A COMPARATIVE ANALYSIS OF THE TOOL-BASED VERSUS MATERIAL-BASED FABRICATION PEDAGOGY IN THE CONTEXT OF DIGITAL CRAFT

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Abstract. This study presents the comparative analysis of two undergraduate courses which focus on introducing digital fabrication to design students. The duration of the compared courses are 5 weeks and 7 weeks respectively. The study employs action research methodology, while the theoretical lectures, weekly exercises, materials, fabrication tools and techniques, and students' outcomes were used as data sources. Particularly the material-based pedagogy and tool-based pedagogy of the compared courses are evaluated in relation with the tools, materials and techniques. The outcomes of the study is expected to provide insights for instructors and design students in the context of digital craft.

Keywords. Digital Craft; Fabrication Techniques; Design Pedagogy; Tool-Based Fabrication; Material-Based Fabrication.

1. Introduction

Over the last decades, there has been a growing interest in the integration of required skills for digital fabrication with design education. One of the challenges in digital fabrication pedagogy remained as how the skills might be introduced to undergraduate students while they have not gained enough experience in designing. Digital fabrication in architecture (Kolarevic, 2003) and architectural pedagogy (Duarte et al., 2012; Celani, 2012; Blikstein, 2013; Sharif & Gentry, 2015; Varinlioglu et al., 2016; Pitkanen et al, 2019) is not a new topic. Apart from the changing student profiles, the increase in access opportunities of architecture schools to digital fabrication tools, the diversification of techniques and methods used, and the material-based experimental approaches make it necessary to discuss the pedagogy of digital fabrication again and again. Adopting from Sheppard et al. (2008), Celani (2012) introduces three pedagogical models ranging from the most defined to open ended approaches called controlled experiments, semi-structure experiment, open experiments and projects. This paper focuses on open experiment models in architectural education with a special emphasis on two lenses conceptualized as tool-based and material-based fabrication pedagogies as delineated in Figure 1.

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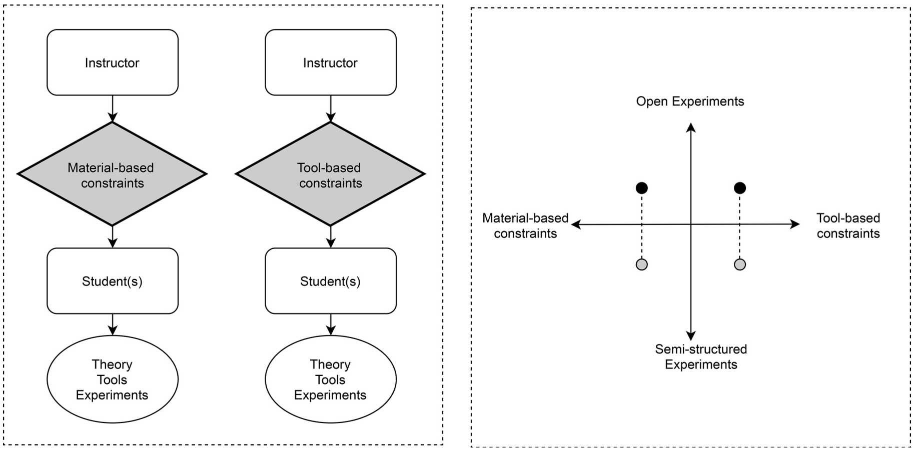

Figure 1. a: Adopted from Celani (2012:476). b: Experiment-constraint relationship.

2. Digital Fabrication Pedagogy

Design Pedagogies have been controversial for decades. Regarding the reflection of the digital fabrication tools, techniques, methodologies into architecture education, there can be listed three transformative factors that have been influential in shaping today's pedagogical models. Over the last two decades, it has been getting easier for architecture schools or architecture students to access tools for digital fabrication. The second factor is the change in the actions of designing and making with the transformation of the design-production flow into integrated processes such as file-to-factory, design-to-production. Relatedly the growingly body of knowledge and complexity of the processes in design and fabrication necessitated novel approaches. The third is the paradigm shift from “instructive” teaching to active learning approaches (Vrouwe et al., 2015), giving the due to students.

Further to the establishment of the Center of Bits and Atoms (CBA) in MIT Media Lab in 2001, institutionalization of digital fabrication laboratories continued with an increasing momentum (Url-01). This development affected the motivation to define a minimum common denominator for the tools that should be in the digital fabrication laboratories and also provide these production tools for architecture schools. Apart from the concrete tools available in FABLABs, this situation also led to the formation of an abstract maker culture and the spread of do-it-yourself (DIY) techniques.

Fabrication labs deal with several parameters in which a designer has to manifest and demonstrate an algorithmic design to the real world with multiple scales as a prototype or scale 1:1. Reflections of fabrication labs into academia have faced multiple challenges due to students' different hands-on design or algorithmic design skills. Oxman (2007) offered ”fabrication-based” design and ”digital craft” terms. Oxman's (2007) digital craft term suggests the design process, guided by fabrication rather than production as a result of design. Therefore, the reciprocal information flow between the designer and the design object, material and digital model, analog and digital, prototypes and their iterations enable a rich potentialities domain for designers. Celani (2012) provides a comprehensive overview on the reflections of digital fabrication on architectural curricula, underlining the challenges of introducing digital fabrication technologies to novice students who have limited knowledge of parametric/algorithmic/computational design methods and limited experience in design. In this case, existence of complementary courses or workshops on specific skills such as scripting, programming, parametric modelling; specific techniques on analog or digital ways of making such as folding, cutting, molding, etc.; and courses binding making processes and design would be also crucial factors affecting students' learning process. Hemsath (2010) discusses the potentials of didactic strategy of teaching digital fabrication in architecture education, while underlining the interconnected nature of the skills such as computational design logic, digital fabrication and programming. Agirbas (2015) approaches digital fabrication as a new mode of sketching in undergraduate level, through insertion of material-based design strategies. Considering the tacit dimensions of interaction between the designing subject and the material space, El-Zanfaly (2015) suggests the term I3 as an abbreviation of imitation, iteration and improvisation. In El-Zanfaly's (2015) proposition, human as a perceiving and experiencing subject is considered as a crucial part of a situated craftsmanship activity. Fabrication laboratories or FABLABs provide a collaboration ground for students, and teachers or instructors to investigate materials' potentials and different tools or machines throughout a design process. Considering the pendulum between open-ended design activities and structured exercises, Pitkänen et al. (2019) uses the term ”scaffolding”.

2.1. TOOLS AND TOOLING

The digital fabrication tools that can be used in a design are directly related to the materials selected and the desired production time depending on the budget of a project. Another constraint is available technology which covers not only the mechanical parts of a tool but also software, processes, operations and the flow of information. When we add the designer to this equation, topics such as the interaction between the designer and the tool, the creative use of the tools by the designer, and the designers discovering new tools needs to be discussed. Therefore, different than merely using a tool, tooling is a versatile and multifaceted concept that is not easy to unfold without appropriate contexts.

Computer numerical control (CNC), laser cutters, rapid prototyping and 3D printing machines, robotic arms can be listed as the most common digital fabrication tools. Apart from the digital fabrication tools, analog/conventional tools for trimming, cutting, filing or forming are widely used in model making processes. Modelling, prototyping and fabrication processes in architecture are conducted with concepts of computational design thinking. Gonenc Sorguc et al. (2019) underlines the priority of creating an awareness on emerging technologies instead of merely teaching the tools.

Communication with the different design models through an analog, mechanic, and digital processes is a cyclic and open-ended activity that provides insights to designers. Aranda and Lasch (2006) investigate the tooling concept through a series of design processes. In those projects “tooling” becomes a medium in which different techniques such as spiraling, packing, weaving, blending, cracking, flocking, and tiling (Aranda and Lasch, 2006) manifest themselves in geometry, form, material, and experiential representations.

Digital fabrication tools and processes necessitate relevant types of data, therefore the way information is coded as data matters. Translation from one mode of representation to another is required at every step of design and production process. In some tools, this conversion process is automated. There are many conversion processes including but not limited to conceptual model to design model, geometric model to topological model, digital model to production model, one scale to another; 3D CAD model to GCode, and vice versa. Regarding the rapidly changing nature of digital fabrication technologies the mechanical components of tools and their end effectors, soft components (graphical user interface, algorithms and software) and their versions, computer aided representations of design models, materials can be considered as active agents of a digital fabrication process, apart from the designing human subject. In this context, instead of defining a concrete body of knowledge in the architectural curricula, providing temporal scaffolds (Pitkänen et al., 2019) for introducing the tools becomes more crucial.

2.2. MATERIALS AND MATERIALITY

Oxman (2010) discusses materiality as a design driver in the context of new materialism. In this conception, material properties inform form and structure decisions in a bottom-up design strategy by incorporating physical form-finding strategies with digital analysis and fabrication (Oxman, 2007; Oxman, 2010).

Beorkrem (2007) introduces a wide range of material techniques and strategies with a specific focus on wood, metal, concrete/masonry, composites/plastics, and recycled/pre-cycled materials. The notion of materiality in the context of digital fabrication is closely connected to the affordances of tools and the interaction between the materials and the techniques applied. When it comes to digital fabrication pedagogy, exploring each material characteristics and potentials in fabrication and design is the first step to orient students into computational thinking design dependent on the used material. Designs have been formed and modeled using multiple substances while nourishing students‘ tactile sense to stimulate students’ sense of material perception and modelling capabilities. Each material varied from rigid to ductile, from porous to solid guides students to use different design techniques to avoid material failure or collapse. Materials with almost opposite characteristics have been imposed to test different modelling and design techniques through a material-based fabrication process.

2.3. FABRICATION STRATEGIES: TECHNICS AND ACTIONS

Aranda and Lash (2006) used a classification of a series of actions that ultimately elicited specific behaviors, namely spiraling, packing, weaving, blending, cracking, flocking, and tiling. Iwamoto (2013) directly focuses on the action and considers actions as a particular function of material. In other words, actions such as sectioning, tessellating, folding, contouring, and forming are considered as both material techniques and design strategies in Iwamoto's (2013) conception. Considering open-ended processes of design and fabrication, the list of the actions can be expanded by designers depending on the needs and feedback from experimental trials.

3. Methodology

Digital and analogue fabrication relies on multiple parameters and variables as illustrated earlier. The study employs action research methodology, while the theoretical lectures, weekly exercises, materials, fabrication tools and techniques, and students' outcomes were used as data sources. The students are expected to gain an understanding of a variety of tools, techniques, materials, and their use in architecture in the context of digital fabrication and gain insights into the workflow and data flow in CAM processes, as well as gain hands-on experience on representing and producing complex geometries by using digital modelling and fabrication tools in both of the courses as learning outcomes. Another common factor between both courses is the fabrication of both geometric and organic forms using multiple fabrication design-based techniques like contouring, repetition, recursion, rotation, folding, stacking and assembling. The main difference between the mentioned courses is the pedagogical strategies namely tool-based and material-based that were employed.

3.1. TOOL-BASED FABRICATION PEDAGOGY

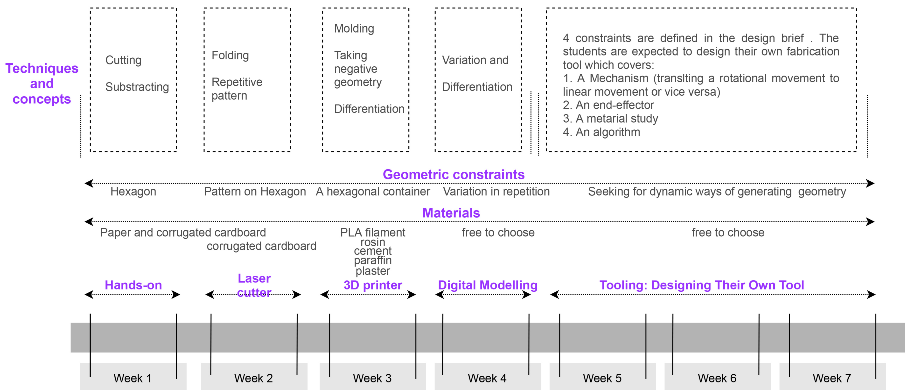

Figure 2. Weekly timeline analysis regarding technique , materials, lectures and concept in a tool-based course introduced to level 2 and 4.

Taught Courses on digital fabrication in undergraduate level aim to achieve new detail solutions for the known design problems, support students' exploring the limits of the material and fabrication strategies in terms of static and dynamic, and developing new and novel-material in the design and construction process, engaging the algorithms and the input collected from physical environmental, as well as test the limits of digital fabrication as shown in Figure 2

3.2. MATERIAL-BASED FABRICATION PEDAGOGY

3D visualization course has focused on developing students' skills through tackling with different materials then manipulating others through digital tools. Digital design has been extensive with metal sheets and paper boards through patterns generation, folding, cutting, and trimming while investigating subtractive fabrication. Then by the end of the course another massive design is modelled using a 3d printer to explore more fabrication. Free-form fabrication has been manifested at the beginning with prototypes using tactile senses on discarded materials, clay, and wire. At the end they follow the same fabrication techniques with scale 1:1 with wooden boards to visualize their designs while adding some textures with patterns using laser cutters.

This material-based course has encompassed three different fabrication techniques while blending digital with analog to fit a tight 5 weeks' schedule. Main sources of inspiration to students are nature (biomimicry), geometry and culture. Shifting their design skills from 2D to 3D forms has been mastered through different tactics include folding, contouring (one-way and two-way as waffle), stacking or packing, Assembling parts from subtraction, repetition of elements or recursion which are the distinctive patterns and strategies of parametric design as yielded in figure 3.

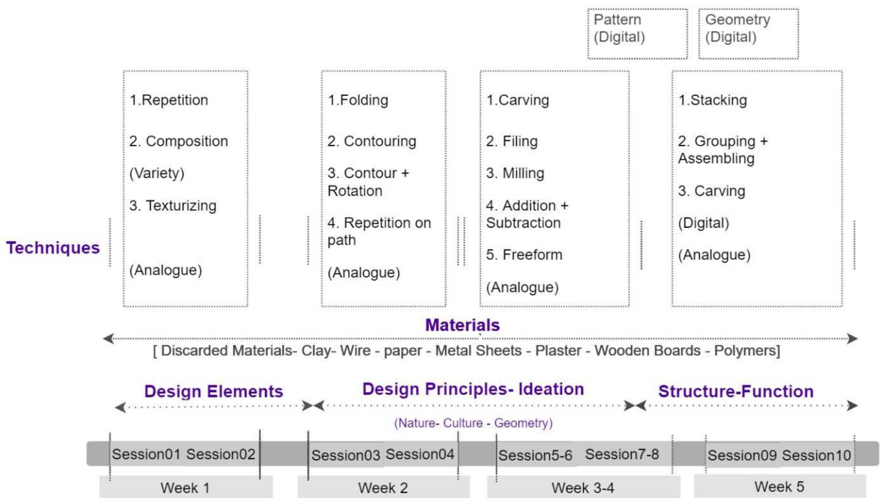

Figure 3. Weekly timeline analysis regarding techniques , materials, lectures and concept in a material-based course introduced to level 2 .

This emphasizes the analog form-finding by well establishing tactile sense with different materials' characteristics and intrinsic boundaries.

4. Case Study

The case study consists of comparison of two undergraduate courses which have been introduced to different student groups relying on their academic level- one is tool-based introduced to level 2 and 3 students - and another is material-based conducted to level 2 students. Each course investigates the current applications of digital fabrication methods in architecture with their theoretical foundations.

4.1. AIM AND SCOPE

The aim of this research is to share both courses experiences and interchange learnt lessons to enhance performance and upgrade digital fabrication pedagogy. Similarities and differences discussion between both curriculum has raised many creative approaches in which both suthers and readers can consider in academia.

4.2. ANALYSIS

Firstly, a material-based course conducted to level 2 students has conveyed multiple materials to stimulate students' tactile senses through exploring different materials characteristics and fabrication potentials as yielded in figure 4. Secondly, a tool-based course presented to level 2 and 3 students has investigated students ability to create their own fabrication tool based on subtractive, additive and free-form ones creating their own process. Design modeling in both courses has benefitted from computational design-based methodology that has oriented the entire fabrication process.

At last, both courses have triggered students' conceptual thinking through the realm of fabrication processes. Both have upgraded their CAM (Computer-aided manufacture) perception in both environments- analogue and digital.

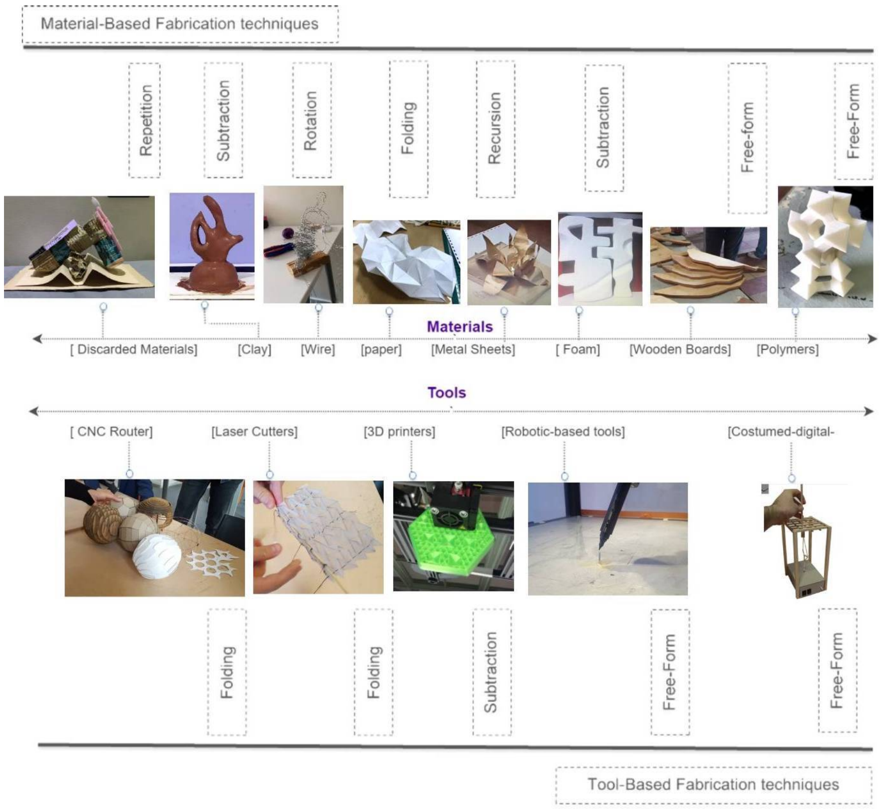

Figure 4. Material-Based fabrication Technique versus Tool-Based one regarding design methodologies; Two courses remarkable students output comparative analysis.

4.3. COMPARISON AND EVALUATION

Both courses attempt to manifest materials and tools manipulation skills of undergraduate students to implement and algorithmic design. Some students have developed a sophisticated mindset to manage digital tools after experimentation the potentials of each material through its physical and mechanical characteristics. However, combining multiple materials and tools together is rather an advanced process that requires more time. Such challenge can motivate students to pursue further exploration in advances courses, workshops, or classes as postgraduate.

Students of both courses tend to manipulate geometric patterns while adopting additive fabrication techniques. Their design potentials were attracted more through combined, morphed and transformed geometries as illustrated in Figure 5.

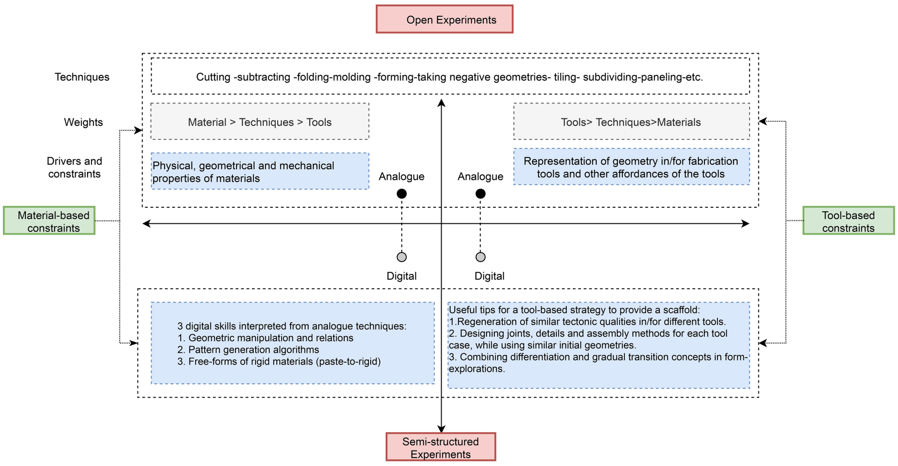

Figure 5. Mapping the pedagogical approaches.

5. Concluding Remarks

This study focuses on the comparison of two courses with similar learning outcomes, in which digital fabrication approaches are taught to undergraduate architecture students. An experiment-constraint relationship matrix, which covers a semi-structured and open experiment axis, as well as tool-based constraints and material based constraints axis was used to gain a better understanding about the teaching process and its evaluation. The main motivation of the study is to evaluate our own teaching methods and make inferences that will be useful for the teaching of the digital fabrication course in the following years.

Initial results show that translation of one form of design information to another, from one tool to another, from one technique to another, from one medium to another, in other words the process of translating the design information has potential to support students' engagement in both cases. In this sense, how to provide common ground and a sense of continuity among different exercises might become crucial. In the presented cases, the notion of scaffolding has contributed a traceable backbone throughout the semester.

Moreover, an open experiment might not be the best thing to start with novice students and get satisfactory results. In the observed cases, semi-structured experiments oriented students toward reliable results which makes them gain more self-confident and encourage them to push their boundaries. The results might be different in the cases where complementary courses focusing on algorithmic/computational thinking skills are available. It can be asserted that semi-structured exercises have potential to support novice students' engagement and motivation in the context of learning and teaching digital fabrication.

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References

"Url-01" : 2021. Available from <https://www.fablabs.io/labs/map> (accessed 07th February 2021).

Agirbas, A.: 2015, The use of digital fabrication as a sketching tool in the architectural design process, *Real Time-Proceedings of the 33rd eCAADe Conference*, Vienna.

Aranda, B. and Lash, C.: 2006, *Tooling*, Princeton Architectural Press, New York.

Beorkrem, C.: 2017, *Material strategies in digital fabrication*, Routledge..

Blikstein, P. 2013, Digital fabrication and 'making'in education: The democratization of invention, *in* C. Büching and J. Walter-Herrmann (eds.), *FabLabs: Of machines, makers and inventors*, Transcript Publishers.

Celani, G.: 2012, Digital Fabrication Laboratories: Pedagogy and Impacts on Architectural Education, *Nexus Network Journal*, **14**, 469-482.

Duarte, J.P., Celani, G. and Pupo, R. 2012, Inserting Computational Technologies in Architectural Curricula, *in* N. Gu and X. Wang (eds.), *Computational Design Methods and Technologies Applications in CAD, CAM and CAE Education*, IGI Global Publisher , 390-411.

El-Zanfaly, D.: 2015, [I3] Imitation, iteration and improvisation: Embodied interaction in making and learning, *Design Studies*, **41**, 79-109.

GonencSorguc, A., Krusa, M. and Ozgenel, C.F.: 2019, A Computational Design Workshop Experience for 21 Century Architecture Education, *eCAADe 37 Sigradi 23*, Porto, 127-136.

Hemsath, T.L.: 2010, Searching for innovation through teaching digital fabrication, *28th eCAADe Conference Proceedings*, 21-30.

Iwamoto, L.: 2013, *Digital fabrications: architectural and material techniques*, Princeton Architectural Press.

Kolarevic, B.: 2003, *Architecture in the digital age: design and manufacturing*, Taylor & Francis..

Oxman, N.: 2007, Digital craft: fabrication based design in the age of digital production, *Workshop Proceedings for Ubicomp 2007: International Conference on Ubiquitous Computing*, 534-538.

Oxman, N.: 2010, Structuring materiality: design fabrication of heterogeneous materials, *Architectural Design*, **80**(4), 78-85.

Pitkanen, K., Iwata, M. and Laru, J.: 2019, "Supporting Fab Lab facilitators to develop pedagogical practices to improve learning in digital fabrication activities, *FabLearn Europe 2019*, Oulu.

Sharif, S. and Gentry, R.: 2015, Design cognition shift from craftsman to digital maker., *Emerging Experience in Past, Present and Future of Digital Architecture, Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA 2015)*, Daegu, Korea.

Sheppard, S.D., Macatangay, K., Colby, A. and Sullivan, W.M.: 2008, *Educating engineers: Designing for the future of the field*, Jossey-Bass, Stanford, CA.

Varinlioglu, G., Halici, S.M. and Alacam, S.: 2016, Computational Thinking and the Architectural Curriculum-Simple to Complex or Complex to Simple?, *eCAADe 2006*, Oulu.

Vrouwe, I., Luyten, L. and Pak, B.: 2015, Teaching and Learning CAAD and CAM in a Fluid Era, *eCAADe 2015-33rd Annual Conference*.