ON AUTONOMY, AGENCY, AND MULTI-AGENT ROBOTIC SYSTEMS FOR A PARTICIPATORY AND EVOLUTIONARY ARCHITECTURE:

Using the genetic algorithm and a behavioural approach to swarm robotics for the development of adaptive and interactive environments.

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I INTRODUCTION

A) Research-Methodological Awareness

Architecture is by nature multidisciplinary and experimental, it draws inspiration from and seeks for knowledge in a wide variety of domains and disciplines. While, as Raymond Lucas says, "no single approach can tell you everything you need to know"[1], choosing the adapted and relevant methods in trying to attempt to learn and develop new thoughts and practices help frame and tailor the research to more specific objectives and positions. Additionally, Lucas explains that "the connection between academic research and architectural practice is […] becoming more common and formalized". This increasing importance of architectural research to the practice today has "reduc[ed] the gap between research and practice."[2] Hence, this renewed closeness between research with practice in architecture only makes it even more relevant to emphasize the adopted methodology in order to produce rigorous, thoughtful and relevant architectural research.

Having a structured and relevant methodology not only frames the research itself but also situates the work within the broader field of research in architecture. This allows such a body of research to grow with pieces of knowledge being continuously added in an organized and systematic manner. It also allows for future research to pick up on previous work with a clear understanding of the position taken in earlier studies and projects as the profession constantly questions and evolves the current state of architectural knowledge and practice.

I believe this course has further deepened and broadened my understanding and value of architectural research as well as help me structure my critical apparatus and methodology in a more rigorous way. The variety of topics discussed in this course offered me some great insight into the diversity and breadth of possible points of view and positions available to the architect in his research. This has helped me both frame my research better by considering the larger body of research around my topic before and then allowing me to focus the strategy I would like to adopt and carefully choose the representational and analytical methods I would use to showcase and document the research. This has in turn led me to make more informed decisions with regards to specific methods in trying to be both selective and relevant.

B) Thesis Topic and Research Question

Inspired by Lefebvre's renewed notion of participation in architecture and by Avant Guard architects and research groups from the 60s and 70s, such as Archigram or Cedric Price, who push the limits of the integration of technologies in architectural design, I am interested in exploring the soft qualities of architecture and the integration of robotic systems to create environments that are responsive, adaptable and interactive. 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 users today, robotic architectural components seem to open up possibilities to give agency to building component. Using generative design methodologies with multi-agent robotic systems, this new field of research has been explored by a few key figures such as Gramazio & Kohler and Raffaello d'Andrea at the ETH[3] in

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[1] Lucas, Ray. *Research methods for architecture*. London: Laurence King Publishing, 2016. p.21

[2] Ibid

[3] Visit Website for more details on their research and practice: http://www.gramaziokohler.com/ and https://raffaello.name/

Zurich, Theodore Spyropoulos from the AA Design and Research Lab in London,[4] or Roland Snooks with the kokkugia research collaborative.[5] Their works are connected in that they require a new understand the built environment as an "adaptive ecology"[6] composed of autonomous agents that interact with their immediate users and context. This architecture "has no blueprint or master plan but rather is goal oriented [and] self-organized"[7]; it is processual, indeterminate and continuously in *formation*.

Following their research in 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 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 generation and acoustic resonance of the space.

I thus becomes interesting to ask: How to translate these architectural intents 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?

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. This 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.[8]

II A BEHAVIOURAL APPROACH TO ARCHITECTURE USING DESIGN-TO-ROBOTIC-OPERATION PRINCIPLES

When dealing with the notion of emergence, swarm algorithms and robotic agency in architecture, it is important to understand how this changes the design process but also the role of the architect. As put by Roland Snooks: "This represents a shift from the explicit design of form and organisation to the orchestration of intensive processes of formation through the design of the underlying behaviors of matter and geometry."[9] As described by Deleuze, this moves away from representational tools and towards more performative and processual ones. Architectural form becomes an architectural process of formation. Therefore, the architect's role moves towards the process of taking a design intent and "recast[ing] [it] as a set of procedures or behaviors that interact

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[4] Visit Website for more details on their research and practice: http://drl.aaschool.ac.uk/

[5] v Visit Website for more details on their research and practice: https://www.kokkugia.com/

[6] 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.

[7] Spyropoulos, Theodore. "Constructing Participatory Environments: a Behavioural Model for Design." PhD diss., UCL (University College London), 2017. p.231

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[9] Snooks, Roland. "Behavioral formation: multi-agent algorithmic design strategies." (2014). p.31

within non-linear processes, leading to a self-organisation of design intent."[10] In the case of my research topic, I am focusing on exploring this methodology by using UAV swarms to self-assemble temporary shelters in public spaces in urban areas.

The research presented here is a methodologically-led one that is based in using design-as-research as an experimental method to integrate multi-agent robotic systems and evolutionary algorithms in architecture. The methodology 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.

A) Behaviours

Rooted in generative design methodology, this behavioural approach to encoding architectural intents relies on swarm intelligence principles and comes alive through evolutionary multi-agent algorithms.

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 "the interaction of these local decisions" and how they lead to the emergence of "complex self-organised design intention, giving rise to a form of collective intelligence and emergent behavior at a global scale." [11]

This methodology therefore brings together a praxeological reading of architecture that 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 in the self-assembly of these structures. Such an approach is relevant here as the robotic ecology need to react to the users' movement, position, and other sources of interactive input in order to reconfigure and adapt the spatial performance and qualities of the emerging space.

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 and are more rooted within praxeology, and human-robot interaction (HRI) paradigms.

In the design, implementation and evaluation of these behaviours, a few heuristic techniques are used. These include biomimetic studies to observe and extract behaviours found in natural systems that are directly related to the objectives of the individual behaviours. Diagramming also allows for the visualization and documentation of the evolution of these behaviours through time and for the extraction of patterns that emerge from the combination of multiple behaviours. Finally computer simulations are used to adequately evaluate the performative criteria of these behaviours such as the structural stability of the assembly.

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[10] Ibid

[11] Ibid

1. 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). These insects use a. When looking at coordinated movement in a swarm, bird flocks and fish schools showcase this coordinated movement in a swarm. Through this biomimetic lens, Craig Reynolds was able to define and encode the three behaviours (cohesion, alignment and separation) that attempt to reproduce the movement of bird flocks.

2. Diagramming

Diagramming as a heuristic method allows to visualize flows, processes and sequences. 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 wether they are morphogenetic, neurological or interactive.

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 abstract the behaviours into more systematic forms of representation focused on expressing the system's capacity and space of possibilities rather than a more direct way of representation which would give a top-down prescriptive view on the system rather than embracing its indeterminate and open-ended nature.

3. 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 and relevant computational heuristic methods and case studies for each of them. The Kangaroo plugin for Grasshopper is used for simulations requiring the application of live forces on the system. This is particularly useful when looking at the performative aspects of the design such as the capacity of the robotic system to effectively act as a rain or wind shelter. The LadyBug plugin which can interact with weather data can be used to evaluate the capacity of the system to act as an interactive shading device. Finally Karamba3D can be used to simulate the structural performance of the assemblies.

4. Evaluation Of Behaviour

Snooks, in his development of a behavioural strategy for generative design emphasizes the importance of "s*trange feedback*": it describes the "constant feedback and interaction between bottom-up algorithmic processes and top-down modelling."[12] This additional loop allows for for the architect's subjective evaluation and a further area of input for the outcome of the design intention. It "creates a synthesis or correlation of direct and generative operations."[13] This notion of '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.

While the behaviours are designed and implemented individually and on single units from an emic account, they are also evaluated when combined with other behaviours and in a multi-agent environment. In the latter, the evaluation is taken from an etic account. Indeed, one does not seek to

[12] Snooks, Roland. "Behavioral formation: multi-agent algorithmic design strategies." (2014). p.13

[13] Ibid

understand each behaviour but to balance their interactions and intensities so as to satisfy both a qualitative and quantitative criteria the swarm attempts to resolve the fitness criteria collaboratively.

The qualitative aspects are, for example, the lifelikeness of the overall behaviour or the aesthetic qualities of the emergent assembly. As emphasized by Theodore Spyropoulos, human-machine interactions look at the "emotive and behavioral co-habitation of humans and machine" where he notes the particular interest in "the life-like tendencies" of the robots which "afford a rich interplay between our relationships with things."[14]

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).

B) 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, they also have strong ties the morphology and sensing apparatus of the individual robot, and such material concerns relating to robotic operation are integrated from the very beginning of the design process. As explained by Roland Snooks, "The feasibility of behavioral processes of formation is dependent on the development and appropriation of a new set of robotic […] assembly techniques"[15]

Using a D2RO methodology in architectural research seeks to establish, from the beginning of the design process, a feedback loop "based on human-nonhuman interactions, which have properties that […] result from the relationships and dependencies they form."[16] This "hybrid componentiality"[17] implies that "building components are cyber-physical and that their design is informed by functional, structural, and environmental requirements."[18]

This part of the research seeks to translate the designed and simulated group of behaviours and implement them in a physical robotic system. D2RO therefore relies on a feedback loop between the robot's morphogenetic attributes, its materiality and its sensing apparatus (sensor-actuator networks) and the expression of these behaviours. Can the top-down modelling of the behaviours in the initial research phase be adequately materialised and expressed? This requires using various analytical tools, and heuristic techniques to formulate positions on the different components of this step. 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. For example, a prototype has already been developed so far using a Kinect camera system to track people in space and dynamically control a distributed, mechanically-operated shading system to modulate the penetration of daylight only where there is a person in the space. Future prototypes will include the study of how multiple UAVs could move in synchrony and connect to each other.

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[14] Spyropoulos, Theodore. "Constructing Participatory Environments: a Behavioural Model for Design." PhD diss., UCL (University College London), 2017. p.231

[15] Snooks, Roland. "Behavioral formation: multi-agent algorithmic design strategies." (2014). p.13

[16] 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. p.870

[17] Ibid

[18] Ibid

C) Methodology Challenges

When using design-as-research as an explorative and experimental framework for architectural research, it is important to carefully maintain a level of focus and depth in the development of this research. Some subjective choices have been made as to prioritize some of the components that could be part of the research. Indeed, Gramazio and Kohler describe that one of the challenges that arise in their 'Aerial Robotic Construction' methodology for architecture is parameter selection in such a multi-variant open-ended pool of parameters. They explain how this "experimental research […] is challenged by the determination of a particular experimental scale and the selection of specific tasks that can be transferred to full-scale construction."[19]

For example, I opted to preliminarily determine the specific architectural and interactive behaviours that I want to develop, such as structure formation and evaluation or the modulation of environmental conditions. This prior selection allows me to maintain focus during the research and explore each of these behaviours and their impact on the emerging system in greater depth. As such, great variety of heuristic and analytical tools are used to produce, represent and document meaningful aspects of the overarching research, which provides great insight and a set of diverse observations for a single phenomenon. Moreover, the same tools are used to evaluate each behaviour allowing to directly establish comparisons between them and take informed decisions going forward.

Another challenge comes from maintaining a constant and systematic set of evaluation criteria for subjective observations of the system such as the behaviours' life-like tendencies. Recent literature and experiments have greatly pushed this field of research further through phenomenological and psychological studies, but also in the expanding literature regarding morpho-functional machines. In their book *Morpho-Functional Machines*, Hara and Pfeifer develop a framework for assessing in a more rigorous way the life-like qualities of such robotic agents. In a nutshell, they propose to develop behaviours that take action at different time scales: short-term behaviours referring mostly to individual body plans and one-on-one interactions; medium-term ontogenetic behaviours that define their growth and adaptive logic of the system (memory, learning); and long-term evolutionary behaviour that govern the possible future of the entire system or its appearance.[20]

III EVOLUTION OF ALGORITHMIC AND ROBOTIC ARCHITECTURE

A) From Parametric To Generative Design Processes

The evolution of parametric design tools has allowed the exploration of new processes to develop architectural forms in an experimental fashion. However, this use of algorithms in architectural design relies on top down control over known variables to directly generate forms which are translated into architecture. Moving beyond this first application of the algorithm as a design and research tool in architecture, the use of the evolutionary algorithm embraces real-time dynamic processes and relies on the interactions between autonomous agents. As Spyropoulos explains, "interactions within adaptive machine ecologies are evolutionary and engage a world of behavioural practice that moves beyond top-down and bottom-up computational logic."[21] Such as rejection of pre-determined

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[19] 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. p. 451

[20] Hara, Fumio, and Rolf Pfeifer, eds. Morpho-functional machines: The new species: Designing embodied intelligence. Springer Science & Business Media, 2003. p.11

[21] Schumacher, Patrik. Parametricism 2.0: Rethinking Architecture's Agenda for the 21st Century. 2016. p.43

algorithms in favour of evolutionary algorithms that are intrinsically indeterminate and plural in what its outcome produces but also how it evolves.

This also has some resonance with contemporary philosophy such as Gilles Deleuze or Rosi Braidotti bringing to the front of the discussion topics such as, autonomy, agency and new materialism, as well as an updated view on the potential of robotics and technologies with relation to the human body and the built environment. Manuel DeLanda in an interpretation of Deleuze's philosophy, advocates for embracing and using the genetic algorithm in the design process as a driver "for a brand new conception of the genesis of form", where "evolutionary simulations replace design, since [architects] can […] breed new forms rather than specifically design them"[22]

Roland Snooks, through the work done with his experimental architecture research group kokkugia, focuses on exploring generative design methodologies "for the development of complex self-organising behavior of biological, social and material systems."[23] This methodology relies on behaviour design and coding as well as the use of 'strange feedback'[24] as the objective component of the research methodology that seeks to evaluate the system's response to the established fitness criteria and the life-likeness of its interactions.

B) Integration Of Robotic Systems In Architecture

Today, advances in robotics and new technologies have enabled to push this concept further and opened up a new field of architectural research focusing on using multi-agent robotic systems in architecture. Two examples are presented below showcasing the use of generative algorithms and multi-agent systems from different points of view.

On the one hand Gramazio + Kohler's project entitled "Flight Assembled Architecture" explores programming swarms of UAVs to autonomously lift and place building blocks to assemble entire buildings. Using evolutionary algorithms based on coded behaviours in the design process and implementing the D2RO principles of implementing a feedback loop between the physical machine, its control system and the established continuous information chain[25]. They call this overarching methodology "Aerial Robotic Construction" which combines 3D modelling techniques, with material/constructive systems and robotic systems' programming to allow for multi-robot collaboration in the architectural building process.[26]

On the other hand, the Design and Research Lab (DRL) has been focussing on the development of autonomous robotic swarms in the form of cube-like shapes that are move through mechanical apparatus or through using soft inflatable materials as a morphological feature. Their research focuses in the fields of soft architecture and soft robotics in an attempt to explore machine lifelikeness, to develop morphologies for movement or geometries for different stacking/connection/assembly modes. Using a behavioural methodology that blends human-machine and machine-machine interaction, they have also developed tools and methodologies for the evaluation of the life-likeness of the encoded behaviours in projects such at the Pet Zoo where a series of robotic 'creatures' were given a series of emotional states and some corresponding morphological features that allowed these snake-like creatures to move and curl autonomously based on their perception of the human's motion around them. Spyropoulos insists that the success of such a research can only

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[22] DeLanda, Manuel. "Deleuze and the Use of the Genetic Algorithm in Architecture." *Architectural Design* 71, no. 7 (2002): 9-12. p.9

[23] Snooks, Roland. "Behavioral formation: multi-agent algorithmic design strategies." (2014). p.13

[24] Ibid

[25] 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. p.439

[26] Ibid

come from the feedback established between the physical and cybernetic systems in attempting to create a powerful and meaningful connection between the user and the robot. [27]

IV POSITIONING

A) Generative Notion Of Type And "Evolving Taxonomies"

The research into the integration of swarm robotics and the genetic algorithm into the architectural design process relates to the notion of taxonomy and topology in architecture. As mentioned in the course with the arguments for a generative notion of type and its evolution from being representational to performative in recent discourse from philosophers such as Deleuze. This new typology relies on notions of emergence governed by the capacity of a 'morphogenetic field' of action where.

Here this robotic architectural species is part of a new "evolving taxonomy"[28] of architectural typologies where "behavioural complexity offers new terms of reference for architecture", as described by Theodore Spyroopulos, which "will engage us, challenge us and enable a new species and taxonomies of proto human-machine ecologies."[29]

B) Notion Of Time And Praxeology In Architecture

This behavioural and time-based approach to architectural research and design depart from the top-down, prescriptive approach to architecture in favour of a series of bottom-up, distributed and non-linear processes interacting with human actors in public spaces. These new emergent typologies have therefore led to new as well as the development of new architectural methodologies and analytical tools to explore how they can be manifested in the practice.

For example, Foucault's notion of *Heterotypologies* repositions the understanding of space as chasing meaning and structure over time, as discussed in the course. Similarly Spyrolpolos, when discussing this new taxonomy which he calls "adaptive ecologies", refers to Cedric Price's explanation of such a praxeological and time-based architecture, arguing that the formation of a site is determined by "the varied and ever-changing activities" happening on the site. The architecture framing these activities, is referred to as an "antibuilding", which "must have equal flexibility" [30].

For Deleuze, the diagram makes a process visible. When considering the temporal dimension added to the architectural design process requires adapting the diagrams to represent this dimension. Here for example, this would be showing the evolution of these behaviours and the different outcomes based on the various possible inputs. Similarly, film and other time-based observation methods are employed here in an attempt to document and evaluate the algorithm and its emerging result. These analytical tools allow to understand the capacity of the system which is being assigned as coded and evolutionary architectural intents or behaviours. When the behaviours are combined, they allow fo the observation of the emerging patterns and lifelikeness of the system as a whole in an attempt to create a strong bond with the human users.

Because of its interactive nature, this type of architecture can benefit from a praxiological approach to architecture. As discussed in the course, the notion of Participation in architecture was developed in contemporary writing by Henri Lefebvre where he elaborates on a new understanding of

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[27] Spyropoulos, Theodore. "Constructing Participatory Environments: a Behavioural Model for Design." PhD diss., UCL (University College London), 2017. p.231

[28] Schumacher, Patrik. Parametricism 2.0: Rethinking Architecture's Agenda for the 21st Century. 2016. p.43

[29] Ibid

[30] Spyropoulos, Theodore. "Constructing Participatory Environments: a Behavioural Model for Design." PhD diss., UCL (University College London), 2017. p.231

'right to the city' and the 'appropriation of space'. He proposes to look at architecture through the lens of spatial and time based activities, emphasizing on the importance of the users' purposeful behaviours enacted in the environment that could be used as an input for the architectural deign process. This position is also supported by Avermaete and Foucault in a discussion on establishing new, meaningful relationships users and space that showcase the connectedness to daily life. Avermeate claims that "architecture ha[s] to be reformed and take an explicit societal function", arguing that "the common man should have an engaged role in the design and building process".[31]

In the context of this research, this praxeoglogical approach to architectural design is explored and enabled by the use of technology and swarm robotics and translated into interactive and responsive environments. This is also inline with the Robotic Building studio's position which seeks to explore the integration of robotics and interactive systems used to creative dynamic, adaptable and interactive architectural environments. In such environments the temporal and behavioural processes becomes part of the design process since it is based on establishing meaningful relationships between human and their environment.

C) Conclusion

I hope to contribute to this relatively new body of research relating to robotics and architecture by applying a behavioural methodology to develop an architectural design system in an attempt to develop a framework for the creation of robotically-enabled responsive and interactive architectural spaces. As such, this research seeks to further to explore the behavior-ialisation of architectural design process relying on the collaboration of a swarm of architectural robotic components, in this case UAV swarms, to create a new understanding of architectural rooted in praxeology and integrating the notion of time in the design process. Furthermore the translation of these behaviours into a physical prototype further reduces the gap between the research and the design by incorporating another feedback loop between the material robotic system and the coded behaviours. Together these two approaches will allow for a cohesive and rigorous exploration of this new architectural taxonomy through these interactive, temporal and behavioural lenses.

By applying this methodology systematically with different intents such as architectural performance, architectural aesthetic and human-machine interactions, the aim is to showcase a mastering of the chosen information flows both in their top-down algorithmic programming, but also in their evaluation when materialized with the D2RO approach. Here these information and material flows include architectural performance metrics (i.e. structure, environmental modulation), developing aesthetics intents (i.e. collective movement of the robotic swarm or their connection and assembly mechanisms), and understanding human interactions (i.e. people and motion tracking in space).

[31] Avermeate, Tom. "The Architect and the Public: Empowering People in Post war Architecture Culture." *Hunch. The Berlage Report on Architecture, Urbanism and Landscape* (2010). p.59

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