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Computational Design Pedagogy for the Cognitive Age

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This paper explores and reflects on an integrative computational design thinking approach, which requires the melding of computation, design and theory as a conceptual framework, to be implemented in architectural education. Until now, digital design education is typically based on the introduction of digital tools and plugins at university courses and the subsequent application of these tools to design tasks of limited architectural complexity. At this time, technological advancement has not been matched by a comparable advancement in computational design thinking. The paper describes in detail a novel conceptual framework for course setup that illustrates the using of computational design as a manner of thinking in patterns of interaction across various scales, reaching from building design to regional planning. This approach was subsequently tested in a series of master-level studios, the results of which will be presented as case studies in this paper.

Keywords: *Computational Design Thinking, Architectural Pedagogy and Education, Dynamic Patterns, System Thinking*

INTRODUCTION

In recent years, the ongoing transition from analogue to digital architecture has materialized through the increasing availability of novel software and new methods in architecture on all levels of production resulting in an unprecedented tooling of the design process (Angelil 2003). In the wake of this revolution, digitalization became one of the main subjects in education research and a focal point in curriculum development in architecture schools around the world (Zhu et al. 2016). Until now, however, there exists neither a framework nor a fundamental structure for the integration of digital technologies into architectural education (Soliman 2019). In other words, technological advancement has not been parallelized by comparable advancements in digital design thinking, which means that the full potential of these technologies has yet to be established (Oxman and Oxman 2013, Lorenzo-Eiroa and Sprecher 2013, Goodhouse 2017).

This shortcoming is grounded in the observation that the teaching of digital design thinking at many universities around the world typically is based on the basic introduction of digital tools and plugins at university courses or conference workshops; subsequently these tools are used in simplified design tasks of limited architectural complexity. Such a tool-based approach enables students to expand their set of architectural design tools relatively quickly. But the black-box character of such education does not activate any metacognition and, thus, is lacking the facilitation of higher-order thinking required to advance design thinking as a whole (Schneider 2001).

As a consequence, the current tool-based approach to digital design can be perceived as a form of automizing or mechanizing the design process for which Terzidis coined the notion of computerization in Algorithmic Architecture (Terzidis 2006). In this study he pointed out that, in contrast to computerization, the development of digital design thinking is dependent on an understanding of computation which is "about the exploration of indeterminate, vague, unclear, and often ill-defined processes; because of its exploratory nature, computation aims at emulating or extending the human intellect. It is about rationalization, reasoning, logic, algorithm, deduction, induction, extrapolation, exploration, and estimation. In its manifold implications, it involves problem solving, mental structures, cognition, simulation, and rule-based intelligence, to name a few." (Terzidis 2006). A critique shared also by more recent exploration of computational thinking by Denning & Tedre (2019).

CURRICULAR IMPLICATIONS

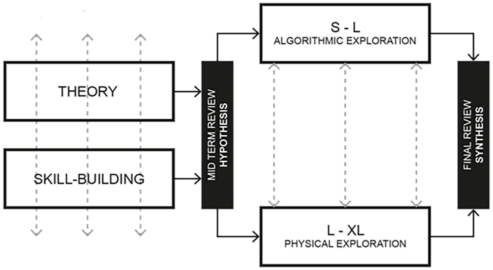
In order to initiate such computational design thinking, courses in digital architecture have to go beyond typical tooling and offer a more holistic perspective that activates different levels of cognitive engagement with the topic. The ubiquity of digitalization within the discipline requires a melding of computation thinking with design thinking and theoretical considerations as an answer to the complex challenges facing the profession of architecture an all levels of design, from building to urban and even landscape design. One university course or one workshop is not able to offer such a multitude of inputs due to limited resources and time.

As a consequence, in the course of three years, an introductory course into computational design has been developed and implemented at Aalto University as a close collaboration between two research groups: the Professorship for Computational Methodologies in Landscape Architecture and Urbanism, headed by Prof. Pia Fricker and the Professorship of Design of Structures, headed by Prof. Dr. Toni Kotnik. This collaboration not only enables the merging of teaching offers but, more importantly, the establishing of computational thinking as mediator across architectural scales and common platform for interdisciplinary research (Deutsch 2017, Bernstein 2018). That is, computation is not introduced as technological topic but primarily as a way of thinking and cross-disciplinary link, as unifying common denominator of discourse, as locus of production and systematisation of knowledge within the discipline of architecture across various scales of application.

NOVEL COURSE ORGANISATION

This course is aimed at students without prior knowledge of digital tool or computation methods but, instead, requires a solid background in architecture or landscape architecture. Titled Pattern of Interaction, the course is offered as a collaborative design studio as part of the Master´s Programme in Architecture at xyz University. Organized by the two professorships, the studio is formally comprised of four courses: two 10-credit studio courses merged together into one week-long studio course and two 5-credit intensive courses, one seminar in computational theory and one skill-building course in scripting (Figure 1). In sum, Pattern of Interaction is a package of 30 credits that covers the full teaching load of one semester for all participants of the studio. This means all students have the opportunity to fully focus their attention on the topic of computation for the entire semester.

Figure 1
Phasing of course with short exercises in parallel streams within the first phase, followed by design exploration on various scales and continual interweaving of activities by common themes and discussions in the second phase



All courses are maintained in constant dialogue through common exercises and discussions. The course on computational theory is a sequence of key readings on the digital turn in the 1990s, early predecessors of machines and intelligent behaviour as well as cybernetic cognition in the 1970s, and the resulting move towards systemic thinking and patterns up to current ideas of material systems and performance-oriented design. Discussions on these topics and their implication for architecture form a theoretical backdrop for exercises in formalization and rule-based thinking that are main driver in the skill-building course.

The skill-building course introduces students to formal languages and set-ups to aid in the use of observed patterns and relationships to explore and resolve design problems (Figure 2). Scripting exercises on topics like agent behaviour, automata, graphic statics, discrete systems, L-systems, fields, rule-based design or simplified flow/erosion/deposition simulations are used to reinforce the skillset and computational thinking required to be creative with the medium of visual or scripted coding (Kelleher and Tierney 2018). The systems explored in these exercises are used to highlight the perks and caveats of computational design enabled workflows. As an intended by-product, students gain increased awareness of a rich vocabulary of computational design approaches with which to address a design problem.

The exercises, linked more closely to the design studio, are used to reinforce the need for formalization and rule-based thinking by means of geometry and connect them with architectural space-making strategies of mixing (Figure 3), the translation of spatial experience into formal relationships between shapes, distances and hierarchies, and the transformation of these relationships into properties of material systems and the articulation of ground conditions (Das 2016).

The sequence of exercises supports the students to achieve a multitude of important learning outcomes. They enable students to transform certain parts of their design problems into a solution space, permitting the possibility to navigate this space using solvers, optimization strategies and machine learning algorithms. By integrating build-in feedback, their variations are compared and the design goals adjusted. Students learn to learn to correlate between the depth of understanding formalized relationships or phenomena, and the building up of the ability to explore and exploit these correlations. The exercises are designed for creating a controlled awareness of complexity and concepts, enabling students to build upon formalized logic compiled by peers. Finally, students become keenly aware of the limitations in bending a computational model to reflect their will, fostering a wish to understand underlying principles in more depth in order to better formalize and control their outcomes.

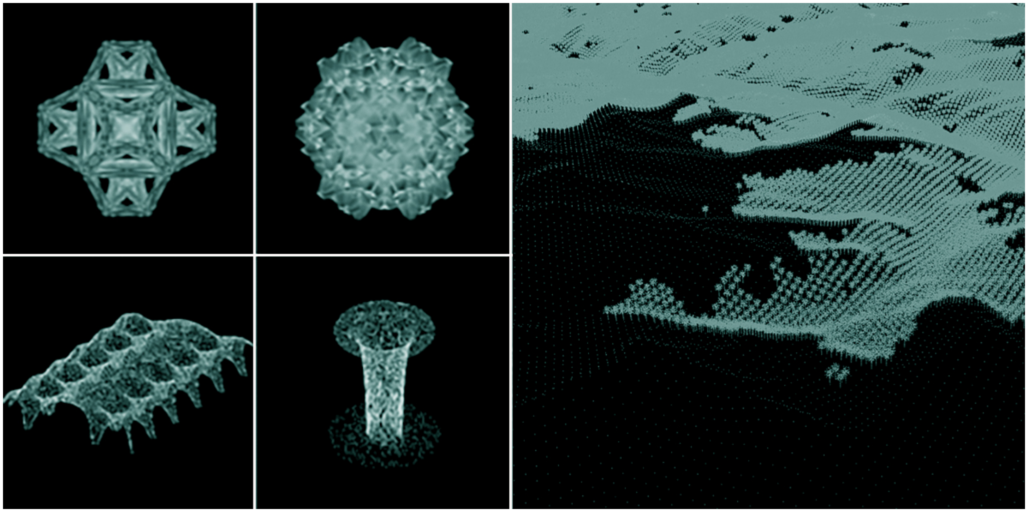


Figure 2
Examples in scripting exercises: Discrete system explorations (top left), Optimization Strategies for discrete system (bottom left) & Field behavior (right).

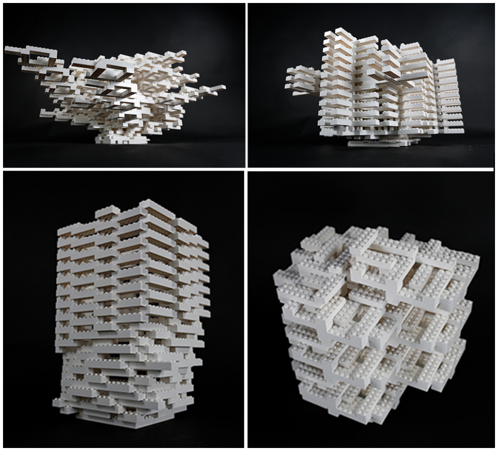


Figure 3
Rule based design using Lego; A point system was devised around a set of proximity and proportionality of a fixed number of discrete elements to award "good performing" designs, the students were then given the challenge to devise a structure that would maximise this metric.

SYSTEMS THINKING AND PATTERNS

Observing natural phenomena within architecture and landscape architecture in terms of their inner logic reveals the multilayered and complex structure of their patterns. This inherent logic can be connected to theoretical basic principles of computer science and represents a theoretical superstructure of computational design methods (Picon 2010). M'Closkey and VanDerSys show the potential of generative patterns with respect to landscape architecture and urban design and refer to the potential gained in the analysis of structures in order to generate a new understanding for relationships and forms (M'Closkey und VanDerSys 2017). James Corner describes patterns in this context as "relational frameworks that simultaneously describe and project; they reveal structures, processes and relationships, as well as structure physical frameworks that give shape and form to our world." The logic of these connections and networks can be shown through patterns of behaviour, which manifest themselves in dynamic, active, binding, connecting, and distributing attributes (Andersen and Salomon 2010). Corner refers to the importance to relate this theoretical framework on the dynamic processes inherent to landscape architecture, in order to "form new patterns and forms that structure new ecologies, new program, and new modes of reception" (M'Closkey and VanDerSys 2017).

Spurred on by these theoretical discussions and

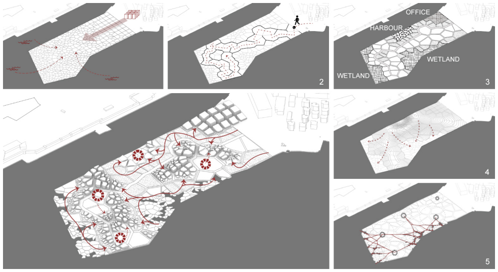


Figure 4
Rule based design using Lego; A point system was devised around a set of proximity and proportionality of a fixed number of discrete elements to award “good performing” designs, the students were then given the challenge to devise a structure that would maximise this metric.

by experts at conferences like eCAADe, ACADIA, DLA, the past several years, one can recognize a positive trend to integrative computational design teaching concepts. With our course we are aiming at an understanding of computational design that does not place a focus on predefined workflows and strict methods, but rather along the lines of embedding the potential of thinking in complex systems (Fricker, Kotnik and Piskorec 2019).

DESIGN STUDIO BACKGROUND

The design questions continue with the exploration into the city as a performative landscape (Cantrell and Mekies 2018), focusing on the relation and interaction between the building and its neighbourhood and the problem of verticality versus horizontality. Computational design thinking is driven by the idea of articulated ground (Schumacher 2013) that is the active use of urban and landscape strategies on a conceptual as well as operative level of design development throughout all scales of intervention. Students from the field of creative sustainability, architecture and landscape architecture were asked to rethink fundamentals of contemporary architecture, urbanism and landscape architecture on an existing site in Helsinki, Hernesaari.

Project Area: Hernesaari, an artificial peninsula of 0,49 km2 is located in the southernmost part of the downtown area of Helsinki, Finland. Hernesaari served as a dockyard and industrial area for several decades. After a series of master plan developments by the City of Helsinki, the ongoing Hernesaari development is part of a sea-oriented change process in Helsinki and sets its focus on the new waterfront development (City of Helsinki 2020). The currently developed urban plan follows a classical modernistic approach, represented by a conventional zoning strategy, which divides the island into three separate functional zones. This plan acts as a starting point for the studio to rethink the future of Hernesaari.

Within the studio, the spatial context of Hernesaari was used as a testing ground for speculative computational design methods. Each student team was assigned a “slice” of Hernesaari as their zoom-in field of intervention. The aim was to define experimental explorations in various scales, developing a general urban design vision and local design articulations, and formulating new approaches for future-oriented waterfront developments in growing cities. The interaction within the assigned slices allows both exploring and formulating small- or large-scale design speculations in the area of urbanistic answers to specific site conditions. Within the student project “Intercellular: Conceptual Design of Hernesaari” by xyz, a new computatoinal design strategy is developed to address the complex settings of the site. Figure 4 showcases the following steps of interaction: 1: General pattern generation and distribution of the cells. 2: Creating logic to automatically organize the cell size according to functions and connectivity. 3: Cells are evaluated and adjusted according to the functional parameters, merging of cells and performance check. 4: Articulation of the ground condition according to water and wind flow simulation. 5: Generation of border conditions, taking into consideration the seasonal climatic aspects. 6: Extension into the 3rd dimension and generation of an overall public space concept according to the concept of “articulated ground” (figure 4).

NEW DESIGN STUDIO FORMAT AS INCUBATOR

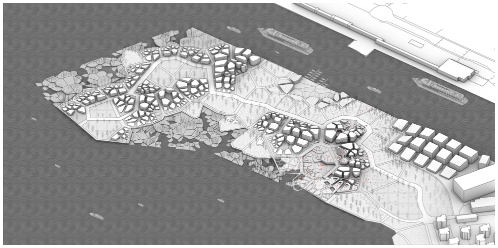


Figure 5
Urban Design Vision: The computational model allows the students to generate a highly complex design proposal with full control on all scales. The implemented formal actions are carefully chosen in order to express the student‘s motivation to create a new form of urban interaction space for people and nature.

The central task of the studio is to rethink the traditional approach of separated functions by applying computational design methods for mixing form and functions into a new spatial configuration. The design thinking is driven by the idea of articulated ground (ZHA 2017) or the active use of urban and landscape strategies on a conceptual as well as operative level of design development throughout all scales of intervention (figure 5). As described within the discourse on the topic of systems thinking and the potential of dynamic patterns, a discussion on the topic of future-oriented computational design thinking for the education of architects can only be led in combination with a theoretical excurse.

The evolutionary didactical backbone of the design task is based upon a carefully orchestrated thematic combination of abstract, theoretical computational explorations and computational design exercises which are design-oriented, hands-on and based upon coding (figure 6).

CONCLUSIONS AND DISCUSSION

As discussed in this paper, the reflection on computational design methods opens up much needed reflection on learning theories. Entering the domain of computer science adds an additional challenge, which requires new didactic and pedagogic approaches to be developed in consequence of the increasing domination of e-learning applications. Siemens (2004) formulated the need for an explicit theory for the digital age - “Connectivism” - to define the development of teaching concepts for the digitally networked world. In a university setting, the principles of andragogy support the development of the individual experiments and tasks and lead to a steep self-motivated learning curve, as the students see the immediate increase of quality in their design (Peltz 2019).

One of the main findings of the students has been the positive evaluation of the development of a combined learning theory, catered to the special needs of teaching computational design thinking in our domain. Our studio set-up embeds several elements of the abovementioned theories, adjusted to the particular application areas linking to phenomena of the area of natural sciences and computer science.

In nature, mixing processes and patterns of interaction are common. They enable the configuring of heterogeneous physical elements into a coherent, homogenous system and the emergence of new qualities out of the recombination of existing ones. This motivates our interest in systematic mixing strategies and their potential for application in the design of the built environment on various scales. In this context, rule-based mixing strategies are of special interest as they allow the designer to actively control the process and, thus, enable the guiding of the mixing according to deliberate design intentions.

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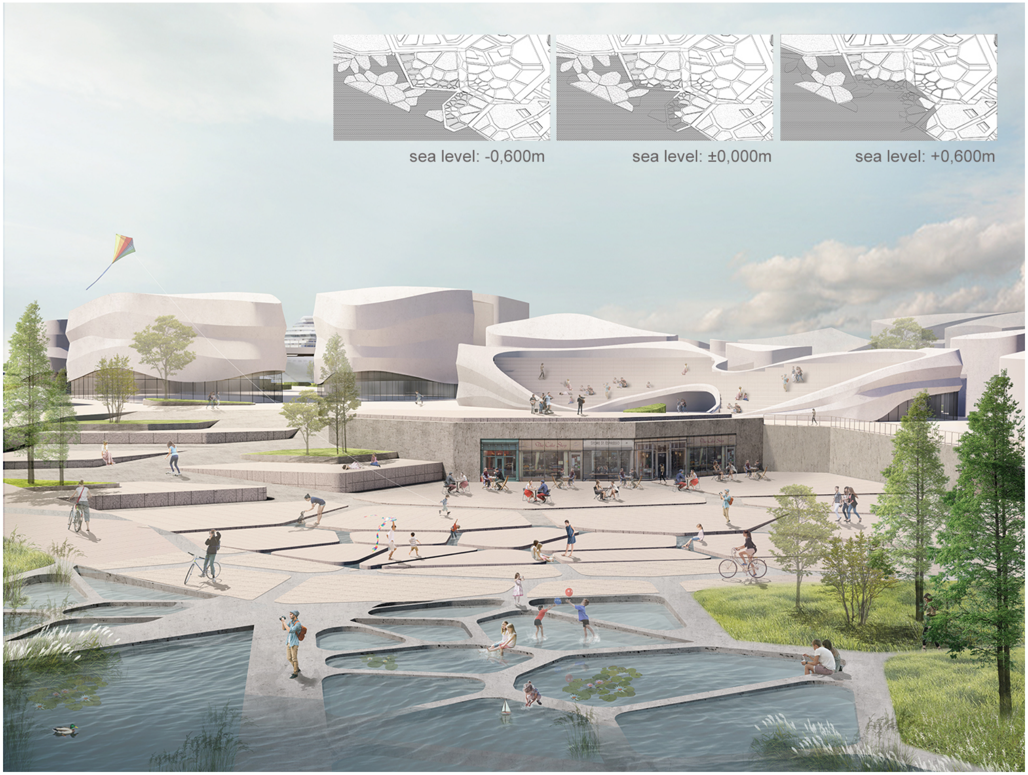
Figure 6
The generated design creates a responsive ecosystem, blurring the boundaries between the built and the unbuilt. The constant change of the environmental conditions creates a process of hybrid transformations and allows the users to interact as an active part in a newly articulates eco-system. Student work: "Intercellular: Conceptual Design of Hernesaari" by xyz



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