Digitizing the Unexplored: Bridging the Concrete Experience and Abstract Geometry Through Physical Experiments

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Bridging the Concrete Experience and Abstract Geometry Through Physical Experiments

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Ways of promoting creative approaches in the context of embedding digital design approaches in education are increasingly becoming a popular topic in architecture schools. On one hand, digital design methods, approaches and tools are diversified, while on the other hand, the danger for students losing control over the design process by appears as a new phenomenon. We argue that experiential dimensions of empirical observation conducted with physical experimentation might be helpful for students to comprehend digital topics creatively. With a particular emphasis on engagement of physical experimentation and computational thinking, this study aims to present a pedagogical model which has been applied from 2014 to 2016 within a postgraduate course. The potentials and limitations of the introduced pedagogical model are investigated through students' bottom-up and top-down algorithm development processes and the outcomes of the digital modelling exercises.

Keywords: *pedagogical model, dynamic process, physical experiment, computational thinking*

INTRODUCTION

Theoretical debates on chaos, complexity and non-linearity have resulted in a series of well-established computational models of dynamic processes such as computational fluid dynamics, self-organisation of living organisms, swarm behaviour, various optimization models and physics engines. As a consequence, emerging models and approaches were introduced to researchers of different fields such as engineering, natural sciences, design, art and architecture.

As the basis or components of these computational models; mathematics, geometry, algorithms, programming languages or representation of space in digital environment can be all considered as a product and reflection of human thought. Regarding the relationship between reality and abstraction, Einstein (1921) used the term “axiomatic”. In the first emergence of concepts, theories and axioms, there might still be relationship among the experienced world, inference and assumptions. After gaining a logical structure, axioms and signs start to perform autonomously and independently of their sources. When it comes to computational models, they usually depart from original sources at least two times, being interpreted and reduced by the theoreticians and by the computer scientist. This reduction process makes it difficult for architects to understand, comprehend and generate new assumptions in relation with the original intuitive content.

Although architects have adapted various computational models to design processes, many architects still tend to approach CAAD possibilities via assumptions of Cartesian space in relation to the ontological crises of the digital age. There is a necessity to explore new relationships in the transitions among 2D, 3D and 4D information beyond Alberti's perspective. With Lonsway's (2002) words, the computational complexity is reduced to the Minkowskian Space in the usage of CAD software. Kolarevic (2000) also emphasizes the dynamic, open-ended and unpredictable characteristics of digitally driven architecture as a new potentiality. However, in difference to other debates, Lonsway (2002) clearly pointed out the differences between visual complexity and computational complexity by asserting Greg Lynn's (1998) blob still does not embody complexity beyond Minkowskian Space conception.

On one hand, ways of thinking, concepts, and vocabulary of conventional approaches dominate how one might comprehend and approach the potentials of digital tools. However, new concepts have been emerging while they effect the improvement of understandings. As a consequence, the emphasis on the concepts such as typology, form and geometry has been replaced by the focus on topology, formation and geometrical relations in the field of architecture. Moreover, new concepts and results are expanding the research area and innovative design processes.

In this study, we focus on how and in which ways it might be possible to introduce computational thinking logic to design students as a way of thinking beyond well-defined software packages and algorithms. With this concern in mind, we examined both bottom-up and top-down approaches of algorithm development. What we mean with bottom-up is related to generating algorithms based on an iterative abstraction and diagramming process. In contrast to this, the top-down algorithm development process refers to the demystification of well-structured algorithms by changing parameters or components.

This study aims to propose a pedagogical model for introducing digital modelling approaches to architecture students with the focus on developing a better understanding on computational thinking. The scope of this study will examine the proposed pedagogical model which has been applied to postgraduate students from 2014 to 2016.

ALGORITHMS IN DESIGN - DESIGNING ALGORITHMS

"Algorithms, software, hardware, and digital manufacturing tools are the new standards that determine not only the general aspect of all objects in a nonstandard series, but also the aspects of each individual product, which may change randomly or by design" (Carpo, 2011, p.99).

In a world in which algorithms replace the visuals and physicals with an increasing speed, it is unavoidable for architects to engage with theses on new faces of representation. Carpo (2011) defined this transformation as "shift from mechanical to algorithmic reproduction" which affect both the way architects design and the role of architects in design processes. In this case, the question of how architects employ invisible and immaterial algorithms in design arise, while constitution of physical spaces and qualities has been most closely concerning architects. The encounter of architects with algorithms leads a dialogue crisis between a structured language and the perceived and designed world of the architect.

The compilers execute programming codes line by line, in a linear order. The expressions, and the relations among different expressions enable a recursive flow, in other words syntactic and semantic relations make a linear text work as hypertext. Developing an algorithm is similar to an attempt to translate any process including nonlinear ones into a finite number string-like lines. As Terzidis (2004) underlines, an algorithm as a computational procedure covers processes such as deduction, induction, abstraction, generalization, and structured logic. In this sense, developing algorithms involve several multiplicities of translation, transformation and conversion of different information types amongst each other, and constitution of new relationships among different domains and dimensions.

In a broader sense, this study focuses on seeking pedagogical approaches which might accelerate students' usage of digital modelling environments more creatively with respect to gaining computational thinking skills. This focus brings out another embedded contradiction: whether it is possible to encourage algorithmic ways of thinking for architecture students while keeping a critical distance to the existing commercial software and tools.

The pedagogical approaches to facilitate creativity in computational thinking, and the tool-independent teaching strategies have been on the agenda of many educators from different fields (National Research Council, 2011; Nickerson et al., 2015). One of the related topics which has been mentioned in "Pedagogical Aspects of Computational Thinking" Workshop was that: "Learning and teaching computational thinking should be contextualized" (Wolz in National Research Council, 2011).

In our study, physical experimentation process is considered as a source of intuitive context and contextualization of variables, expressions, loops and functions. Exploration new relations based on students' empirical observations and constitution of new links between the explored relations and existing computational models, in other words defining new problems took priority in our study different than other problem solving based approaches which has revealed problem solving based strategies might invoke students learning motivation. Moreover, findings similar with the literature (National Research Council, 2011), working collaboratively had an advantage over individual learning environments.

We aim to make a particular emphasis on expanding and utilizing the potentials of computational complexity towards a dynamic understanding of the things and the world instead of merely representing cartesian space. In this regard, we attempted to constitute a cyclic connection between well-established computational models on dynamic systems and the empirical research based of simple dynamic and changing environments. Related notions of flow such as flow as an abstract concept, flow as a particular feature of elements, flow as an observable phenomenon of dynamic systems have triggered the emergence of various research environments in the field of computational design. Usage of dynamic systems as a source for intuitive explorations is not new in architecture.

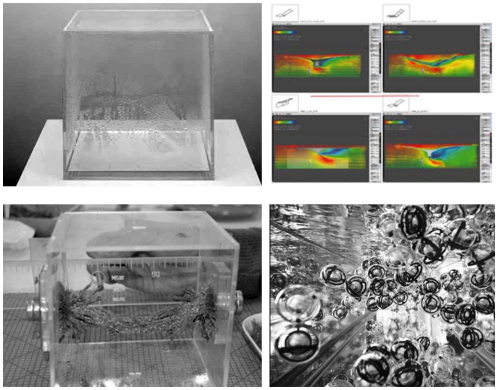


Figure 1
Examples from studies on condensation(Hill, 2006, p.101); fluid dynamics Kaijima et al. 2013, p.121); magnetic fields (Bello Diaz & Dubor, 2013, p.239); fluid crystallization (Url-1)

In Figure 1, top-left, an image of condensation is shown, which was introduced by Hill (2006), as a part of immaterial aspects of computational design. Dubor and Diaz (2013) presented a material behavior driven form-finding approach based on observation of magnetic behavior in different scales and scopes (Dubor&Diaz, 2013). A part of Dubor and Diaz's (2013) experiment setup is shown in Figure 1, bottom-left. One of their remarkable contributions is the workflow associated with digital fabrication process (Dubor&Diaz, 2013). In Figure 1, bottom-right an empirical study focusing on crystallization of fluids is shown (Url-1). Implementation of a well-established computational fluid dynamics in architectural design is shown in Figure 1, top-right (Kajima et al. 2013).

In his 2006 book entitled ″Immaterial Architecture″, Hill pointed out the potentials of the dialogue between material and immaterial, concrete and ephemeral, conception and perception. Hill (2006) contributed to theoretical debates on exploring new meanings for creativity in design. Hill (2006) quoted from Moholy-Nagy that: ′A definition of space which may at least be taken as a point of departure is found in physics- ″space is the relation between the position of bodies″ (Moholy-Nagy, 1947, p.57; Hill, 2006, p.67). Giving the experience its due in early 20th century, Moholy-Nagy's expression can be considered as a manifestation of space-self-time interrelationship towards a new and dynamic understanding of geometry. In respect to the priority of experience, this study is an experimental process which involves attempts to multiplicate the viewpoints of the perceiving subject looking to static geometry via one-to-many model. In addition, many-to-many model which is explained in detail in the next section aims to accumulate the singular abstractions of the subject who observes dynamic process

PEDAGOGICAL MODEL

In the scope of the study, two models that we call one-to-many and many-to-many were tested in postgraduate courses. Duration of the implication of each model was 4 weeks. The course involved introduction of the sample studies, theoretical discussions, and readings separate from the experimental process. The implementation was repeated 3 times in different semesters. The one-to-many and many-to-many models included explorative, experimental and structured exercises. The physical experimentation, digitization of the observed information derived from experiments, and the outcomes of the modelling exercises were evaluated.

One-to-Many

This model was considered to depart from an initial static geometry. The source of the initial geometry was changed in different semesters, and the changes included things such as a part of a body or a part from the built environment preferably involving rich topological relations or complex geometrical information. The students were expected to depart from the initial geometry and gain experience in exploring generative and behavioural relations while generating a series of digital and physical models.The four-week module included but was not limited to the following phases:

- Measurement and 3D scanning. Extraction of geometrical relations from a given context.
- Generation of the same geometry in digital environment through a systematic topological investigation (Eg: sequentiality, repetition, in/out, near/far, etc.)
- Exploration of performative relations based on fabrication with different materials.

The modelling exercise shown in Figure 2 consisted of 3 steps. First, the data were collected with a 3D scanner. Subsequently, the lines of the layers were manipulated and surfaces were created inside the layer curves. Finally, joints' details were optimized and a 1:1 scale model was prototyped.

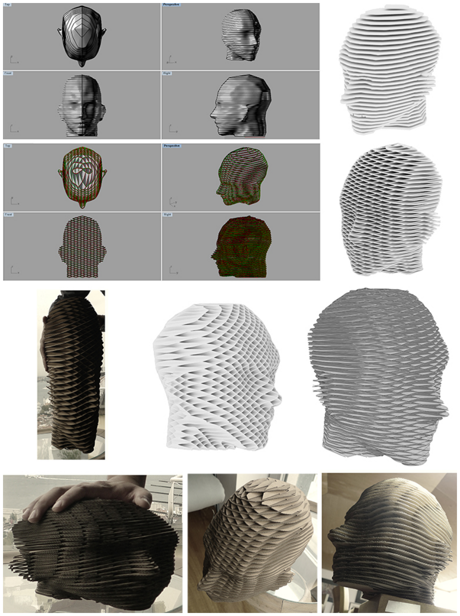


Figure 2
Digital and physical head models by Aren Semerci

Figure 3 illustrates a process in which the column heads can be varied by different modelling techniques.

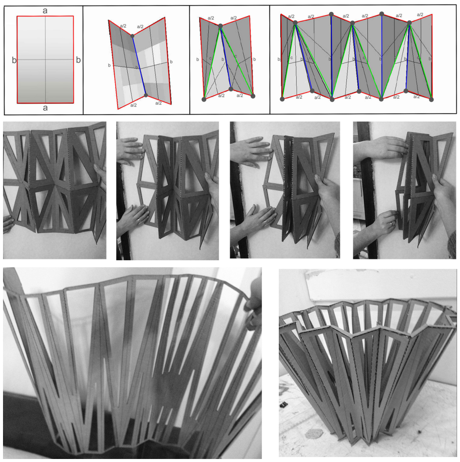


Figure 3
Generation of column heads with folding and subtraction operations by Gülce Kırdar

In Figure 4, an existing muqarnas geometry is modelled with a conventional 3D modelling tool. Reproducing the geometry with a parametric tessellation. A non-continuous form was generated with Voronoi. The new form was filled with a simulated cloth. The digital model was prototyped with the combination of plaster and cloth. Hang points and length of the strings were calculated in Grasshopper.

Figure 4
Muqarnas analysis and computational interpretation by John Bogren

Many-to-Many

The main difference between one-to-many and many-to-many models was the assumption of initial source. Instead of a static geometry, a dynamic physical, biological or chemical process was selected for examination. This model included:

- Explorative experimentation: Selection of a dynamic process such as movement-based behaviour (magnetism), or particle behaviour (liquid behaviour - fluid dynamics, crystallization, etc.).
- Trial-Error: Repeating the same experiment through a series of structured experiments. Therefore, this phase involved a design experiment setup. The emphasis was on the exploration of qualities and parameters.
- Documentation: (Video record and time-based framing, phenomenon-based framing, etc.)
- Analysis: The students were asked to extract information from the experiments that they did. Although extracting information in most cases depended on visual analysis of the video records, this phase might cover various analyses such as phenomenon-based, event-based, and threshold-based ones.

- Developing algorithms for digital modelling: This phase involved both bottom-up algorithm development and top-down merging and adaptation of the existing algorithms. In the first case, the process was more important than the end results. The final outcome did not need to be a precise working model. However, it needed to be a new insight which can be improved by others in a long term. The second case focused on merging, manipulating, adapting and re-compiling different algorithms and samples on purpose.

Observed Phenomenon	Materials Used in Experiment Setup	Parameters	Bottom-up (analysis, abstaction, algorithm development)	Top-down (usage and adaptation of existing algorithms)
Magnetism	printer toner, motor oil, oleic acid, metal balls, magnets, ammonia	amount of metal balls, ratios of materials, coordinates of magnets	polarization, milling	swarm behavior, metaball
Diffusion in Liquid	water, oil, ink	density of liquid, temperature, time	image processing based rotational geometry creation	computational fluid dynamics
Materialization in Liquid	sulfuric acid, ammonia, solution, cotton, wool, shrink	speed of shrink, height of shrink, viscosity		dynamic ink diffusion, computational fluid dynamics, particle-based physics simulation
Fizzing in Liquid	water, oil, food coloring, effervescent antatic tablet	amount of materials, time		cellular automata, fluid dynamics, PhysicsJS
Condensation	liquid, planar glass, heater	temperature, time	circle based analysis of bubbles	voronoi
Crystallization	sugar, water, food coloring	density of liquid, shape temperature, time	shape based analysis and adaptation, growth analysis, gravity related findings	voronoi, agent based bahavior

Table 1
Selected student experiments of many-to-many approach

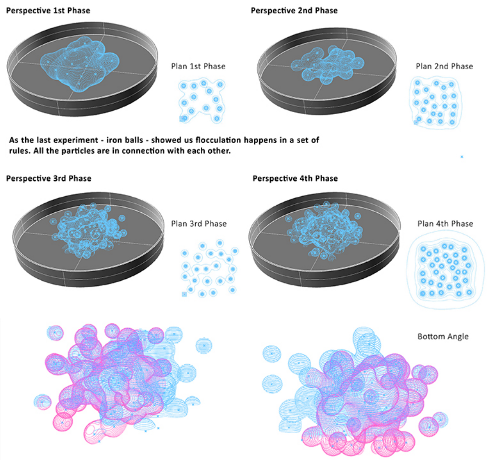


Figure 5
Flocculation of iron balls related to the generated magnetic field by Yiğit Can Ülkücü

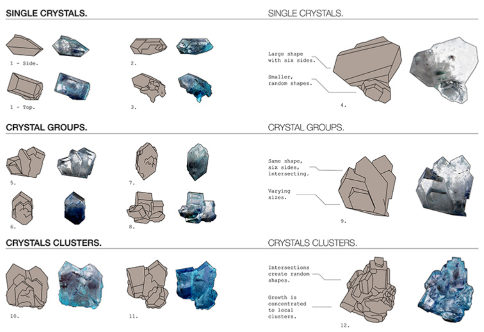


Figure 6
Analysis and interpretation of sugar crystalization by John Bogren

FINDINGS, OUTCOMES AND EVALUATION

This part evaluates the common aspects and the differences of the student works, which were derived from implementation of the proposed pedagogical model between 2014 and 2016 in postgraduate courses. The selected student works of the many-to-many model were based on experimentation of viscosity, magnetism, ferro-fluid behaviour, cracking, diffusion and crystallization processes. The gaps and connections between the information extracted from the physical experimentation and the top-down examination of the existing algorithms are explained.

CONCLUDING REMARKS

The foundations of computational thinking are rooted in abstraction, translation and transformation processes. These processes conducted with physical experimentation might be considered as one of the core experiences for gaining a better understanding on the potentials of computational complexity. In other words, physical experimentation, documentation, abstraction and digitizing would lead to perceptual knowledge, which is different than well-established closed computational models. Therefore, we argue that revisiting the empirical research by architects will be important in the digital age to explore new and open-ended relations beyond well-established algorithms. In this sense, this study may be considered as an attempt to explore new ways of

Figure 7
Flow diagrams of experimentation and images from experiments by Taylan Kılıç.

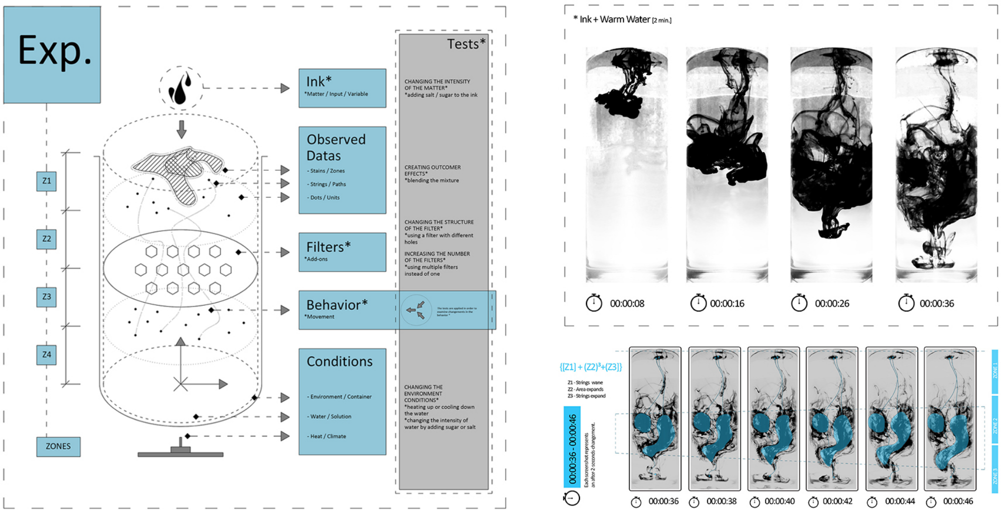
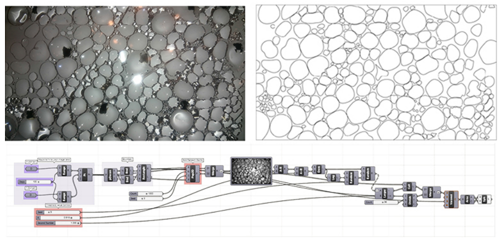


Figure 8
Regeneration of the pattern of condensed water on glass surface via image sampler by Ahmet Onkas



introducing computational models to architecture students with the aim of supporting students in developing personal reflections on the existing and also unexplored computational design models.

One of the findings of this study is that, in the case of the bottom-up processes where algorithms introduced explicitly as a foreign language involving vocabulary elements, syntactic rules and logical operations, it might be difficult to integrate the experience of developing algorithms with different scopes and contexts. On the other hand, gaining experience in algorithmic thinking depending on particular and digestible contexts might lead to tacit learning. We argue that the context-based tacitly acquired knowledge has the potential to be transformed into different problems.

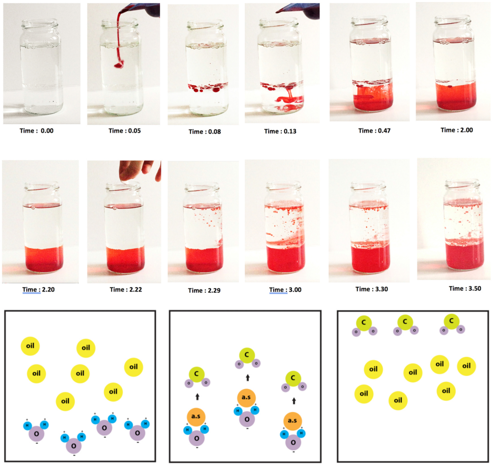


Figure 9
Sequential photos of experiment and diagramming the outcomes by Begum Moralioglu

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