Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Personal information	
Name	Thierry Syriani
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Studio		
Name / Theme	Architectural Engineering - Robotic Building	
Main mentor	Henriette Bier	Architecture
Second mentor	Ferry Adema	Building Technology
Argumentation of choice of the studio	Because of my interest in looking at an application of swarm robotics and using generative design algorithms in architectural design process, I believe my graduation topic aligns with the approach of the Robotic Building Studio within Architectural Engineering which aims to explore the new relationships between robotics and architecture, particularly in processes of production, and building operation. As such graduating in the RB in AE studio offers the opportunity to work closely with teachers and professionals who have experience and knowledge in the fields of robotics, computational design, algorithmic design, in an environment driven by exploring this relatively new field of architectural research.	

Graduation project	
Title of the graduation project	**Towards a robotic architectural species**

Goal	
Location:	Expo 2025, Yumeshima, Osaka, Kansai, Japan
The posed problem,	Inspired by Henri Lefebvre's notion of participation in architecture and by Avant Guard research groups and architects and from the 60s and 70s, such as Archigram or Cedric Price, who pushed the limits of the integration of technologies in architectural design, I am interested in exploring the 'soft' qualities of architecture together with the integration of robotic systems to create an environment that is highly responsive, adaptable, interactive, and resilient. This architecture is directly informed by the users' activities, environmental conditions, and other information flows. It relies on principles of emergence, indeterminacy and generative design. In this quest to breathe new life into public spaces and engage with its today's increasingly (inter-)connected users, robotic architectural components seem to open up possibilities to give agency to building component. A new field of research has been looking at using generative design methodologies with multi-agent robotic systems in architectural design process. Key figures include Gramazio & Kohler and Raffaello d'Andrea at the ETH in Zurich, Theodore Spyropoulos from the AA Design and Research Lab in London, or Roland Snooks with the Kokkugia research collaborative. Their works are connected in that they require a new understand the built environment as an "adaptive ecology" composed of autonomous agents that interact with their immediate users and context. This architecture has no blueprint but is self-organising; it is processual, indeterminate and continuously in *formation*, as opposed to the dominance of static, predetermined forms and functions in the organisation of the environment today. Following this body of research, I would like to propose the examination of a multi-agent system composed of unmanned aerial vehicles (UAVs, or drones) that can collaborate together to self-assemble into structures, and to express this desire for interactivity and agency. These structures are composed of a many of these 'drone-bricks' that form shelters that can grow and morph to accommodate users' changing positions and movements through time. They should also be able to modulate environmental conditions such as wind and rain shelters, daylight penetration and the acoustic resonance of the space.
research questions and	How to translate these architectural intents (performative and qualitative metrics) to a swarm of UAVs in an attempt to create a robotic architectural 'species' where autonomous agents collaborate to form temporary shelters that respond to local environmental conditions and human interactions?

design assignment in which these result.	This will be developed by looking at a behavioural and praxiological approach to architectural design that establishes a feedback loop between the algorithmically-encoded robotic capacities (behaviours), the material properties (morphogenetic processes) and sensing capabilities (neurological processes) of the agents and the emergent interactions and their self-organization in the environment in real-time. This research therefore attempts to look at the ways these behaviours are digitally coded and physically expressed, as well as evaluate the overall agency granted to the system through the implementation of these behaviours with the overarching aim of developing new relationships between space and users through multi-agent robotic systems.

Process

Method description

In order to experiment with the integration of multi-agent robotic systems and evolutionary algorithms in architecture, a design-as-research methodology is applied here. Specifically, it consists of successively adding simple behaviours to the autonomous agents and evaluates their implementation. The behaviours translate the data that is autonomously gathered by the agents and the actions they can then take on these inputs. Once these behaviours have been designed and simulated, a process of design-to-robotic-operation will establish a second feedback loop between the system's physical material properties and embedded sensing capabilities as inputs to drive the coded evolutionary-algorithmic behaviours. In each stage, a variety of methods will be used to explore, document and visualize these behaviours in order to extract their emerging patterns when applied in a multi-agent system.

1) <u>Behaviours</u>

A behaviour corresponds to a simple architectural intent or decision process. These are then distributed through the population of autonomous agents. The aim is to observe how these different behaviours, or decision-making processes, interact to form emerging complex and self-organised design intentions revealing a collective intelligence at a larger scale.

This methodology looks not only at human behaviours in their environments (here considered as human-machine interactions), but also develops machine-machine interactions to allow the UAVs to operate autonomously and collaboratively to form these structures. Such an approach is relevant here as the robotic ecology need to be responsive to the users' movement, position, and more in order to adapt the spatial performance and qualities of the emerging space accordingly.

In the context of this research, the behaviours can be of three natures. The first have an architectural intent looking at more quantitative metrics and studies. These include the structural performance of the overall assembly and its ability to modulate environmental conditions such as act as a wind or rain, provide control over daylight penetration, or dynamically adjust the acoustic performance of the space. Secondly, aesthetic intents relating to qualitative metrics are examined. These relate to form or appearance of the overall system.Thirdly, interactive behaviours explore the human-machine interface.

A. Biomimetism

Biomimetism studies can provide for example a lot of insight on natural systems that exhibit swarm intelligence to intelligently translate these mechanisms into the design intent of the implemented behaviours, but also into the physical sensing apparatus of the robotic prototype. Some examples include looking at ants and termites from inspiration about stigmergic communication strategies (communication with nearby neighbours, in this case using pheromone trails). Or looking at flocks of birds or fish schools for indications on how they coordinate their flight or motions with such a responsive agility and synchrony. These are also sources of inspiration for the emerging aesthetic qualities of how these motions are perceived as a whole.

B. Diagramming

Diagramming as an analytical and visualization tool allows to represent the evolution of flows, processes and sequences through time. In this case, because of the considerations of evolutionary algorithms, as well as notions emergence and time-based processual architecture, the diagram can reveal the evolution of these processes whether they are morphogenetic, neurological or interactive, by decomposing the process into a series of snapshots.

These diagrams can take the form of flow-charts showing the different outputs based on certain inputs, or a series of images showing the materialization of a process through time. They allow to better evaluate the behaviours by representing their evolutions in a systematic way.

C. Coding And Computer Simulations

The behaviours are then encoded and simulated to visualize how they combine and drive the system. This is done using Processing, a scripting software, which allows both to code and visualize its output. The coding of these behaviours is then evaluated using appropriate computational tools. For example, the Kangaroo, LadyBug and Karamba3D plugins for Grasshopper are used to simulate physics and the effects of forces on the structure, evaluate the performance of rain, wind and sun regulation, or evaluate the structural performance of the structure respectively.

D. Evaluation Of Behaviour

In order to assess the output of the generative architectural algorithm that is given out to the robots to enact, it is important to include a feedback loop into the system. This additional loop allows for the subjective evaluation of the performance of the algorithm, and allows for improvement. This ‘strange feedback’ therefore makes explicit the recursive and iterative relationship between the top-down behaviour coding and the emergent collective behaviour, where one becomes the input for the other and vice-versa.

The qualitative aspects are evaluated, for example, on the lifelikeness of the overall behaviour or the aesthetic qualities of the emergent assembly. The quantitative aspects on the other hand refer to performative objectives such as responding to people’s position and movements in space or the capacity of the structure to meet the environmental modulation criteria (rain/wind protection, daylight generation, acoustic performance, and more).

2) Design-To-Robotic-Operation (D2RO) And Prototyping

Similarly to how the behavioural approach requires the later evaluation of the behaviours to be assessed qualitatively and quantitatively, it is also important to consider its relationship to the morphology and sensing apparatus of the individual robot, and such material concerns relating to robotic operation need to be integrated from the very beginning of the design process.

Using a D2RO methodology in architectural research seeks to establish, from the beginning of the design process, a feedback loop based both on the performance of the algorithm but also to its translation into physical components which in turn affects the human-nonhuman relationship between the robotic creature and the humans interacting with it.

The D2RO strategy relies on establishing a feedback loop between the robot's morphogenetic attributes, its materiality and its sensing apparatus (sensor-actuator components) as well as the the expression of these behaviours. In order to evaluate the performance of the robotic operation of the system, various analytical tools and techniques will be used. For example, physical modelling will enable the exploration of material properties for a single or a small group of robot, while computer simulations in Processing (scripting software) can be used to anticipate how these material properties will behave when scaled up to the level of the swarm. On the other hand, the development of sensor-actuator prototypes will be developed to examine the robotic mechanisms employed to modulate the environmental conditions and connect to other robots in flight in order to form larger structures.

Literature and general practical preference

LITERATURE

Avermeate, Tom. "The Architect and the Public: Empowering People in Post war Architecture Culture." *Hunch. The Berlage Report on Architecture, Urbanism and Landscape* (2010): 83-95.

Bier, H. H., Turkuaz Nacafi, and Erik Zanetti. "Developing Responsive Environments based on Design-to-Robotic-Production and-Operation Principles." In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, vol. 36, pp. 870-875. IAARC Publications, 2019.

Bier, H. H., Alexander Liu Cheng, Sina Mostafavi, Ana Anton, and Serban Bodea. *Robotic Building as Integration of Design-to-Robotic-Production and -Operation*. 2018

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Callaghan, V. "An application of swarm robotics in architectural design." In Intelligent Environments 2009: Proceedings of the 5th International Conference on Intelligent Environments, Barcelona 2009, vol. 2, p. 362. IOS Press, 2009.

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Snooks, Roland. "Behavioral formation: multi-agent algorithmic design strategies." (2014).

Spyropoulos, Theodore. "Behavioural Complexity: Constructing Frameworks for Human-Machine Ecologies." *Architectural Design* 86, no. 2 (2016): 36-43.

Spyropoulos, Theodore. "Constructing Participatory Environments: a Behavioural Model for Design." PhD diss., UCL (University College London), 2017.

Spyropoulos, Theodore, Brett D. Steele, John Henry Holland, Ryan Dillon, Mollie Claypool, John Frazer, Patrik Schumacher, Makoto Sei Watanabe, David Ruy, and Mark Burry. *Adaptive ecologies: correlated systems of living*. Architectural Association, 2013.

Willmann, Jan, Federico Augugliaro, Thomas Cadalbert, Raffaello D'Andrea, Fabio Gramazio, and Matthias Kohler. "Aerial robotic construction towards a new field of architectural research." *International journal of architectural computing* 10, no. 3 (2012): 439-459.

PRECEDENTS

Composite Swarm, Roland Snooks with Kokkugia, Melbourne, Australia, 2013

Convention and Exhibition Hall Chicago, Illinois Research Project (Yale University) 1960eMotion Spheres, Festo, Germany, 2014

Cyber Physical Macro Materials project, Institute of Computational Design, University of Stuttgart, Germany, 2018

Flight Assembled Architecture, Gramazio+Kohler, ETH Zurich, Switzerland, 2011

Hypercell, AA Design and Research Lab, London, 2015

Luminous Orbs, TeamLab, Tokyo, 2014

New Korea Garden, SKNYPL, Seoul, 2019

Omnipresence, TUDelft, Netherlands, 2016

Pet Zoo, AA Design and Research Lab

Pneumatic Masonry, PNEUHAUS, Rhode Island, Boston, USA, 2017

Soap Bubble Experiments, Feri Otto, 1965

West German Pavilion, Frei Otto, Montreal (for the World Expo), 1967

Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

The integration of new technologies and robotic system in the built environment enable it to better engage with its inhabitants given today's increasingly technologically mediated world we live in. Driven by the exploration of how buildings can become more responsive and reconfigurable using robotics is an attempt to explore solutions not only to architectural challenges and opportunities, but also to experiment with various applications of robotic systems in the built environment with regards to building operation, reconfiguration, and interactivity. By contributing to the relatively new body of architectural research, my aim is to develop a conceivable robotic "species" that is able to autonomously form temporary structures in public areas of urban space.

As such I believe this graduation project sits at the intersection of robotics and architecture which aligns with the Robotic Building studio's direction and attempt to examine an application of swarm robotics in architectural design   On the one hand it seeks to develop a design-to-robotic-operation/assembly strategy for the design of this robotic architectural species which is inline with the objectives of the Robotic Building studio; while on the other hand, it explores the development of a genetic algorithm to operate these robots for architectural purposes by looking at performance criteria (structural performance, providing wind-rain-sun shelter, artificial lighting and improve acoustic performance for example), but also by examining the qualitative, or 'soft', aspects of the algorithmic design, with the new understanding of aesthetics as being an emergent quality and with how to negotiate its becoming through coded intentions. It is also concerned with the human-robot interactions and the life-likeness of the robotic creatures in an attempt to ensure the acceptance of these creatures by the human inhabitants.

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2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

Recently, new fields of architectural research have on the one hand delved into using robots and drones to enhance the construction process and assembly precision, as well as exploring new forms of assembly that these new tools can perform; while on the other hand a new understanding of parametric design is being increasingly adopted and experimented with: one that is not only based on generating new forms, but one that is more generative, autonomous, and goes beyond top-down or bottom-up computational logic towards a real-time one.

As such the themes and topics tackled by this research are relatively new and are highly multidisciplinary between coding techniques, robotic prototyping, architectural thinking, and interaction design. However in this case, they are all applied towards an architectural application as a new 'companion architectural species' co-inhabiting the urban landscape with humans.