Chapter 21
Teaching Spatial Thinking in Design Computation Contexts: Challenges and Opportunities

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ABSTRACT
A new generation of design computation systems affords opportunities for new design practices. This calls for potentially new teaching requirements in design education, in particular the development of the requisite spatial thinking skills. In this chapter, the authors review the pertinent literature, followed by two case examples that illustrate how spatial thinking was taught in two undergraduate design courses. The authors’ experiences suggest that early exposure to spatial thinking concepts, coupled with practice using computational design tools in the context of a project, can significantly help students to improve the skills necessary to design in a digital environment. Through the use of team projects, the authors discovered the potential variances in design representations when students switched between digital and physical modeling. They propose further research to explore the spatial processes required in computational design systems and the implications for design education.

INTRODUCTION
Design computation involves the use of software systems when conceptualizing, representing, and realizing design. Today, the rich variety of design computation systems used in research and design practice reflects the diversity of design needs and tasks, different design contexts, as well as rapid advances in information technologies. This range of tools is used for supporting collaboration, algorithmic modeling, digital modeling, symbolic modeling, simulations, testing, fabrication, etc.
The classical notion of Computer-Aided Design (CAD) is becoming obsolete as design systems are evolving to be more complex, intelligent and ‘supportive’ of creativity (Shneiderman, 2007). In response to these changes, the practice of design is reforming itself. For example, parametric modeling systems enable interaction with the ‘design models’ at multi-levels and multi-perspectives; and use representations at each level of sharing information (Aish & Woodbury, 2005). An algorithmic representation generating complex forms receives input from physical representation of the same form in 3D design space. ‘Form creation’ using these systems enabled designers to not only ‘imagine’ but also ‘specify’ for construction of complex free-form structures. New possibilities have been offered to designers that have never been available before. This new generation of design computation systems affords opportunities for new design practices.

These systems heighten the requirements for spatial skills, particularly for domains involving complex forms of spatial design such as engineering, architecture, urban planning, and product design, just to name a few. This is seen in current design practice where designers define spatial characteristics of a design in the virtual world that eventually will be built in the real world. In the virtual world, spatial thinking skills are required for (i) conceptualizing complex design forms, (ii) using computational systems as design-support and representation tools, and (iii) communicating solutions. The challenge of moving between these two contexts becomes more pronounced during the iterative process of design. Although both worlds employ the same design concepts, they have structurally different representations of spatial entities. Thus, there may be distinct spatial thinking skills required when creating these representations and moving between virtual and real worlds. We believe that design-focused courses may fall short in highlighting and developing these skills. Therefore, spatial thinking needs to be intentionally integrated into the learning process to prepare students for designing in virtual and physical worlds.

The following two examples illustrate different spatial requirements when performing design tasks in virtual and real worlds. The first shows differences in representations and operations performed on them. Imagine two Lego bricks of equal size relocated from parallel state to perpendicular state with four end-cells connected. Figure 1 shows the same task performed in digital and real worlds. The digital tool requires incremental, precise, and discrete operations planned and executed with the goal in mind. However, in the physical world (Figure 1, right) the task is intuitive and the requisite spatial operations of rotation, translation and alignment of two objects in relation to one another are continuous when compared to its digital version.

The second example demonstrates how strategies for decomposition and composition of objects in these two worlds can be different. Let us look at the construction of a simple cube with three holes centered on its faces (Figure 2). In the physical (real) world, an obvious solution is ‘cut...
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