Mine Özkâr received her B.Arch. at the Middle East Technical University in Turkey and holds a M.S. in Architecture Studies and PhD (2004) in Design and Computation from Massachusetts Institute of Technology. She is a faculty member at METU Department of Architecture and is currently teaching first year design studio along with a variety of undergraduate and graduate courses focusing on the topic of design and computation. Her ongoing research agenda is focused on extending the critique towards the positivistic understanding of computational design in order to include visual and other sensorial aspects of design thinking. She proposes hands-on basic design instruction as a possible setting for introducing the notion of design computing to architecture students in the first year of their education.

LEARNING COMPUTING BY DESIGN; LEARNING DESIGN BY COMPUTING

Mine Özkar
Assistant Professor, Ph.D.
Middle East Technical University
Faculty of Architecture, Department of Architecture
Ankara, 06531 Turkey
ozkar@metu.edu.tr

Abstract.

A pedagogical approach in the first year of architectural design education for integrating the basic notions of design thinking and computing is introduced and discussed. The approach aims to underline design thinking as a reasoning process while enunciating computing as a natural component of design. In the studied examples from two consecutive basic design studios, the analytical modes of design thinking in a simple design task are systematically and visually recorded. This documentation is utilized as a means for the students to consciously reflect on their design thinking.

Problem based learning or learning by doing, is today at the core of a widely practiced model of design education which has the studio as its core. In curricula taking after the Bauhaus school, the approach directly involves the tools and materials in learning about design thinking processes and encourages students to create while constantly testing out visual or spatial outcomes of ideas.

Today, tending towards the integration of digital tools, architectural design education is going through a transformation. How the culture of hands-on learning corresponds to the use of these tools could be investigated through establishing a relation between the logic behind digital tools and design processes at the very early stages of design education. The idea of computability in design, thus attained, can help students develop an initial sense for the link between design and process technology.

The paper inquires analytical thinking as an aspect of design computation that can be introduced at the level of the first year. The theoretical framework, the process and the results of a teaching strategy tried in a first year design curriculum are discussed through two comparable examples from two consecutive years and the contents of supplementary courses. The inquiry seeks to develop ways for beginning students to analytically become aware of their design ideas, design operations, and to understand systematic and relational thinking, analysis and synthesis in design processes in order to develop a sense for the computability of their processes of design.

Keywords. basic design, design computing, design thinking, first year architectural education, visual and spatial computing

A Framework for the Beginning Design Education

Learning by doing, a term coined by renown philosopher and educator John Dewey a century ago, is a well accepted method in design education, and it is rightly so. Hands and eyes are simultaneously at work in acquiring not just abstract knowledge but also individually tested, personalized, and thus, experienced knowledge, which is essential to design creativity. The method of hands-on or problem based learning develops awareness and aptitude in *how to* rather than *what to*. The visual and spatial reasoning processed while producing a possible response to a design problem in the learning by doing approach involve the development of personalized

design methods. Nonetheless, first year design education could become quickly confusing to the student who is overwhelmed by the plurality of approaches to design.

In order to demystify design to the beginning students and to convey to most that design is a reasoning process each in time can develop aptitude in, foundational design teaching should be clear about the existence of methodical thinking in design in addition to the plurality of approaches. Schank (1995) emphasizes the key role of "doing devices," such as tools, devices, media or game objects that are incorporated by the educator as the means to *do* to guide the students towards a better understanding of their developing design methods. While students are constantly creating and learning by doing so, they should be able to reflect on their processes through the use of these devices. The notion of computing, which generally implies reasoning within the scope of this study, is considered as such a device and an aspect of it is tested in a pedagogical approach in basic design assignments.

Discussions have been ongoing regarding which aspects of design, in relation to its computational ways, can be introduced at the level of the first year, ranging from how to handle the varying backgrounds of first year students to how to adapt architectural computing to early stages of education (Mark, Martens and Oxman 2003). Ivanka and Temy (2005) propose to reconsider the traditional design teaching ways within a modern view, in order to make the most of what has been long tested, however obsolete it may be. This particular study follows their model and aims to integrate the hands-on design learning in the foundations studio with the notion of computing for understanding the reasoning behind it. Moreover, Dewey's legacy and learning by doing has been a critical reference to multiple studies in artificial intelligence and education sciences, as well as those in the fields of design computing and design inquiry, notably by Gero (1999). Such investigations set up precedence and context for the integration.

To being with, it is necessary to reconsider the concepts and the definition of computation in terms of design reasoning, in order to maintain the reflective practice of design in the integration with computing. Stiny (2001) recognizes computing as a way of thought, reasoning, beyond its mechanical usability in technological tools. More importantly, he extends its definition from the positivistic understanding of computation to visual calculating, which then can relate to non-mechanical thought processes such as design. (Stiny, 2006)

Stiny's approach mends the detachment at the structural level between computing and design reasoning. Design reasoning utilizes the senses just as much as learnt abstractions, and demands a more ambiguous space, where definitions are conditional, and the structuring is possible when necessary. This ambiguous reasoning is the very same that overwhelms the beginning design student. Stiny suggests that we call it computing, in its enhanced description iterated above, and we are able to talk about it in structured ways as necessary. Such a conception of computing that allows for uncertainties as well as temporary definitions is significantly easing its integration into the culture of design. As previously stated (Özkar, 2005), it should be introduced to the culture as early as in the first year of architecture education, and concurrently with design reasoning. This particular study takes up one of the most fundamental analytical modes of design thinking to guide first year students through the ambiguities of visual and spatial thinking that may otherwise seem mystical.

An Inquiry into Analytical Modes of Design in a Beginner Design Studio

According to the Course Catalogue description, the first year studio in Department of Architecture at Middle East Technical University, Ankara introduces the students to basic concepts and principles of design via exercises to develop mental and manual skills to cope with design problems. Students are encouraged to develop visual values for structuring and articulating two and three-dimensional spatial compositions in different media.

Design exercises in the course develop from simple and abstract to more complex in terms of variables such as the number of elements dealt with, the variety and complexity of the materials used, the level of complexity in themes utilized for arrangement (e.g. similarity is a simpler notion than hierarchy), of the constraint level of the design problem (from more constrained to less), and the complexity of the contextual constraints in the design problem.

Variables in assignments change faster in the first half of the semester. In the second half of the semester once students are acquainted with numerous variables, they are encouraged to approach the design problem more systematically. As they are better equipped with graphic communication techniques then, they are expected to benefit from these tools in systematic, analytic thinking and for providing opportunities of seeing and reflection. The study in this paper is an intervention at this point in the semester.

The general teaching model accepted and applied in the beginning design studio at Middle East Technical University is based on the self-educating student model. The studio instructors define the framework and present it to the student through the assignments. Students are the key actors that contribute to the environment of the studio by creating objects that respond to the given design problem. Because the assignments are quick and with little time for feedback from the studio instructors during the work, students are mostly on their own or within the community they form together. The plurality of the responses students produce provide the richness in the discussion of the works afterwards. Rather than through lectures that introduce students to concepts externally, concepts are verbalised in semi-structured discussions in accordance with the works that they have created.

In this general framework, the student is expected to develop his or her own methods for design. On one hand, this attitude gives a message to the student that there are no prescribed methods to learn externally, but problems and approaches are unique and individuals can come up with their own reasoning. This is the pragmatist approach to creativity that stems from plurality. On the other hand, however, this attitude is confusing to the student and harsh as the students often find themselves lost in the plurality of possibilities and relative truths. This paper presents an approach that is following the pluralist ideology but at the same time attempts to balance its pragmatic insufficiency by introducing guidance to students with regards to doing. General instructions are given to encourage them to reflect on design processes. Actions are not prescribed but guided into experiencing that design is neither accidental nor solely dependent on personal likings or talent.

Two particular studio exercises that are the subject matter of this inquiry are carried out in two consecutive years but follow the same framework thus establish a platform for comparison. In the general framework of the studio, these exercises fit into the same time slot within the sequence of exercises from simple to more complex. The general aim in both is achieving three-dimensional composition, which implies the organization of volumes and the elements that create these volumes in space.

For the purposes of the inquiry, exercises are utilized to articulate an analytical mode of a design process. While creating a composition, students are instructed to analytically reflect on the process of achieving it through a particular method of documentation. The criteria considered can be outlined as follows: 1) Design is a reflective process. 2) The method introduced to the students is the forming of a dynamic library of relations between pairs of elements used in the composition. 3) The device for creating the library is the medium of ortographic drawing, which establishes 4) a feasible and consistent level of abstraction. 5) In a supplementary course, students are equipped with the knowledge of Euclidean transformations and symmetry operations in relation to 6) the notion of visual computing, where visual rules set relations between

elements. 7) All these help understand the analytical mode of design thinking and in turn the skill of self-evaluation.

1) Design as a reflective process

One of the aims of the particular investigation described in this paper is to make known to the student that design is a reflective process as coined by Donald Schön and accepted by many others. The act of design involves interaction with the object of design which is undergoing change each time the designer looks at it. The change is directly the result of the designer's perceptions and actions taken upon. That design is a reflective process implies that the designer is aware of the actions. Even when actions seem to be accidental, the designer needs to analyse and understand their implications for the whole.

The beginner design student is usually alien to the notion of critique, that is the analytical evaluation, and is yet to build an awareness of the designer's need to self-evaluate and legitimize a consistent approach in the whole of the design product. This is an important experience for the first year student so that he or she does not fall back to believing the black-box models of design. The design process should be conveyed as a transparent process, which can be analyzed through its certain aspects, and is not solely left to be evaluated upon taste. This is also crucial for all students to gain self-assurance and self-confidence in the beginning of their education.

2) Comparative inquiry into design elements

The investigation introduces the students a method of comparative inquiry into the design elements by forming categories of the relations among pairs of elements. This approach is valid for design problems with discrete design elements to begin with, so that it is possible to talk about discrete relations between pairs of discrete elements.

Developing a library of relations stands for a categorical documentation of spatial relations physically tried between the elements. Within the context of integrating computing to design, this approach is precedented in the educational application of shape grammars where spatial relations of a limited number of basic shapes are enumerated to show all possibilities with a given set of rules. (Knight, 1999) This exercise differently serves to identify the possible spatial utility of each selected relation in the context of creating a composition.

3) Abstraction

Abstraction, defined as the isolation of certain aspects in order to have a more concise description of an element, is a notion that METU first year students are familiar with through assignments practiced in the proceeding half of the semester. From the beginning of their studio, students go through a series of exercises where they are asked to understand formal features of various design elements, identify and isolate them in order to make use of them in relation to one another or in different contexts. They are not prescribed any given means to do these abstractions in. Often students represent their abstractions to the studio verbally. Sometimes they are asked to trace structural lines.

4) Orthographic projection as an abstraction tool

In the particular assignments that are the subject matter of this paper, students are instructed to make the same kind of abstractions with the help of a tool that is prescribed to them. They are assigned to draw their elements and the relations in between pairs of elements in orthographic projection. The nature of the technique provides a selection of features in each projection thus channeling the abstraction to formal properties of the relations.

5) Utilizing knowledge taught in other courses

A side motive to have the students draw their design elements in orthographic projection was to have them get into the habit of combining knowledge learnt in different courses. Studio is described in the course catalog as the melting pot. Along these lines, the content of two supplementary courses are considered in parallel with the agenda of the studio, and the topics of instructions are considered as direct input to the exercise. The orthographic projection is the subject matter of a required course in Graphic Communications. Another required course the content of which is utilized as an input to these particular exercises in studio is the Introduction to Information Technologies and Applications. In this course, first year students are introduced to the basic notion of visual computing. They are lectured on the symmetries of basic geometric shapes, symmetry groups, and Euclidean transformations, which in turn help them identify spatial similarities or differences of pairs of elements in the library categories.

6) Computing: rules setting relations between elements

The knowledge from the second course is versatile in forming the library of relations, the categories and in turn, the design. The spatial relations identified and evaluated by the student according to the analyzed properties in the library are put to use towards achieving a composition. The student through systematic thinking explores the possibilities of visual and spatial relations in space through symmetry operations. Computing enters the design vocabulary of the student, firstly through the link between the courses, and secondly through the employment of relations, as if they were visual-spatial rules, understood through analytical means, in a design process.

7) Self-evaluation

These exercises are hypothetically helping the students to develop a self-evaluation method as well as a design methodology. The student is instructed on the expectation to have a consistent set of rules present in the finished composition as criteria for success in the end product. The library set up by the student is an articulate set of rules that inform him or her towards achieving consistency.

The Case: Capturing an Analytical Mode of Design Thinking

The assignments that are the subject matter of the inquiry are three week projects just before the four-week semester final. Thus, the assignments start roughly at mid-semester and end in the second half. The supplementary courses by that time have taken up the issues of orthographic projection and fundamentals of visual computing described above.

In both assignments, given in consecutive years, the general task assigned to the students is a three dimensional thematic abstract composition. However, there are differences in the details.

(Table 1)

2005	2006
2D design elements	3D design elements
Design elements of choice	Design elements given
The relations between elements are entirely upto the student	Prismatic solids that belong to a geometric and proportional system
Size of elements not adjustable	More criteria to handle with elements (their size is adjustable)
Documentation in orthographic projection	Documentation in orthographic projection
Drawings show the shape of one element	Drawings show parts of both elements
First 3D study	previous 3D study

Table 1. A comparison of assignment details

In the assignment that was assigned in the year 2005, the task was to achieve a three-dimensional composition out of two-dimensional elements. Students were to decide on the formal properties of the elements themselves. They were not given a set of elements to work with. Moreover, due to the extended emphasis on two-dimensional and relief compositions earlier in the semester, this assignment was their first experience with organization of volumes.

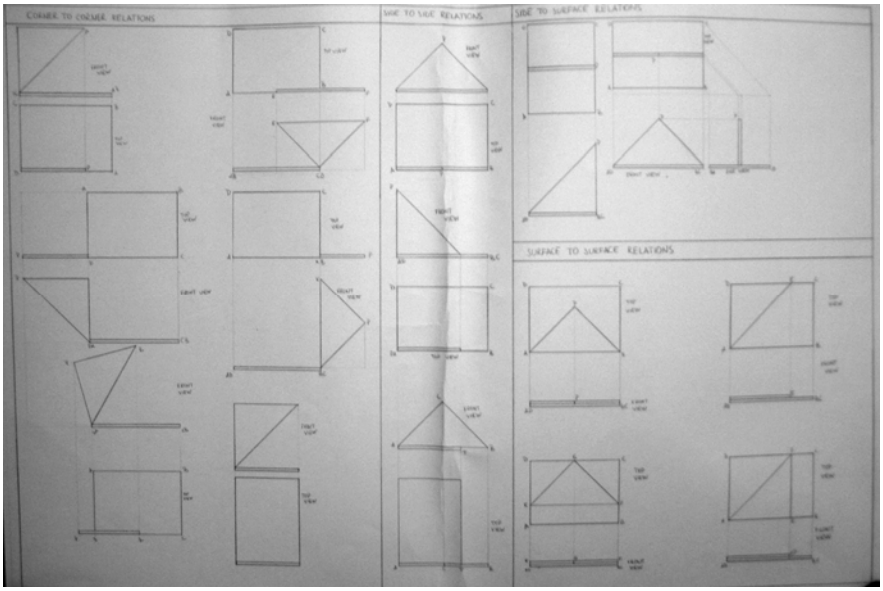

Figure 1. Categories of pair relations by Bengü Korkut, 2005.

The basic instruction for the task was to come up with two plane shapes and try out different ways the two elements can be fixed together in space. They were instructed to draw in orthographic projection as many of these pair relations as possible while categorizing them according to spatial features that they designated along the way. These spatial characteristics ideally were to guide them in their composition. Students mostly specified categories such as perpendicular edge-to-edge, edge-to-point relations. (Figure 1) Drawings hence helped the students understand the formal attributes of the elements. Moreover, due to the nature of the

elements, one of the shapes in these pair relations almost always was reduced to a line, while the relation of this line to the plane of the other element was isolated as a feature. (Figure 2) This was an advantage in comparing the spatial relations and categorizing them according to similarities.

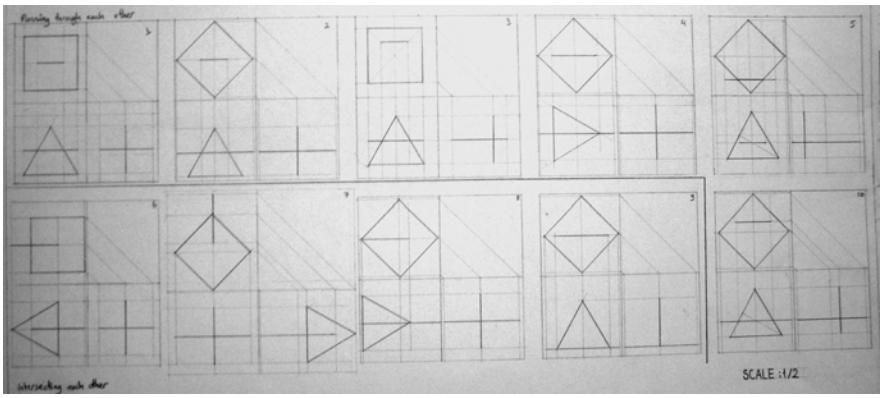

Figure 2. Categories of relations by Melike Akyol, 2005.

In the assignment given in the year 2006, the same task of achieving a three-dimensional abstract thematic composition was assigned. This time the set of design elements were given to the student. They were pieces from the Chinese Tangram game and were identified as prismatic solids with adjustable thickness. This meant there were more criteria to handle with the elements. Accordingly, drawing three-dimensional elements and spatial relations between pairs of them proved to be more complex than in 2005, as orthographic projection provided a more indirect way of representing the formal attributes of these elements. (Figure 3) This was in contrast to the advantages ortographic projection provided for planar design elements. Even though the drawings were to help with abstracting the formal attributes, there was more to consider in the drawing, and the drawings turned out to be complex to look at. They did not have the hypothesized advantages of contributing to analysis with abstraction then comparison of isolated features.

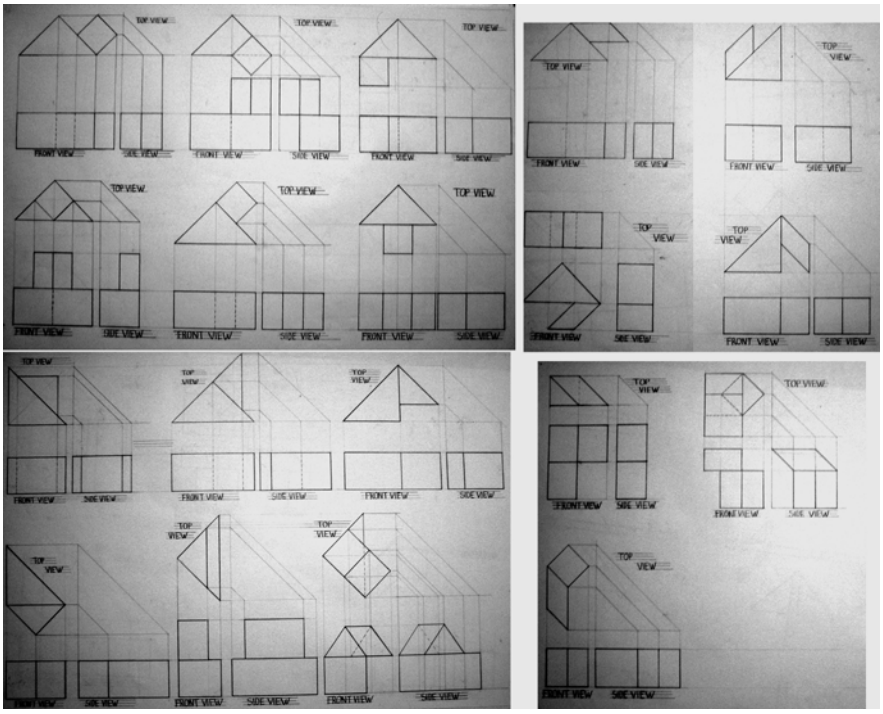

Figure 3. Categories of relations by Başak Yüncü, 2006.

For the reason that drawing these three dimensional pairings was a confusing task and that the outcomes were mostly not clear, most students did not draw as much as their peers did the previous year. (Figure 4) The small number of orthographic projections most of them drew seemed to help them little in understanding comparable formal and spatial attributes of the pairs.

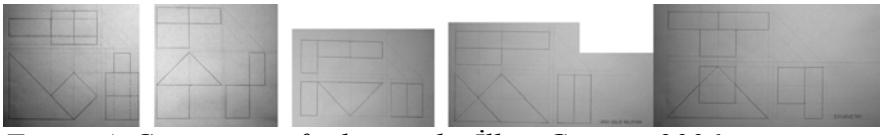

Figure 4. Categories of relations by İlkay Güryay, 2006.

On the positive side, these students had had previous experience with volumetric organization in proceeding assignments. Moreover, the existing geometric/proportional system among design elements helped the students identify similarities and differences between the pairs without relying much on the drawn library.

The outcomes according to how they answer to the initial criteria of the inquiry are shown in comparison in Table 2. In both years, design was conveyed as a reflective process. The certainty of this claim is due to the didactic nature of the assignment in prescribing a method of analysis to the students.

2005	2006
Design is a reflective process	
Comparative inquiry of design elements mostly due to orthographic projection	Comparative inquiry of design elements mostly due to existing geometric and proportional relations between given design elements
Abstraction successful due to orthographic projection of two plane shapes	Abstraction not successful in orthographic projection
Orthographic projection drawing	
Utilizing knowledge from other courses	From computing yes, but three d thinking is more complex. from drawing, not very effectively
Analytical mode of design computing captured by the prescribed documentation method	There are aspects that are not analytically captured by the prescribed documentation method
Self-evaluation	

Table 2. How do the assignments answer to the criteria of the inquiry? Grey areas represent common grounds.

The comparative inquiry into the pairs of design elements was different in between the years. Considering the representation in the assigned medium, the inquiry in 2005 was more

successful due to the efficient representation of two-dimensional elements in orthographic projection. On the other hand, considering the existing geometric and proportional relations between the design elements in 2006, the comparative inquiry was still possible, but not in the prescribed medium.

Abstraction was controlled and kept consistent among all students' processes through the method employed in documenting. Orthographic projection worked well for the two-dimensional elements in 2005, as in each projection one plane was diminished into a line and the relation was reduced to that of a line and a plane. The relative positions of these lines and planes were easily compared. In 2006, however, the three-dimensional elements kept their multiple features in all projections and presented more criteria for comparison.

The integration of knowledge learnt in other courses to the studio and a design process was successful in both years. Differently in 2006, due to the three dimensional quality of the design elements, there was much more to transfer from the supplementary course to the practice in the studio. The Euclidean transformations of three-dimensional elements in space was more complex to grasp.

The analytical mode of design thinking was observed in both years, even though there was uncaptured bits of it in 2006. The pairings of elements with particular spatial relations of choice from the library were named as the rules of design. Coupled with other organizational rules, these relations helped the students establish consistent languages of composition in their works.

Discussion: What seemed to have worked and not

Utilizing a newly acquired knowledge in drawing and employing drawing as a tool for reflecting in design is positive. Moreover, the particular type of drawing employed works well for abstraction. It isolates certain attributes of elements and defines the limits to a consistent evaluation system. The formal relations between the elements are isolated and easily compared with one another.

Categories help identify similar and different attributes of relations. Supplemented with previous experience in organizing design elements and the acquired applied knowledge of concepts such as rhythm, hierarchy, harmony, balance, contrast, categories constitute organizational rules for the composition.

Euclidean transformations are helpful in creating varieties while maintaining decisions regarding relations between elements. They are another set of isolated properties of forms.

On the negative side, the link between the analytical modes assumed to be partially represented through the drawn documentation and the final design products is not explicit. Due to the emphasis on process rather than end product, the discussion here focuses on the methods applied rather than the concrete outcome. However, this link also needs to be investigated.

Drawings need to be produced more rigorously and recreated multiple times to better emphasize the process of reflection in action, and that it is a constant feed to the design process. One aspect of this is the limited time frame of the assignment. The practice of drawing to think could be made a part of earlier projects and thus normalized in other ways before the students are expected to use it effectively in creating the library of relations. A second aspect is the complexity of design elements and the limits of orthographic projection. Although orthographic projection helps students constrain some aspects of the form, it is only one way of doing so and sometimes not sufficiently the desired one. This especially is true for cases where students try oblique angles and prisms in 2006. Introducing students to other ways of representation could be a possibility but needs to be well thought out for multiple implications. For example, if computer modeling is a tool, then the student will need to consider mathematical or geometrical aspects of his or her design to a greater detail. Two possibilities exist. In the first, choosing the tool

according to the design thought, the student can be encouraged to create, seek and find the most suitable method for their design thinking in that particular project. In the second possibility, the tool is assigned and thus guides the design thinking. In the discussed examples, this is the case. In a further study, the two options should be comparatively inquired and evaluated.

Acknowledgements

The author would like to acknowledge Selahattin Önür, Tuğyan Aytaç Dural, Nihal Bursa, Nicolai Steinø, Derin İnan, Başak Uçar, Pelin Yoncacı for their contributions in the preparation and execution of the design exercises, and Arzu Gönenç Sorguç for her contribution in the preparation and coordination of the Information Technologies and Applications course.

References

Gero, J S (1999), *Constructive Memory in Design Thinking* in G Goldschmidt and W Porter (eds) *Design Thinking Research Symposium: Design Representation*, Cambridge, MIT, pp I.29-35.

Ivanka, I and Temy, T (2005), *Using Historical Know-how to Model Design References: A Digital Method for Enhancing Architectural Design Teaching*, in B Martens and A Brown (eds.), Computer Aided Architectural Design Futures 2005, Springer, Netherlands, pp. 179-206.

Knight, T (1999), *Shape grammars in education and practice: history and prospects*, International Journal of Design Computing, 2.

Mark, E Martens, B and Oxman, R (2003), *Preliminary stages of CAAD education,* Automation in Construction, Design e-ducation: Connecting the Real and the Virtual Vol 12 No 6 pp 661-670

Özkar, M (2005), *Lesson 1 in Design Computing Does not Have to be with Computers: Basic Design Exercises, exercises in visual computing*, in J Duarte, G Ducla-Soares and AZ Sampaio (eds), eCAADe 23 Digital Design: The Quest for New Paradigms, Technical University of Lisbon, Lisbon, Portugal, pp. 679-686.

Schank, R C (1995), *What We Learn When We Learn by Doing. Technical Report ILS Technical Report No. 60*, Institute for Learning Sciences, Northwestern University.

Stiny, G (2001), *How to calculate with shapes*, in E. Antonsson and J. Cagan (eds), Formal Engineering Design Synthesis, Cambridge University Press, New York, pp. 20–64.

Stiny, G (2006), *Shape: Talking About Seeing and Doing,* MIT Press, Cambridge, MA.