maximum effectiveness in the objective of providing high value. That objective combined with the social and political framework in which state-funded institutions must operate results in a quest to generate a large number of graduates, in the shortest time possible, and at low cost. As a result our mandate is to reduce our undergraduate programs to a maximum of 120 credit hours (*Associated Press*, 2012). Currently operating at 126 credit hours with courses that exceed the relation of credit hour and instructional content, it is not possible to assume that our curricula will support more credited content. This implies that ARCH263, our required course in digital design will remain unique in the curriculum; becoming the cornerstone for further individual student-led learning in the subject.

The educational policy framework of our institutions has therefore a substantial impact on our instructional strategy. Because we are aware that we will not be able to teach everything our students may need to learn, it becomes imperative that we support the process of learning to learn in a proactive way. We also know that this particular domain is in constant evolution and that periodical formal retraining processes would not be practical in contrast with the more sustainable approach of continuing professional development. In that context, it is important to develop a learning environment that is similar to the environment in which our graduates will continue to learn. The implementation of student owned computing policy and the eradication of commodity-level computer laboratories are important steps in that direction. In such an environment the students are largely autonomous in their choice of hardware, system configuration, and networking attitude. At the same time, our institution is freed from the fiscal responsibility to implement and maintain traditional computer labs and can concentrate in supporting higher-end infrastructure that in terms allows our students to have access today to resources that will be mainstream technologies when they graduate.

Beyond the process of learning to learn and how our instructional strategy may support that process, we must also keep in mind that the course on digital design stands within the curricula that supports other learning threads and that those threads can and should also support learning in digital design. For instance, in lower-division undergraduate studios we concentrate on fundamental design issues such as form-giving, and it is in part because of that reason that our course is in particularly robust on software that supports management of geometrical modelling;facilitates crossing back and forth between the digital and analog domain through scanning and prototyping; and provides exposure to state-of-the-art knowledge that will be predominant when the students graduate a few years down the line(namely parametric modelling). In similar way, as the student makes his/her way into upper-

division undergraduate studios and acquires knowledge on building materials and systems, workshops in the application of building information modelling and database management becomes supported and the students are exposed to software usage (i.e. Revit, Ecotect, etc.) in accordance with progressive practices understanding once more that such knowledge will be predominant when they soon graduate. Additionally, other advanced simulation and parametric modelling techniques (i.e. Grasshopper, Digital Components, etc.) are also taught in specialized courses within the certificate of Digital Fabrication of the graduate program. Finally, as the student moves into graduate school and it is required to perform a period of professional internship, we expect that the student will be exposed to a current digital productivity environment that combined with his/her constantly updated knowledge of digital design will allow them to be competent in the customary professional environment.

THE NEW DIGITAL DESIGN COURSE

In the re-design of the course there were two questions to be answered: how to teach digital media and how to teach to design with digital tools. In our CAAD course the students are made aware that a computer can be used as a productivity tool, but we rather use it as a tool for learning and design. First of all, we believe that digital media should "provide a good conceptual model and make things visible" (Norman, 1988). Four operational principles explain how to achieve modelling and recognition of the digital tool affects: visibility, affordance, natural mapping, and feedback. Whenever the students use digital media, students will function best if they can understand how these tools work, which actions may actually be carried out, and the effect of their actions on these tools on the resolution of the overall design task. As a consequence, all our instructional resources, including tutorials and guidelines, were explicit and non-ambiguous; all suggested digital processes and expected results were overt and subjects of demonstration. We showcased parametric modelling tools, and demonstrated through examples not only the results of the process, but also tried to render the computational black box transparent explaining the inputs, outputs, relationships, propagation, modification, and variation of parameters.

Moreover we believe that the most effective way to teach digital media is in the context of their application in a design task. The design tasks are embedded within a modular framework of assignments. In the recent past our students have implemented design processes that are iterative in nature and rely on the production of vast amounts of representations that inform about explorations, evaluations, and adjustments. The design ends when the alternative at hand somehow satisfies the briefing in the time allocated by the project; but there is no warranty that the final result is the most efficient or the most creative. Due to lack of prior knowledge and experience, our students -who are novice designers- usually spend vast amounts of time understanding the context and constraints, and searching for a viable solution; they spend less time evaluating and adjusting and therefore generate few or no alternative solutions. Conventional CAAD offers many tools for modelling, rendering, and animation in support for the creation of representations that these conventional design processes require.

The new ARCH263 introduces the concept of parametric thinking (Moussavi, 2011) into the conventional design processes hoping to push the boundaries of conventional design reasoning to make explicit the relationships of the design aspects and parts. Parametric thinking entails that designers explain how things relate and how by modifying the variables and/or the relationships between the variables we can generate alternate solutions that respond to the same context. In this way parametric thinking supports the processes of evaluation and adjustment that are mostly disregarded by the students. Our ultimate pedagogical aim in this regard is to create a cognitive shift in our students' design thinking -from generating form as a purely aesthetic concern- to understanding and valuing the connections and dependencies between form, materials, and performance.

We believe that the constructivist approach can support the learning and instruction of digital design as it follows a parametric thinking design process. A constructivist approach to education implies that learning is the active process of constructing rather than passively acquiring knowledge, and instruction is the process of supporting the knowledge constructed by the learners rather than the mere communication of knowledge by the instructors (Jonassen, 1997). In this approach, the role of the instructor is regarded as of a facilitator. In our course the instructors give general guidelines as to how the design problem may be approached. It is important to highlight that the instructors of the different sections have the expertise to teach design studio classes. The constructivist instructional methods that we have implemented can be described as follows:

- The assignments describe a significant design task for the generation of creative geometrical solutions in the context of a well-defined problem. The instructors provide resources "scholarly scaffolds", that inform about methods on how to solve the problem. In a process of **assimilation** (Piaget, 1950), the students should recall prior design knowledge (i.e. relevant cases)and integrate new knowledge with old. By recognizing the suitability of the digital resources, students should learn on demand the tools and the processes needed for each particular task.
- Students are expected to follow an iterative trial and error process until reaching the desired result. It is a dynamic process through oscillations between prototyping, testing, and accommodation. **Prototyping** is implemented by undertaking constant switches between representations in physical and digital media. The students are able to consider the design alternatives from different points of view. Modelling methods include the creation of 2-dimensional and 3-dimensional geometries using vector, surface and solid techniques. A select taxonomy of digital fabrication tools, strategies and methods (Schodek et al., 2005) are used by the students for physical prototyping. Visualization is instrumental through state-of-the-art global illumination techniques for rendering and animations. **Testing** the design results against meaningful criteria encourages the students to establish and discern about design values, and undertake strategic decision-making between optimization and satisfaction of design concerns. Parametric modelling is implemented through simple scripting and graphic algorithm editors and offered to the students as snippets they can use to test the performance of their designs. This testing triggers reflection on students who become aware of the role of variables and parameters and the relationships between the parts of the design. The understanding of the parametric relationships helps them to formulate a new solution through accommodation (Piaget, 1950). **Accommodation** leads into the creation of new prototypes or adjustment of old ones. Only if the parametric relationships exposed during testing are well assimilated, the students can be introduced to geometry generation through parametric modelling or to follow a conventional linear process of modification.
- Final reflection about the experience is implemented with online design journals for metacognitive reflection. Self-evaluation of the different design processes and results are made explicit by each student through brief writing assignments at the end of each assignment. Each assignment had a questionnaire for the students to respond and record their own understandings of their process and result.

Using these instructional objectives and adjusting to the constraints imposed by the context, we have implemented the new course through a modular framework of assignments and a multi-layered delivery system.

	Webpage Journal	Patterned Screen	Urban Tower	Undulating Wall
Drafting	Layout planning + draft	2D Pattern; CAAD Operations + Transformations	Laser Cutting Files	Diagramming
Modeling + Testing		Model space navigation; Light Apperture Testing	Surfacing + form making; structural skeleton development; geometric transformations; Occlusion Testing; Gross Area Calculation; Massing Envelope + Setbacks	Component modeling; surface tiling; meshing; Lighting scenario tile generation; Occlusion Testing
Rendering		Mental Ray daylighting system; material mapping; basic shaders; target camera animation	MR daylighting systems; intermediate shaders; free camera animation	Interior rendering; electric lighting systems; advanced shaders; interior animation
Fabrication		Laser cutting 2D patterns	Laser cutting: 3D Model > 2D Components > 3D Assembly	Manual Clay modeling; 3D Printing
Communication	Graphic Design; HTML web skills	Web page documentation + journal	Web page documentation + journal	Diagramming; webpage documentation + journal

Figure 1
Excerpt of skill set matrix, overlaid with specific design assignment.

Modular framework

The new ARCH263 aims to provide awareness of a wide range of design-oriented programs, techniques, and skills. But beyond that general objective, we have sought to promote the understanding of five distinctive skill sets, namely: drafting, modelling, rendering, fabrication, and communication. Each assignment required the student to incrementally learn about each kind of skill.

The instructors proposed four separate assignments over the semester as shown in Figure 1. The web page journal was a graphic design oriented assignment for posting student work and explaining process. The three other assignments used patterning and repetition as generative design motif. The projects are described as follows:

- In the second assignment students were asked to design two flat "Patterned Screens" for filtering sunlight through an existing building façade.
- The third assignment dealt with the design of an "Urban Tower" form with a patterned structural envelope system. Fabrication of this assignment focused on prototyping a three-dimensional assembly from two-dimensional components.
- In the fourth assignment students designed three-dimensional solid components that were aggregated into an "Undulating Wall" system.

In each project emphasis was given to external and internal parameters for the generation of patterns and forms. Testing these against specific criteria allowed students to interrogate the many connections between geometry and performance. Parametric thinking was framed to the students as a way to manage the complexity of each project, while improving design schemes to meet performance goals in an iterative fashion. For each project, the students were required to create an array of literal (pictorial) and analytical (diagrammatic) representations (selective examples shown in Figures 2, 3, and 4), revealing different stages of the design process, as they were used as elements of testing and reflection.

Figure 2
Example "Patterned Screen" assignment including a graphic pattern composition (left), exterior rendering of the screens in context (centre), and a laser cut scaled panel prototype (right).

Figure 3
Example "Urban Tower" assignment including (from left to right) a occlusion testing, structural system development, exterior rendering, and scaled laser cut model.

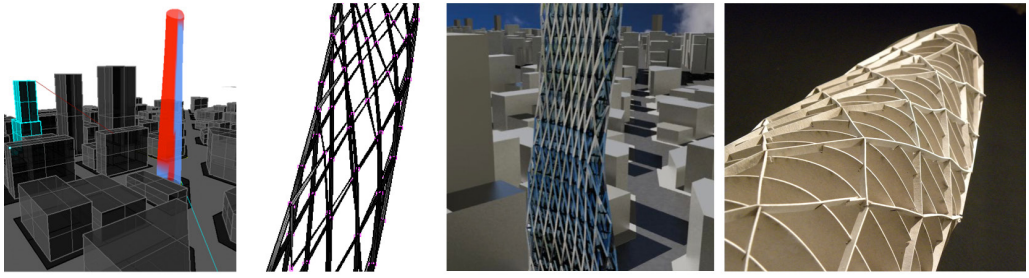
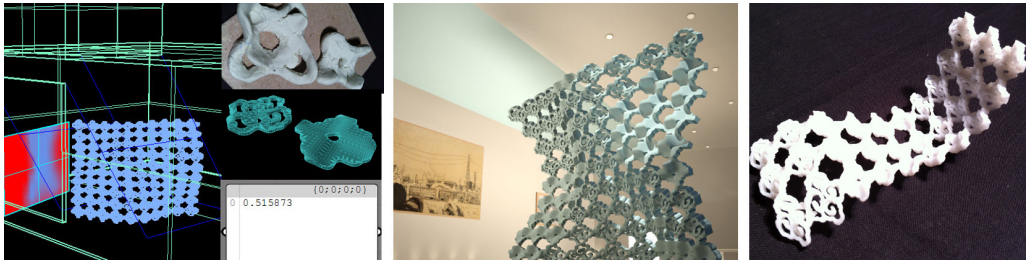


Figure 4
Example "Undulating Wall" assignment including component development in clay (physical) and Rhino (digital) along with occlusion testing in Grasshopper (left), interior rendering (centre), and 3D printed scaled model (right).



Multi-layered system

The characteristics of the multi-layered system of delivery are described as follows:

Redundancy of information: The lecture classes that are mandatory for all the sections of the course are recorded for voice-over explanations and viewing of the interactions on the screen. These recordings are edited and made available online immediately after the actual class. The guidelines and procedures explained in the lectures are available also as tutorials; these are used by the teaching assistants to help the students as needed.

Sharing of resources: All the class resources which include PPT presentations, tutorials in text and animated formats, scripts, image libraries, and some executable applications were prepared by the instructors. These resources are shared inside common archives with access online.

Multimodal channels: Although we teach the millennial generation, not all students have the same proficiency in the use of digital tools for design. We offer several multimedia formats to adjust to their different learning styles.

Student-centred instruction: The most important skill that we can convey is to "learn how to learn" the relevant skills for digital design. Many tools will become obsolete and many others will emerge, thus the students are encouraged to step into the process of being aware, acquire understanding, and practice using suggested methods but to reflect and choose the most satisfactory and time-effective strategy.

Scalable effort: The students may vary considerably in their capabilities and aptitude to search for innovative solutions. We encourage them to explore solutions beyond the standard expectation and support individual advanced exploration.

Practice-based learning: The students are required to practice extensively and therefore develop strategies that yield the most effective results. Students need to learn what they can reasonably accomplish in a set amount of time and maintain a well-articulated workload for a practical expectation of success.

The blog of the course [1] gives evidence on how we have implemented the delivery system; it is a hub for many links to students, instructors, teaching assistants, access to course information, and access to resources dealing with the solution of assignments: tutorials, lectures, scripts, and others.

FINDINGS AND FUTURE ENHANCEMENT

After the deployment of the course we have obtained relevant data sets from class observations and learning outcomes of 4 sections. This information has provided us with positive indicators of the effectiveness of the implemented instructional methods. Additionally, we have also obtained feedback from the students as data taken from their online journals. The feedback has shown positive indicators of students' level of satisfaction regarding the instructional methods and their perceived learning. Some of our findings after this implementation are elaborated separetly.

Even though the digital culture is pervasive in our actual society we have not yet reached a "plastic range" in the training of digital media in design. High-impact tools would demand new digital skills (i.e. algorithmic and analytical skills) and a new attitude towards design (i.e. parametric thinking). We have taken a step forward to cultivate parametric thinking among our novice design students, but sustained effort is needed.

Educational policies applied to universities seek a balance between skills, credentials and cost; our digital design course must adapt itself to the current policies and with a pragmatic attitude it must progressively demand strict pre-requisite skills (i.e. image editing, 2-dimensional vector drawing, WYSWYG web editing, and document editing) and discriminate what can be left to self-teaching when domain-knowledge is available (i.e. building information modelling and database management, performance simulations).

Our organization of assignments within a modular framework that encourages the learning of the same diversified set of skills on an incremental basis had a positive outcome and high level of acceptance among students. One semester after the entire sophomore class has been exposed to the new ARCH263 we see them extensively applying these newly acquired skills in other courses, especially in design studios.

The results of the instructional objective in regards to instilling the skills of parametric thinking were difficult to quantify. We have observed that all of the students have used the available small, custom-written end-user scripts and Grasshopper plug-in definitions to test the design performance of their best options. We have also observed that most of the students understood the logic behind the causal relationships among the parameters in their projects' outcomes. Most students have discovered the inner workings of parametric thinking. Only a few of them considered it practical (due to time constraints) to learn parametric modelling and explore a large array of alternatives; conversely, to finish the assignment on time they identified the direction of improvement/modification using the conventional digital means they had utilized and reached a satisfying solution. The design results of the class were more believable; they showed a mature aesthetic

concern validated by selected performance issues. We need to unify the efforts of studio instructors to promote the practice of parametric thinking we have introduced through this course.

The content and objectives of the course are vast and ambitious but they have been encapsulated into a system that delivers high-impact results through the use of redundant, decentralized, and multimodal resources. We have reached a balance between cost and expected outcomes. This is a three credit course offering that implies nine hours of study and three teacher-student contact hours per week. However, the instructors and teaching assistants are available on-demand to guide the students. Beyond that we assume that the students are in control of their learning and are responsible to self-regulate the time and effort to be invested. The following are few recommendations for the immediate enhancement of the course:

- Provide specific tutorials about parametric scripting and representations. Additionally, complement the discovery method on parametric structures based on class assignments with in-depth explanations of how to formalize design intent, design constraints, and design variables. The use of case studies will be promoted.
- Create more opportunities to handle physical media (1) through traditional models prior to the use of digital processes and representations, and (2) through digital prototyping for the sake of testing concepts.
- The online journal can be improved to re-direct the attention of the student to find the usefulness of the skills to resolve an expanded set of design problems; and to learn to adapt and combine methods of digital design for similar problems.

REFERENCES

Associated Press 2012, "Indiana places new limits on college credits," in *Evansville Courier & Press News*, Posted March 7. Last accessed on May 12, 2012, http://www.courierpress.com/news/2012/mar/07/indiana-places-new-limits-college-credits/.

Jonassen, DH 1997, "Instructional Design Models for Well-Structured and Ill-Structured Problem-Solving Learning Outcomes" *Educational Technology Research and Development,* vol.45, no. 1, pp. 65–94.

Moussavi, F 2011, "Parametric Software is no Substitute for Parametric Thinking," in *The Architectural Review*, Posted September 21.Last accessed on May 12, 2012, http://m.architectural-review.com/8620000.article.

Norman, DA 1988, *The Design of Everyday Things*. New York: Doubleday.

Pew Research Center 2010, *Millennials: Confident. Connected. Open to Change in Millennials: A Portrait of Next Generation*. Last accessed on May 12, 2012, http://www.pewsocialtrends.org/2010/02/24/millennials-confident-connected-open-to-change/.

Piaget, J 1950, *The Psychology of Intelligence*. New York: Routledge.

Prensky, M. 2001, "Digital natives, digital immigrants."*On the Horizon.*vol.9 no. 5, pp. 1-6.Last accessed on May 12, 2012,http://www.marcprensky.com/writing/Prensky%20-%20Digital%20Natives,%20Digital%20Immigrants%20-%20Part1.pdf.

Manovich, L 2001, *The Language of New Media*. Cambridge, MA: MIT Press.

Schodek, D, Bechtold M, Griggs J, Kao K, and Steinberg M 2005, *Digital Design and Manufacturing: CAD/CAM Applications in Architecture and Design*, Hoboken, NJ: John Wiley & Sons.

Strauss, W and Howe, N 1991, *Generations: The History of America's Future, 1584 to 2069*. United States: Quill.

Szalapaj, P 2005, *Contemporary Architecture and the Digital Design Process*.Amsterdam: Elsevier, Architectural Press.

[1] http://arch263bsu.wordpress.com.