Proceedings Paper:

Ireland, T. orcid.org/0000-0002-7845-8834, Spyridon-Athanasopoulos, G. and Bus, P. (2023) Some spatial experiments: student work exploring intersections between computing, biological and semiotic theory through architecture. In: Dokonal, W., Hirschberg, U. and Wurzer, G., (eds.) Digital Design Reconsidered - Proceedings of the 41st Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe 2023). 41st Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe 2023), 20-23 Sep 2023, Graz, Austria. eCAADe, 1 . eCAADe , pp. 21-30.

https://doi.org/10.52842/conf.ecaade.2023.1.021

Some Spatial Experiments

Student work exploring intersections between computing, biological and semiotic theory through architecture

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The MSc Bio-Digital Architecture at Kent School of Architecture & Planning is a post-professional program developing a specialist approach to architectural thinking and design execution, encouraging students to engage with broader theoretical debates that are pertinent to contemporary practice. The program emphasizes the conundrum of "what is space" and provokes students to explore the concept of space and the problem of configuring space in architecture. Taking an interdisciplinary approach (spanning theoretical biology, social science, systems theory, cybernetics, semiotics and computation) students are expected to establish ways and means of rethinking and designing architectural space. In the current situation, where the integrity and primary role of architecture is seriously challenged by specialized research and partial interpretations of the discipline, there is a growing need to articulate a body of knowledge and understanding capable of reconciling the fragmented areas of knowledge within the given reality of current contemporary architectural practice. The aim of the course is to establish a comprehensive understanding of architecture rooted in the humanities, with an emphasis on the digital turn in architectural discourse and theory, to integrate knowledge of specialized disciplines into a unified and meaningful whole. The integrative nature of the student investigation's opens the possibility to come to terms with the situational structure of architecture and can serve at the same time as a foundation for a more fully developed human ecology.

Keywords: *Computational Design, Biology, Semiotics, Architecture, Pedagogy.*

INTRODUCTION

Exploring the intersections between architecture, computing, and biology the MSc Bio-Digital Architecture program at Kent School of Architecture & Planning (KSAP) is designed to provide students with a theoretical basis of Computer-Aided Architectural Design as an academic discipline whilst simultaneously educating them in the use of the computer for analysis of design problems as a tool for the generation of space and form (*cf.* Coates 2010). Theory and practice are taught in tandem so that students learn theory through application and testing, enabling them to apply this knowledge and understanding in design studio projects. Grounded in the ethos that nature is a creative engine (Emmeche 1996, Hemelrijk 2005), whilst also reflecting the interdisciplinary makeup of computational design and its application to architecture, the program amalgamates architecture and computing with biological and semiotic theory to promote computational modelling and coding as a means to stimulate a biological approach to architectural design thinking (*cf.* Sabin 2017). The emphasis of the course is behaviour and how geometry may be an emergent product of actions, based upon the distinction of differences (i.e., a percipient acting in the world towards some activity), as opposed to an ideal property. Thinking conceptually about behaviour and the generation of shape, form (and thereby the configuration of space), to understand how these may arise as a product of the consequence of interactions and performance, students are tasked to think about how architectural ideas and solutions might emerge and to apply this way of thinking and working to generate architectural scenarios. A selection of student projects that illustrate the programs ethos and demonstrate the fusing of computing with biological and semiotic theory through architecture is presented.

ABOUT THE PROGRAM

The program is an offshoot of the MSc Computing and Design program at University of East London: one of the earliest master's courses in computational architectural design. Initiated by computational architectural design pioneer Paul Coates (1969-2013), and later co-directed with Christian Derix. Following Coates and Derix, the focus of the current program is coding and generative modelling. There is a strong emphasis on natural processes and how these transfer to architecture, and specifically the generation of spatial formations and configuration of architectural assemblies. As Coates states:

> The point is that there are hardly any things in the natural world whose form/shape are the products of a simple linear morphological process. On the contrary, they all seem to be the result of lots of things happening at once. This is not surprising because the world is essentially made up of lots and lots of things which act at the same time as each other, and many morphologies arise by the way the multiple things interact with each other simultaneously over time. In other words, the way we design and make shapes is most unnatural, since it depends on a 'one thing at a time' way of working (Coates 2010:165).

Central to the computational design paradigm is the notion of generating architectural solutions from the bottom-up. That processes of self-organisation will give rise to productive activity, whereby instructions imprinted into the system will form, or rather, replicate and bring about novelty, or the emergence of something initially unspecified. Referring again to Coates, the point is to take a systems view of space.

> This provides the possibility of modelling space and form as based on very simple algorithms defined as part of a process. The processes we look at are part of a long history of ideas in post-modern thought derived from experimentation in mathematics and computer science […] These new ways of seeing form and spatial organisation all show the phenomenon of 'self-organising morphologies', often referred to by the general rubric of 'emergence'. […] seems to provide a nice paradigm for architecture as the emergent outcome of a whole lot of interconnected feedback loops, which replace top-down geometry and the reductionist tradition, with dynamic relations and emergent outcomes not defined in the underlying model (Coates 2010:1).

The key driver for Coates, other than to explore form generation, was the question of space, and how space is an emergent phenomenon as opposed to the negative of form. A perspective characterized by Derix, whereby space is 'self-organising'. Coates approach was bedded in the idea, or potential, of syntax to drive formation. He refers to an algorithm as 'a set of linked activities', arguing that algorithms should be expressed as text (a text-based system of signs), to determine some degree of 'distance between the description of the algorithm and the intended outcome'. Drawing the analogy between code (as an artificial language) and natural language, Coates demonstrates how instilling ambiguity in the instructions develops abstraction, which defines what he refers to as a generative grammar. In this way an algorithm is perceived as a concatenation of text through which "we will be able to have a conversation [...] with common lexicon and syntax, without restricting the universe of discourse to some ill-defined sub-set of design but be able to contemplate an infinite set of outcomes" (Coates 2010:3), in a way that uses the computer as 'a tool to think with'.

Coates thinks of code as semiotic, but his focus is structuralist. "I have to admit that the general position of this book is structuralist in nature, partly due to a heavy dependence on the thought of Bill Hillier, and of course on the use of artificial language and Chomsky's generative scheme as a model for form production" (ibid :160). Coates outlook is based in the semiotic logic of Ferdinand de Saussure (1857-1913). From a generative design perspective this is a mistake, and this is where the two courses differ: in their philosophical and logics perspective.

Thinking in terms of the semiotics of Charles Peirce (1839-1914) and Charles Morris (1901-1979) pragmatic semiotic model, an algorithm is a set of axioms appropriate to particular conditions under which specific rules are actioned relevant to context; or conditional 'frames'. For example, an agent may be actuated to move forward wiggling in a random direction. Finding something (be it another agent or feature of its environment) it responds according to rules relative to what it has 'found' and its status. Some behaviour is thereby triggered, but most significantly this occurs through the conditions under which the agent and what it has 'found' exist. That there is a relation, or some form of commonality is formed, between the agent and that which it has found. From the agent's perspective this is determined by, or conditional on, its internal state. In effect, as Coates argues, a computer program may be seen as a system of signs, having a syntactic dimension (the relations between the rules) and their expression (the semantic dimension), but these are only affected through conditions effecting the instructions; the latter constituting a pragmatic dimension. It is the triadic nature of meaning-making (as defined by Peirce), not dialectic structure (as defined by Saussure), that drives productivity (be it morphology, or pattern forming) in natural systems (Hoffmeyer 2008). In this sense the structuralist position presented by Coates may be shifted towards a Peircean conception, following Morris' more general behavioural model of syntactic, semantic and pragmatic dimensions. Of course, in a computer program, no meaning-making is claimed to occur. The semantic dimension is fixed, as any open semantic activity would involve semiosis, and that would require abduction to occur. The process outlined is of basic agent-environment interaction, which is responsive as opposed to abductive, and, as formulated, is semantically closed.

This theoretical perspective underpinned the modelling approach of the presented programs design studio for the students concluding thesis project, demonstrating the amalgamation of theory in practice through code and generative methods. A brief overview of the program structure is now given before a summary of example student outputs.

Structure

The course is organised in three "steps". The first, incorporating two modules, introduces fundamental skills and theory of computer-aided design. Students are introduced to parametric design principles using Grasshopper and computer coding using Processing. The first module "Principles & Methods" introduces students to thinking about form and spatial organisation as a bottom-up process and use of the computer as a tool to model dynamically. A blend of lectures/seminars introducing principal concepts (i.e., self-organisation, decentralisation, emergence and, algorithmic thinking) and workshops introducing computational generative modelling methods using grasshopper, through the theory is demonstrated. Students produce a report explaining their application, understanding and adaptation of delivered content. They also present a design project that exemplifies and builds on a concept and method of the students choosing applied to an architectural proposition.

The second module "Introduction to Programming" teaches the basics of computer programming using the Processing language and platform. Students learn Processing methods, and transferable programming techniques, to create architectural spatial formations. Introduced to Object-Oriented Programming and agent-based modelling students build an artificial organism to generate 3D spatial compositions through agential-environment interactions. They produce a report describing their individual agent program, methodology and results.

For the second step students are exposed to an interdisciplinary theoretical discourse prompting them to engage philosophically with ideas about space, the generation of form, behaviour, and agency, whilst also extending their generative modelling skills. The module "Morphogenetic Programming" amalgamates the previous two modules to extend their coding skills and use of Grasshopper. They are taught the C# programming language. Working within the Grasshopper environment students are introduced to various methods of simulating natural processes of growth and pattern formation. Working with generative algorithms students are tasked with exploring their application in creating structures to challenge traditional notions of designing architectural form and space, and (in tandem with the "Discourse and Theory" module) to cultivate a bio-digital outlook to architectural design. They produce a report explaining understanding, application, simulation and adaptation of bio-inspired spatial self-organisation.

The Discourse & Theory module introduces students to a series of concepts and theories from outside of architecture to promote and enhance their perspective on architectural space, design and the built environment, and to provoke an interdisciplinary research-oriented outlook. These two modules work in tandem to enable the students to establish a theoretical basis for the main thesis project, through which they develop conceptual architectural propositions.

For the final step students undertake an independent research-oriented thesis driven by a working algorithm designed and implemented by the student. The thesis project is the final piece of the program, through which the student is required to demonstrate their capacity to apply the acquired knowledge and techniques in a creative and innovative way to an architectural problem. The thesis is an illustrated account of an original inquiry in design research, pursued through a close and careful study to propose an innovative architectural proposition that demonstrates a theoretical and practical application of bio digital architecture.

STUDENT WORK

We present here a sample of three student thesis projects. Hasin Zahin and Kaveh Dagar (2021) and Hamid Zoab (2022). Each of the projects represents a different path to express computationally the idea of an emergent complex system of interacting components within an environment, aiming to understand the behavioural characteristics of the system in iterative processes. This, as a result, creates the configuration of space, spatial boundaries, or a scenario, which, in turn, influences the behaviour of the initial acting units within the system itself.

Zahin (2021): Agential Boundaries

Exploring the idea of space to be an emergent phenomenon, as opposed to the negative of form, this project explores the capacity for agency determined spatial organisation. That unspecified boundaries will arise through cooperative and competitive agential interactions. Effected through agent-agent and agent-environment exchanges, the premise is that these communicative forces establish limitations on the agent population defining margins correlating to the agent identities. The emergent boundaries (figure 1) are descriptions of social space, which emerge giving imposing spatial order on the agent population.

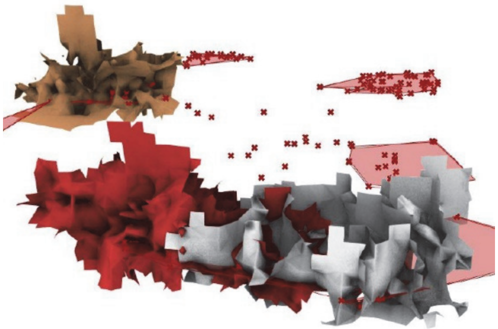

Figure 1
Growth pattern and density of the configuration observation

The project elaborates the Uexküllian's view on the perception of agents with their surroundings, their interrelations, and interpretations of actions of forces from the environment, and their acting upon what they perceived (Uexküll 1992). This led to a definition of space according to the interpreted perception and the capacity to make rational decisions which allow the agents to interact decisively, benefiting from those interactions to create a growing structure, reflected in informal settlements, where subjective perceptions of the surroundings play a pivotal role in negotiations, cooperations, and mutual concluding scenarios between the inhabitants (Zahin 2021).

The algorithmic representation of those theoretical reflections on how the space is determined by the richness of negotiations and interactions upon the perception of a subjective space is tested in a predictive model allowing the planning process to manage conflicted spaces in the settlement more efficiently. As such, the model offers an understanding of the dynamics of space through a subjective worldview.

Dadgar (2021): Stigmergic Construction

The project "Architecture without blueprint", is built upon an understanding of the dwelling as an open-ended spatial and structural system, following the relational qualities of the incremental growth of matter within given environmental conditions. The aim of this project was to investigate how the space is organised and created if the process is not controlled by the designer and is rather influenced by behavioural notion of the system itself and its individual units interacting between each other. There is a relationship of the emerging substance of the scenario creating the spatial components-driven architectural configurations influenced by the events and outer processes of the environment affecting the behaviour of the building agent.

The initial formal language employs the component-driven assembly process, following the natural process of growth, controlled, and limited by the discrete shapes and orientation of the components on the one hand. On the other hand, the decision-making process how the shapes are organized in a hierarchical and unforeseen non-linear way is taking the natural notion of the wasp nest builders (so called paper wasp: *Polistes Fuscatus*) as a base for the communication and interaction between the builder and the environment. In this system, the builder agent acts as an individual entity interacting with the environment. The computational iterative system mimicking the logic of the paper wasp nest building strategy, implements the influencing ratio of deposit cells over iterations, affecting the growth and density of the cells geometry massively. The builder agent makes the decisions, which may change in the process based on the conditions that trigger different behaviours resulting in different rules of construction method of the nest (Dadgar 2021).

The builder responds to a variety of stimuli with different actions; therefore, the different stimuli result in different responses and different spatial configurations in a non-linear way. The previous iterations and decision also influence the next step in the iterative growing process, so each new

configuration is triggered and guided by the previous one, following the additional properties of the nest, such as the location of the neighboring cells, distance between the cells, the cell orientation, or a force field, referring to a gravity force (Downing and Jeanne 1990).
The computational strategy translated those read and write processes of stigmergic behaviors into the geometrical representation, resulting in more complex spatial models expressed in geometry. The rule-based mechanism for a builder agent follows the set of instructions, operating with the library of components, deposited in a sequential way, combining a variety of placement strategies, and considering already deposited components, their orientation, mutual distances, and densities (Figure 2).

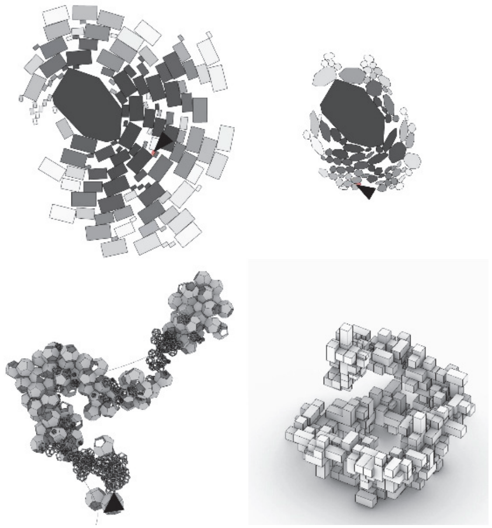

Figure 2
Simulation of the iterative process based on builder's behavior

The project brought the idea of understanding architecture as a systemic instructional set of rules to create a spatial scenario, inherently encapsulated in the process of iterative growth, because of interactions between acting components. Supposed hidden intelligence behind the process prompts the question whether the proposed computational methodology can learn, understand, and predict the builder agent's behavioral decision-making (and the interplay between constructor and a user of space) can adapt the system itself towards a close-to-ideal spatial entity.

Hamid (2022): Fungi Wars

Along the lines of Coates's simultaneous interaction of self-emerging morphologies Hamid presents a multi-layered juxtaposition across notable systemic thinking discourse precedents. Tools and ideas vary from Fish Shoaling (Shaw 1978) to Conversation Theory and the Boredom Program (Pask 1980). At the core of the work remains an original fungi growth pattern construction through Reynolds's Flocking algorithm (Reynolds 1999). By exploring different population sizes, a first aim is to examine spatial boundary negotiations in a pseudo Dirichlet (1850) subdivision. A process inspired by how fungi species compete and define spatial proximities (figure 3). This boundary investigation further continues with the implementation of cybernetic principles and Gordon Pask's Conversation Theory. The notion of "agreement" through information exchange is used as a vehicle to suggest a solution for a wicked design problem (Rittel and Webber 1973), and is sought in spatial arrangements where fungi cells independently interact defining territories. The

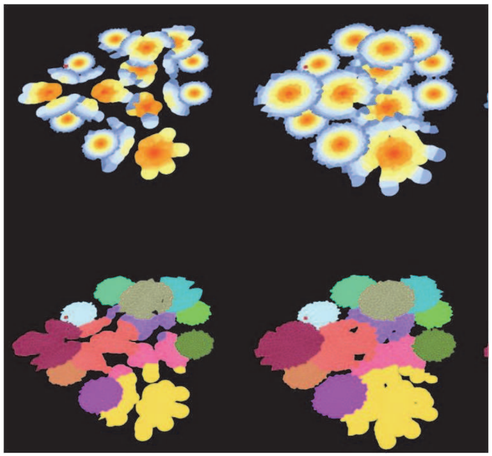

Figure 3
The Flocking Algorithm on set areas with unequal populations.

approach marks an innovative interpretation of Conversation Theory's framework as the flocking algorithm provides an adaptive and continuously interchangeable property echoing the dynamic function criteria emphasised by Pask.

Following the theoretical thread of Pask and the *Generator Project* (Steenson 2010) the methodology is extended towards the adaptation of external, or exosystemic, environmental parameters. This aspect is aimed to expand the syntax with additional external agents by means of attractor points, following a fish shoaling approach. Figure 4 shows an example of introducing proximity influencing points on a two-dimensional grid whose subdivision pattern is affected mimicking a predator/prey behaviour. This is then further developed in the thesis in three dimensions and finally implemented on the full cross-systemic Fungi War amalgam (figure 5).

Overall, the thesis offers an authentic and elaborate approach to implementing a bio-digital performance-based strategy for developing a spatial construction syntax and negotiating its cross-methodological self-emerging entities. Given the character of the tools, the process results in challenging the established vocabulary examples of the theoretical backgrounds under research while remarkably, at the core of the investigation remain the doctrines' own radical hypotheses, such as the dynamic notions of adaptability and flexibility.

DISCUSSION

"Bio Digital Architecture" (BDA) is a term defining architectural enquiry into the use of computational methods characterised by biological processes, distinguishing the topic from the more general phrase "computer-aided architectural design" (CAAD). The latter being an overarching field concerned with the application of computers in design. As such CAAD requires no biological aspect and may instead draw on other specialities such as physics and mathematics. BDA Design is fuzzy. It is not concerned with defining definite distinct solutions but with exploring processes to generate solutions (or rather scenarios) that reflect processes observed in nature; or rather process we understand underpin the generation of patterns and forms we observe in nature. BDA is defined by the computational field of Artificial Life (Alife) (Levy 1992, Langton 1995, Emmeche 1996). It is in this sense that the program presented in this paper is an offspring of the MSc program instigated by Coates;

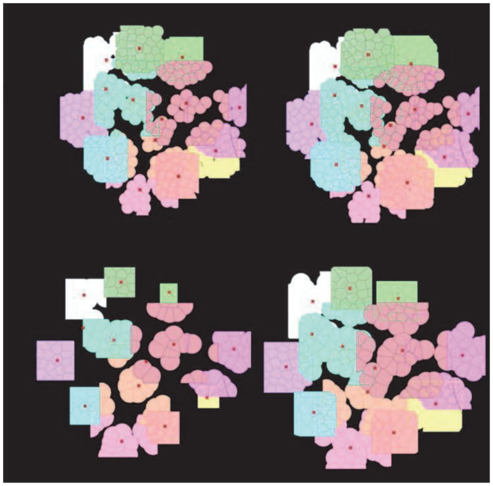

Figure 4
Overlaying the agreement configuration

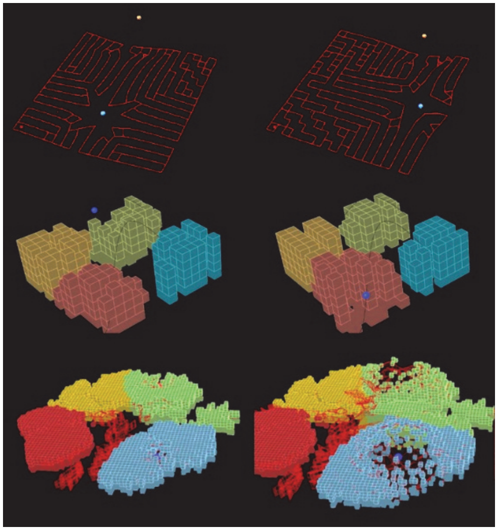

Figure 5
Top: Fish Shoaling on 2D and 3D grid configurations.
Bottom: Emergence of the cross systemic juxtaposition

described above. The example student projects presented are exemplar outputs of the BDA program described and the wider CAAD field, but do they demonstrate the aims of the BDA program? Is there, for example (as questioned of Dadgar's project) any hidden intelligence behind the process and if so, might the proposed computational methodology learn, understand, and predict the builder agents behavioural decision-making? In short no. We will explain why shortly but first it is important to contextualise the student projects. They demonstrate the ethos described by Coates: i.e., that morphologies arise by the way multiple things interact with each other simultaneously over time, through which space and form emerge based on simple algorithms defined as part of a process. Based in the ALife ethos they operate with and contribute to the BDA paradigm. The student projects are defined by the presented program's philosophical outlook. Hence, their methodologies and algorithmic perspective exemplify the underpinning semiosic philosophy of the program. However, the processes involved do not replicate the stated semiotic dynamism. They demonstrate the idea, through philosophical interplay (i.e., by overlaying the philosophical outlook onto the methodology (and biological phenomena or process) that inspired it, and thus the outcomes that arise but the algorithms involved equate to typical computational logics. However, there is no semiosis occurring in the processes described. Consequently, the answer to the question raised of Dadgar's (2021) project is an emphatic "no".

Only natural systems are capable of semiosis: at least to date and to the authors knowledge. Semiosis is a process intrinsic to living phenomena. This not a critique of the projects presented. They are demonstrable of BDA. Machines are not capable of semiosis. Hence, the comment is rather a reflection on computational design methodologies inspired by natural phenomena and biological processes and the distinction between these (natural processes) and computation (artificial processes). It demonstrates that there is a need to critically reflect on the programs we (as CAAD practitioners) create, how and why we do and how we present them. Philosophy has a key role to play in this, as does theory to underpin the philosophical outlook - which in this case is that *life = semiosis*. Consequently, living systems are a product of semiosis (Hoffmeyer 2008). Hence if we are to model architecture, or rather the generation of shape and form to establish (architectural) spatial configurations based on natural processes then our models should be, or be built on, semiotic logic. A semiotic that follows from Peirce (see Coyne 2019), not the Structuralist position of Saussure – and which drove the furore of semiotic enquiry that infused architectural discourse and climaxed with Deconstruction. Especially, if our models are descriptors of behaviour, or seek to generate outcomes based on behaviours: typically founded in observation of natural systems. As Geoffery Broadbent claims: architects, whether they like it or not "are playing the semiotic game. One can play as an amateur, or one can play as a professional, but - like all games - you can play better if you actually know the rules" (Broadbent 1980:27).

The essence of semiosis is the interrelation between an organism (or agent) and its environment, and how its behaviour is affected by signs. Or, to use Dretske's analogy, how signs (in effect) get their hands on the steering wheel and guide the agent (Dretske 1988). Semiosis is a process of interconnection between perception and action. Abduction is key to this, which Coyne (2019) points out, provides a bridge between design logic and computational design.

Paul Bourgine and Francis Varela (1992) emphasised the significance of abduction to ALife, stating "one central topic in artificial life is how to define and implement, as part of the systems closure, effective abduction processes". Bourgine and Varela highlight, by stating the focus ought to be to make ALife abductive, that computers are themselves not. They are symbol processing machines, and so vaguely semiotic, but they are not capable of *genuine* semiosis. They are structurally and semiotically closed. Based on formal logic they are discrete machines that "reduce continuity to the binary logic of 0's and 1's creating a problematic conceptual and, at times, practical gap between the natural and the artificial" (Bottazzi 2018:3). Making computers, or making agents, capable of inference remains the objective for state-of-the-art computation today. It is perhaps why some are promoting a shift in technology to our analogue roots (see for example Kornblum and Pangaro 2019) and some architectural researchers are today exploring computational design processes through biology and unconventional computing practices. In *Out of Control*, Kevin Kelly argues a range of human activities (including design and manufacturing) are increasingly defined by "ways of biology", or what he calls "bio-logic".

CONCLUSION

The BDA program outlined introduces students to bio-inspired generative design and presents them a theoretical frame through which to deliberate the design and application of algorithmic processes in architectural design. They are taught to code and generally operate within the Grasshopper environment. Students are encouraged to approach design through what Kelly calls "bio-logic" and to recognise computation as a means, not to generate wiggly forms to produce superficial outcomes that impersonate natural phenomena, but to tap into the creative capacity of natural systems. They are hence provoked to invest in understanding processes underpinning natural morphologies and system behaviours. The aim being to emphasise the proclivities and creative tendencies of natural systems, which are what they are not because of any aesthetic agenda but because all living systems strive to satisfy and sustain their physiological and social needs, and because architecture ought to provide for and enhance the same qualities. We stress "social" because all living things are assemblages of many cooperating and associating individuals, such as the reader being a construction effected through masses of interacting assemblies of cells.

The semiotic agenda is a challenge. Not specifically to the students, but to the tutors who are engaged in computational design research and the wider community. Whilst the students are limited in their capacity (effectively because computers are not abductive and incapable of semiosis) they are aware of the distinctions raised and that whilst computational design strives to generate space and form derived on natural process there are limitations on the capacity to do so – at least on the premise that what underpins the intrinsic creativity capacity of natural systems does not transfer to artificial systems. At least not through the algorithmic process presently available. The challenge laid down by Bourgine and Varela remains and if architectural computational design is to reach beyond the confines of form making and fabricating architectural scenarios on the premise of simulating natural systems, as it presently does, effort ought to be invested in establishing a method of introducing semiosis into the process.

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