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Yazici, Sevil

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La informática a través del sistema holistico de diseño: taller de materiales

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Sevil Yazici
Istanbul Technical University, Turkey
✉sevilyazici@itu.edu.tr
Arquitecta, Istanbul Technical University.
Master en arquitectura y urbanismo, Architecture association, Londres.
Candidata a doctor, Istanbul Technical University.

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Abstract

The emergence of interdisciplinary fields of interests in architecture (digital media, more specifically computational design tools) has transformed the common design, analysis, and building processes into a new discipline in which the skills and knowledge required of the architectural designer should be adapted. With the exception of a few innovative higher education institutions, there is no across the board academic implementation regarding emerging computational design applications at undergraduate level in architecture. Material Formations Workshop, organised by the Department of Architecture, Istanbul Technical University, investigated the logic of computing through Holistic Systems Design Method (HSDM). All participants had diverse skills and knowledge and used HSDM to deal with multi parameter problems as observed in nature where physical material was the main derivative of the design process. Specific rules were defined, and relationships were established among system components. Possible future lines of the research are also suggested in this paper.

Keywords: Architectural education, systems thinking, computational design, form finding, material formations.

Resumen

La emergencia de campos de interés interdisciplinarios para la arquitectura (medios digitales y, más específicamente, herramientas de diseño por computador) han transformado el diseño tradicional, el análisis y los procesos de construcción en una nueva disciplina a la cual las habilidades y el conocimiento del arquitecto deben adaptarse. Salvo algunas pocas e innovadoras instituciones de educación superior, aún no existe en los niveles de pregrado de arquitectura un consenso sobre la implementación académica de aplicaciones de diseño por computador. El Taller de Materiales, creado por el Departamento de Arquitectura de la Universidad Técnica de Estambul, ha investigado la lógica de la informática a través del Sistema Holístico del Diseño (HSDM, por su sigla en inglés). Todos los participantes tienen diversas habilidades o conocimientos y usan el HSDM para tratar con problemas variados que se observan en la naturaleza, donde el material físico fue el principal resultado del proceso de diseño. Reglas específicas fueron definidas y se establecieron algunas interrelaciones entre los componentes del sistema. Posibles líneas futuras de investigación son sugeridas en este artículo.

Palabras clave: educación en arquitectura, pensamiento sistémico, diseño por computador, búsqueda de la forma, formación en materiales.

Background

Interdisciplinary fields of interests in the architectural design process

Today's architectural design process is understood through an interdisciplinary approach. There are two examples of how interdisciplinary knowledge affects the design process. The first is from a technological perspective: the techniques used in the design development, analysis, and design implementation are enhanced though the contribution of interdisciplinary knowledge. For instance, Computer Aided Manufacturing Techniques (CAM), which have crossed over into the field of architecture from other disciplines related to engineering, such as the boat or car industry, are used in today's innovative practices to build complex architectural forms. Another example is the Digital Project (DP) developed by Gehry Technologies, which is a comprehensive design and manufacturing platform to build complex forms. It is a by-product of the CATIA V5 software, and was originally produced as an aircraft-manufacturing tool. DP is based on Building Information Model (BIM), which has emerged as a technological paradigm promising a way to comprehensively encode all the information necessary to describe a building's geometry, enable various analyses of its performance, and directly facilitate the fabrication of various components and their on site assembly.[1]

1 Kolarevic, "Towards integrative", 335-344.

The other effect of the application of interdisciplinary knowledge on the design process is the increased creativity in form finding. Nature is always perceived as a wise basis for establishing the most efficient and elegant forms. Master-builders and architects have always taken interest in nature as a source for design, whether in a direct, metaphorical, or analogical way. The interest in biology as a discipline is, however, a more recent phenomenon.[2] Nowadays, biology (ecology in a wider context) is used as a creative generator in the architectural design process. Through an awareness of being able to represent natural phenomena (formations and organisations) computationally, the interest of the architectural designer towards advanced mathematics and computer science increases in order to understand and resolve systems found in nature. Computational design techniques enable the establishing of systems, even with complex properties in a holistic (unified) manner and re-building them if necessary by adjusting the systems' criteria.

2 Hensel, "Performance-oriented Architecture", 36-56.

In this paper the author focuses on the creative effect of nature within a framework of systems thinking.

Systems thinking and computational design

Ecological and systemic awareness was presented first by Aristotle (384-322 BC) as a metaphysical vision of the systemic and ecological order of nature in his biological systematic.[3] Systems thinking appears as a problem solving method in natural, scientific, human, conceptual, and engineering systems in which it is considered as a whole, and whe-

3 Skyttner, "The Future of Systems Thinking", 193-205.

re interconnectivity and interactions among the system elements are investigated. Systems theory is considered a specialised area within systems thinking.

Computational design tools are transforming common design processes in architecture when problems are evaluated within a holistic manner. The architectural designer is able to establish generative systems with tools such as the parametric design. The idea behind parametric design is that one can manipulate a particular form and study many alternatives by changing the variables, or parameters, or by defining the geometry of an object or assembly.[4] Often building on parametric concepts, generative design transforms the computer from a modelling assistant to a generator through the use of a defined set of production, or grammar, rules.[5] Systems established through either parametric design, scripting, or programming are governed by rules that are mathematically defined. The relationships among the elements of the system are set at the beginning of the design process as with bottom-up approaches, in which the design problem becomes well-defined and is even valid for sophisticated problems. For example, a design student can write a computer algorithm to generate a form in which complex geometrical relationships are calculated, and also in which recursive or recurring spatial patterns or forms are incorporated into the design. Or, a design student may structure a feature tree of solid modelling software which enables the exploration of a particular set of optimised conditions or constraints.[6]

4 Kvan et al., *Ditching the Dinosaur.*

5 Shea, Aish, and Gourtovaia, "Generative Design Tools", 253-264.

6 Kvan et al., *Ditching the Dinosaur.*

Form finding through systems informed by material

Form finding informed by material, has the greatest potential to generate the basic understanding of how systems perform in general. Physical models should be evaluated as holistic systems where the system elements are interconnected and the system is perceived as a whole. Physical properties of material directly influence its performance (behaviour). For instance, wood is an anisotropic material, which has two distinct behaviours: tension and compression; respectively, one is parallel, the other one perpendicular to the direction of its fibres.

Form finding through material systems is an age-old method, in which the material performance was the main driver of the design process. In the 19th century, Gaudi argued that nature generates the most efficient forms. His Church of Colònia Güell in the outskirts of Barcelona was based on a 1:10 hanging model. The model interactively expressed the behaviour of mass under gravity induced tension, which, when considered inverted was taken to be a dynamic reflection of mass behaviour under gravity-induced compression. In this experiment in equilibrated structures, Gaudi showed that neither walls nor columns are naturally vertical; they are instead complex resolutions of forces expressed such as 3D vectors.[7]

7 Burry, "Almost rectangular", 182-184.

In the 20th century Buckminster Fuller continued to analyse nature by investigating the formal possibilities for the most efficient structures and material systems. He invented geodesic dome structures, which use the minimum amount of material to enclose a space. In response to those who suggested that the geodesic structures were merely replicas of natural forms including radiolaria and fly's eye, such as those illustrated by Haekel and D'Arcy Thompson. Fuller argued that geodesic structures cannot be compared by those natural forms, which were only superficially similar to them, by underlining the structural performance of geodesic domes. He gave the example that the radiolaria would collapse when taken out from the water or fly's eye would not provide a structural precedent or man-occupiable structures. He also explained synergetic phenomena, which is defined as the surprise complex behaviour of associated principles, where the behaviour of the whole is unpredicted by the behaviour of the parts. In his explorations on synergetic geometry, Fuller believed that he was investigating nature's own coordinate system.[8] Following Fuller, Frei Otto has undertaken remarkable research on biological structures in which he pioneered computer-based procedures for determining shape and behaviour of material systems.

8 Gorman, *Buckminster Fuller*, 115-122.

Problem definition: computational design in undergraduate architecture degrees

The integration of computers into the design curricula varies according to the institutional culture, resources available, and level of talent within different design schools.[9] Within this context, the integration of computational design into undergraduate curricula is undertaken by relatively few institutions around the world since computational design is perceived to require a high level of programming or scripting skills. These are not taught as an integral part of conventional architectural education. There is no general procedure applied to integrate emerging computational design applications into the existing undergraduate curricula, other than giving some technical tutorials on how the tools themselves operate. There is however, no attempt to discuss the logic behind computational design.

9 Kvan et al., *Ditching the Dinosaur.*

The courses that include detailing the logic behind computational design are taught at Masters and PhD level at Istanbul Technical University (ITU) where the Material Formations Workshop was held. ITU has a strong educational tradition, and has been influenced by the modernist movement. Projects in architectural studios are undertaken, in general, as top-down approaches, and a formal composition is generated first and foremost through the site constraints, users profile, and programmatic needs. The secondary specifications are, respectively, the structural system, materials, and details as engineering solutions in the later stages of the design process. Every single modification that occurs in the later stage of the design process affects the overall architectural scheme, in which the architectural designer moves back and forth in the design process.

However, by integrating a holistic systems method into the undergraduate curricula, bottom-up approaches (such as computational design), would be investigated when the rules and relationship among system (design) elements are defined at the beginning of the design process. The result would be that the most efficient solution is generated by the system itself. As previously mentioned, systems driven by computational design can respond even to complex problems, such as a building. In this context, the crucial aspect of undergraduate education in architecture should be evaluating the computational design logic rather than adding technical tutorials in programming or scripting, which are applied widely today.

Aim: establishing holistic systems informed by material performance

The Material Formations Workshop aims to build holistic systems informed by material. The underlying logic of computational design needs to be considered by every participant through which they can gain an insight into analytical thinking for computational design in general. By establishing systems, the intent is to handle projects with multi-parameter problems. Building elements, such as the structural system, building shell, floor, roof, and walls, should be re-interpreted as concepts and investigated as the elements (components) of a continuous system.

Materials with specific properties perform by applying forces. By analysing bottom-up approaches, participants should contemplate the role of the material systems in the architectural design process. In this approach, there is a form finding process, rather than a form generation one, because the system performs to find the optimum solution based on pre-defined rules. Form follows performance,[10] strategies are widely accepted in innovative architectural applications. Incorporating performance models to guide computational generation processes will lead to tools that help architects, designers, and engineers think critically about system, rather than just component.[11]

10 Kolarevic, "Towards Integrative", 335-344.

11 Shea, Aish, and Gourtovaia, "Generative Design Tools", 253-264.

State of the art and problem definitions

In studio projects under the supervision of Hensel and Menges, material systems were tested through different projects. Material systems were considered not to be derivatives of standardised building systems and elements, but as generative drivers in the design process. Extending the concept of material systems by embedding their material characteristics, geometric behaviour, manufacturing constraints, and assembly logics within an integral computational model promotes an understanding of form, material, structure, and behaviour (performance): not as separate elements, but rather as complex interrelations.[12]

12 Hensel, and Menges, "Inclusive Performance", 54-63.

Oxman and Rosenberg's research demonstrated the association between geometry and material behaviour, specifically the elastic properties of resin impregnated latex membranes, by means of homogenising protocols that translated physical properties into geometrical functions. The method enabled form finding based on material properties, organisation, and behaviour. A tool was introduced for the simulation of material behaviour and its prediction under specific environmental conditions.[13]

13 Oxman, and Rosenberg, "Material Based Design Computation", 25-44.

Zero.1 research group investigated the material behaviour of Bistable Structures through a series of prototypes. Their method was based on form finding process through physical modelling and re-building the system with a computational model driven by the prototypes. In the first phase of the research, the Bistable Structure material, which is a special type of steel, was investigated in various assembly models as composites, in combination with other materials, exploring its rich formal and organisational repertoire. In the second phase, the material system was brought into the computational model, in which the parameters of the material systems could be altered.[14]

14 Yazici, S., Chima, J., Nikolakaki, S., and Leung, E., "Bistable Structures."

The research projects mentioned above are based on bottom-up approaches driven through material systems, and were undertaken as either Masters or PhD level studies in which programming, scripting, or advanced parametric design tools were used in the design processes. However, for the undergraduate students in architecture who do not have any knowledge in computational design, the aim should be the teaching of the fundamental principles of systems thinking in general and creating a base for their further studies. Systems thinking can be applied as a method in programming, scripting, or parametric design tools, and, also when using physical models, sketches, 2D, and 3D drawings in conventional design environments.

Material formations workshop

The Material Formations Workshop that took place at Istanbul Technical University from 17th February – 24th March 2010 was run by the author and formed part of the course called Contemporary Building Materials (MIM 328). The overall aim of the course is to provide a fundamental understanding of contemporary building materials produced by the on going scientific research. The purpose was also to gain the ability to evaluate the effects of contemporary building materials on innovative architectural design solutions in terms of their types, intrinsic and extrinsic properties, applications, and to give the ability to choose the suitable building materials to order for the purpose of increasing the quality of construction.

Fourteen students took part in the workshop. They were encouraged to work in teams to exchange ideas and knowledge. The workshop participants ranged from 1st year to 4th year undergraduates. For this reason, students possessed varying degrees of knowledge and skill in terms of architectural design and the use of digital techniques. The introduction consisted of how computational design tools could be effectively used. The veritable logic of these tools was emphasised and discussed by means of systems thinking, rather than by simply giving tutorials on how they operate.

Participants investigated material and form in a holistic system strategy where the rules of the system elements and their relationships needed to be well defined. Once the rules and relationships were defined, the system could be repeated and restructured many times. Projects aimed to explore generating designs with singular material systems in a continuous manner: not a common method applied in architectural schools. In this method, students evaluated structural systems, shells, floors, walls, and interior spaces in a holistic manner, as applied in bottom-up approaches. The performance of various materials was tested through a series of prototypes. During the workshop, students generated ideas on how the conceptual form would be affected if their projects were implemented on a 1/1 building scale.

Holistic systems design method

Students generated rules and relationships with the framework of systems thinking. The principles of systems thinking applied in Holistic Systems Design Method (HSDM) are the following:

- Interdependence: Independent elements can never constitute a system. Objects and their attributes need to be interconnected.
- Holism: A holistic approach needs to be defined.
- Goal seeking: Systemic interaction must result in a goal or final state.
- Inputs and outputs: Inputs and outputs need to be specified systematically. By re-processing the rules, the inputs will match their same outputs. Based on systems thinking, inputs are determined once, and they are constant in a closed system. On the other hand, in an open system additional inputs are admitted from the environment.
- Transformation of inputs into outputs: This is the process by which the goals and final states are obtained. Smooth transition among system elements should be achieved through the gradient effect where the system is continuous.
- Hierarchy: Complex systems are made up of smaller subsystems. Hierarchy connects system elements in a vertical or horizontal manner either directly or indirectly.
- Differentiation: Specialised elements perform specialised functions. Different elements may perform different purposes.

The workflow of the workshop

Nature has the master skill to generate the most efficient systems. In the first phase of the workshop, the rich organisational and formal repertoire, and the efficiency of natural organisations were investigated by making certain that the rules and relationships within the natural systems could be investigated and expressed computationally.

The next phase included the teaching of technical tutorials on computational design tools that are effective and commonly used. Introductory tutorials on RhinoScript and Grasshopper parametric design tools were also given to the class.

In the following stage of the workshop, different materials with various performance properties were tested. Participants were encouraged to research new materials and to experiment with them. Participants explored material performance via HSDM through prototyping processes.

In the final phase, participants were encouraged to bring their knowledge learned through prototyping, to the realm of a digitally driven computational model, since they had established a fundamental understanding in computational design via HSDM. Digitally driven computational models enable complex problems to be dealt with by increasing the number of elements radically through maintaining their interrelations, and also by adding a highly sophisticated level of differentiations among the system elements.

Outputs

Projects were exhibited along with prototypes at Istanbul Technical University from 14th May – 31st June 2010. Additionally, they were published and displayed in the Spontaneous Schooling Event at the London Festival of Architecture, which took place from 18th June – 4th July 2010 and was sponsored by Nous 4M and Derwent London.

Students were encouraged to test different materials via HSDM. These materials were cardboard, aluminium sheet, copper sheet, plastics, paper, foam, wooden sticks, metal sticks, and metal mesh.

Paper does not have stand-alone structural properties without making formal arrangements. In order to obtain strength as a structure, the physical properties of the material, the geometry, and the scale of the modules play significant roles. One of the project teams analysed the behaviour of paper and created modules in order to increase its strength. Simple logic was applied to the paper modules generated through folding. The structural system was established with the modules from different scales. The number of smaller modules increased when the structure developed vertically. Also, the modules were connected in various ways to reduce the weight of the system and to generate openings by maintaining the strength of the structure. Rules, such as how the modules were folded, how many types of modules existed in total, what the logic of vertical growth was, and what types of different connections existed were defined for the system (fig. 1). The other project generated paper modules by the use of a repetitive pattern. By stacking these modules in a systematic manner the system gained strength and spatial quality (fig. 2).

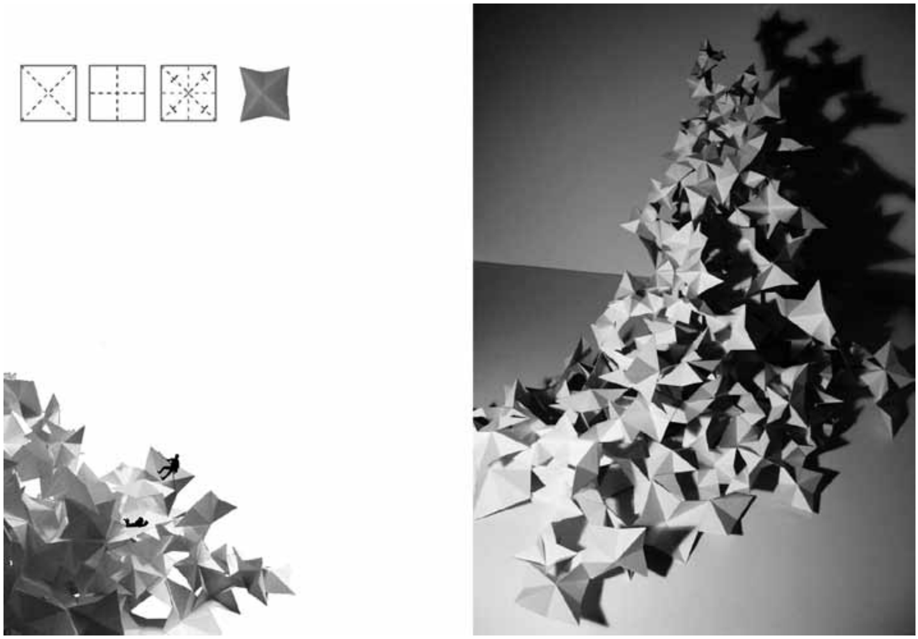

Figure 1. Folded paper modules that grow vertically (Student credits / Idil Yucel, Nehir Gumuslu).

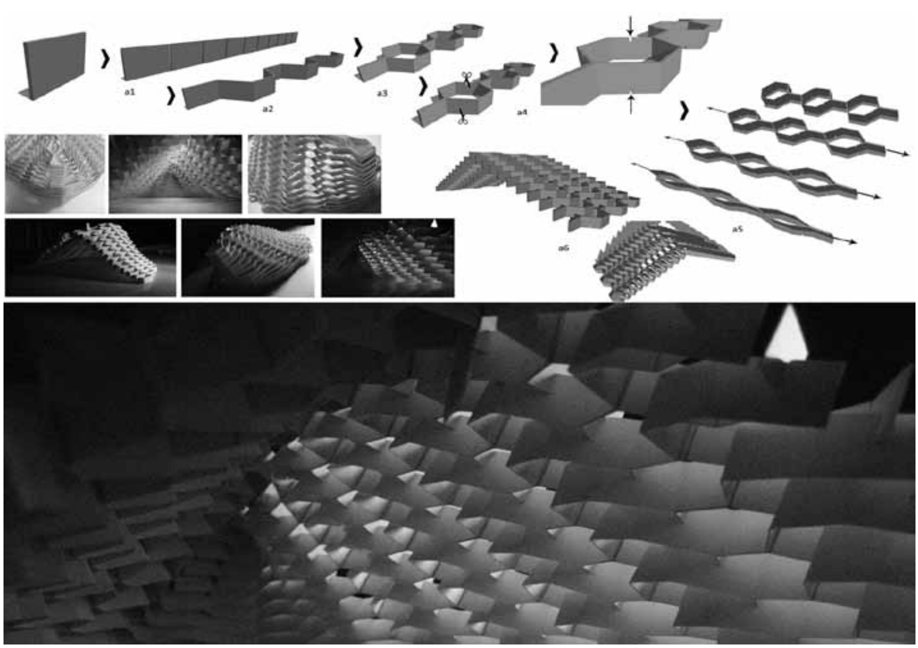

Figure 2. Stacking paper modules with a repetitive pattern (Student credits / Mehmet Kaya, Yunus Kivanc).

Another project offered modules with two material components: one was a sphere (4cm diameter) and the other was three brass rods with the length of (2 x 20 cm and 1 x 25 cm), which penetrated the sphere. In order to gain structural strength, the modules were allowed to fall from a specific height to the ground. This approach reflected the logic of systems in loosely bound aggregates. The system found their own balanced state by themselves. In order to observe the holistic system behaviour, the quantity of the modules was significantly important. Eighty of those modules were used during the prototyping phase. This system was able to produce cantilevers, and structures that could grow vertically. Following the prototyping phase, a digital computational model was established in which the quantity of the modules could be increased even more to a level that it was possible to observe more complex behaviour and where the forces effecting the overall system such as gravity and friction could be altered (fig. 3).

The project with aluminium sheets was investigated by the system made by double-curved surfaces. Double-curved surfaces obtained two curvatures in two distinct directions on their surfaces. As previously mentioned, participants were asked to assess the buildability of their projects as part of their scope in the workshop. In this particular project, the manufacturing logic of double-curved surfaces needed to be expressed systematically because of the challenge in manufacturing double-curved surfaces in architectural scale (building). By being aware of this issue the geometry was rationalised systematically. The cut lines that were defined on the surface enabled the form to be repeated with the same manufacturing logic by generating flat segments. The difference of the elements and their connection types were investigated during the design process. A series of tests was undertaken by aluminium sheets of varying thicknesses in order to explore the formal and structural possibilities of the modules (fig. 4).

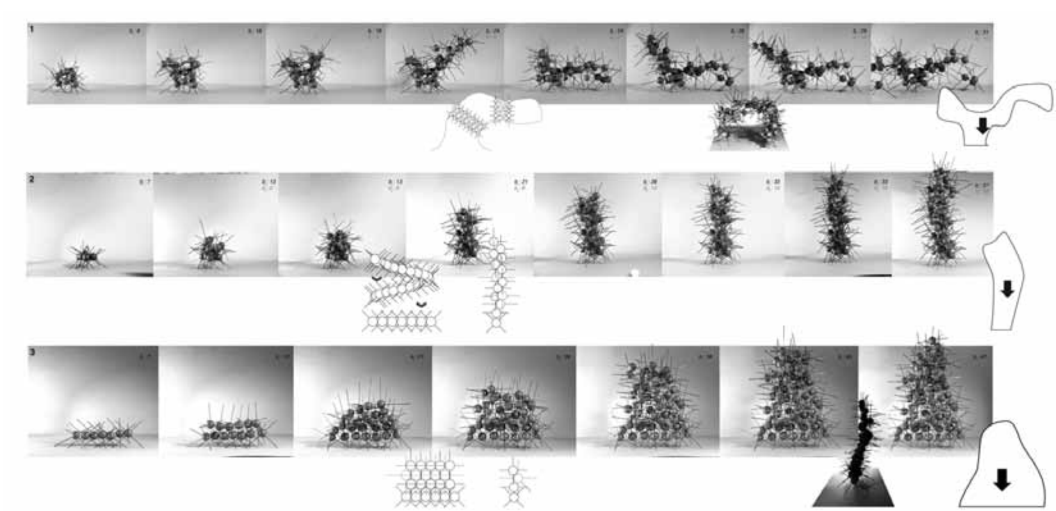

Figure 3. System, for example aggregates, which are loosely bound (Student credits / Sina Ozbudun, Erdem Tuzun).

Figure 4. System of double-curved surfaces made out of aluminium sheets (Student credits / Dilsad Anil, Gizem Eroz, Esin Ozkula).

Summary and results

Today's innovative architectural practices are aided by the interdisciplinary fields of interests through the design development, analysis, and building phases and they enable a transformation into a new reality. Computational design, in terms of its underlying logic, needs to be further investigated and incorporated into the general undergraduate curricula in architecture.

The Material Formations Workshop, run by the author at Istanbul Technical University, aims to create a method based on systems thinking by referencing nature in order to generate a fundamental base for undergraduate students of computational design. HSDM was used in the workshop where participants explored form through physical materials in a holistic manner.

Contributions and future lines of research

Computational design tools, which dominate today's innovative architectural design processes, operate through systems. In order to establish systems in undergraduate architectural design education, which do not require a knowledge of programming or scripting, systems thinking should be investigated. It would be efficient for their future careers, as well as their professional experience in innovative practices, if students could achieve a fundamental base in computational design by systems thinking.

In the following phase of the research, the aim is to integrate material performance, structure, and form systematically where their relationships are quantitative and measurable. The system should be investigated to perform, with multiple parameters for complex problems, such as building systems. The ultimate goal would be generating algorithms that evaluate the complex data related to the building and the optimisation of the system by objective criteria.

I believe that the design process driven by material systems will transform the immaterial world of our age (dominated by the computer) into a more realistic environment. This would bring the issues related to the materialisation and building processes right to the beginning of the design process, where the architectural designer can handle form finding and building processes parallel. This approach will shape the future of architecture and challenge the norms of the conventional practice.

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