The Development of 'Agent-Based Parametric Semiology' as Design Research Program

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Abstract. A new framework, agenda and practice is called for to address the challenges and opportunities architecture must confront in the age of our computationally empowered Post-Fordist network society. This paper introduces the research agenda of 'agent-based parametric semiology', and explains the necessity of introducing a new tool, agent-based life-process modelling, as part of the design process, in order to cope with the new complexity and dynamism of architecture's social functionality. The paper reviews the development of this design research program over the last 10 years. Finally, the paper describes current efforts to move from the illustrative use of life-process modelling to a scientifically grounded quantitative analysis and generative design optimization.

Keywords: Crowd simulation · Life-process agent modelling · Semiological project · Agent-based parametric semiology

1 Theory Background

As the founder of Parametricism, Patrik Schumacher put forwarded "Parametricism as Style – Parametricist Manifesto" at the 2008 Venice Architecture Biennale [3]. He argues that Parametricism is an epochal style after Modernism, and it is the response of architecture to the technological and socioeconomic transformation brought by the information age [4]. In 2012, Schumacher published his theoretical treatise "The Autopoiesis of Architecture 2 - A New Agenda for Architecture" and further put forwarded a new conceptual framework for contemporary architecture to address the challenges and opportunities facing architectural design in the context of the current social and technological environment [1, 2].

Schumacher emphasizes the need to distinguish architecture from art and engineering. He raised that the social function of architecture—engineering is mainly related to technical functions, and architecture is mainly related to social functions [5]. This means that architects consider the social interaction of users as socialized actors, while engineers consider the physical safety and comfort of users understood only as biological objects [9]. The unique societal role for the architecture is no longer just to provide a tangible shelter, but a communicated frame for social life.

Just like the achievements of Modernism reached in the 20th century, Schumacher hopes that in the 21st century, Parametricism can achieve an equivalent success in terms of

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becoming the defining epochal style for the 21st century. As mentioned above, architecture has its unique social functions, every social system needs a clear spatial relationship to make the social communication stable and orderly [7, 8]. In the knowledge economy of the post-industrial age, fundamental changes have taken place in both social relations and communication methods—from hierarchical to network-based, how should architecture respond?

Parametricism was relaunched as Parametricism 2.0 in 2016. Schumacher insists that the real concern of Parametricism shifts to social functionality and how to innovate society [11]. He argues that all design is communication design [6], and each space can be regarded as a kind of communication, which gives potential social participants a message about what interaction types may occur and broadcasts an invitation to the public to participate. As Schumacher said "The elaboration of spatial complexes in accordance with a designed semiological code is thus a key to upgrading architecture's core competency. The semiological project implies that the design project systematizes all form-function correlations into a coherent system of signification, designed as a network of similitudes and contrasts, organized via a spatio-visual grammar. Each territory is a communication." [6]. Social order depends on spatial order: by reading the spatial semantic system, people can share and establish the appropriate, intended interaction situations [10]. The task of architecture can be divided into organization and articulation. In turn, articulation is differentiated into the sub-tasks of phenomenological articulation and semiological articulation. The "meaning" of the architectural space lies in the (subtle) events or social interaction types that may occur within the space.

New tools will rebuild architectural semiology into parametric semiology [12]. Like traffic lights, the various traffic lines on the road are set by artificial rules, and everyone has been accustomed to obey and follow it. This could be seen as the most straightforward symbol.

2 Why We Need Agent-Based Life-Process Crowd Simulation

Parametricism is rooted in digital technology and is based on advanced parametric design systems and scripting methods. In terms of parametric semiology, a key advance is the development of an agent-based life-process modelling tool that simulates social interaction processes that can achieve a well-adapted architectural design [15]. This would be an architectural optimization tool, in the hands of architects, analogous to the engineer's structural optimization software.

The crowd simulation usually can be classified into Macroscopic simulation (continuum-based model) and Microscopic simulation (agent-based model). Macroscopic crowd simulation is generally aimed at a wider range of crowd movement scenarios, which having people move like particles in a fluid and describe the crowd density and velocity by using different equations. This type of simulation of crowd behaviors has been widely used in traffic engineering. Microscopic simulation is focused on the study of individual behavior in the crowd, the interaction of the virtual human and the virtual environment. The crowd continuously senses the surrounding environment information and adjusts their reactions accordingly. In this paper, the author refers to the second type: agent-based crowd simulation.

There are various agent-based crowd modelling tools. However, concerning assisting the architectural design process, there are at present no tools that recognize the specific task of architecture as defined by Schumacher.

As Patrik Schumacher raised in 2016: "…models reproduce and predict collective patterns of movement, occupation, and interaction as emerging from individual, rule-based actions… It is of great importance that architectural semiology can hook its project onto a new design simulation tool that is bound to become a pervasive medium to test and anticipate architecture's social functionality" [12].

There are three levels that the agent-based life-process simulation needs to achieve in the architectural design process, the basic level is representation. During the period of CAD and 2D drawings, the overall image of the building only exists in the designers' imagination, later with the help of 3D renderings, designers can get a better understanding of their design before it is being built. Similarly, how the space will be used in the future exists only in designers' imagination, or not. In contrast to the current empty or "blank" design models, the life-process crowd simulation tool can be very helpful for the designers' understanding of the social usability of the different spaces. This leads to the second level: evaluation. Similar to structural simulation models, through a generate-and-test process, designers can use the life-process simulation tool to optimize the design space in terms of both organization and articulation, and test different design assumptions. Ultimately, this could be developed into an evolutionary loop, and thus would become a new generative design tool. Following these three stages, the social meaning of architecture can be really brought into and explored within the design model [13, 14]. In this way, architectural semiology can be finally implemented within a truly predictive design project.

The use of agent-based life-process simulation is very powerful in terms of bringing the semantic layer of the designed spaces into the design model. It is become possible to test the dynamic patterns of social interaction through computational agent-based crowd simulation techniques, and to use this as constructive and generative design feedback As Patrik Schumacher summarized, the three key innovations for the agent-based life-process crowd simulation are [12]:

1. *the generalisation of crowd modelling from circulation flow simulations to a generalized life process modelling.*
2. *the shift from physically conceived agents and crowds to communicatively conceived agents and crowds with the crucial augmentation of sign-or frame-dependent behaviours.*
3. *the differentiation of agents according to different social roles and social valences.*

Based on this, Schumacher has proposed an original innovative methodology for architectural design processes "using evolutionary algorithms that use agent-based life-process simulations with social interaction frequencies as success measures to optimize social functionality" [15]. This research agenda 'Agent-based Parametric Semiology' (ABPS) is currently shared and developed by three main research groups under Patrik Schumacher's leadership: a small team of Ph.D. candidates at the University of Applied Arts: Robert Neumayr (team leader), Daniel Bolojan, Josip Bajcer, Bogdan Zaha, and Michael Fuchs, a research team at Zaha Hadid Architects: Tyson Hosmer (team leader,

leading the development of the ABPS Research Group and software development), Soungmin Yu, Sobitha Ravichandran, and Ziming He, as well as multiple student teams from AA DRL.

3 The Intelligence Upgrading of Agent-Based Crowd Simulation

To develop a reliable agent model beyond mere flow modelling in engineering is the key for the operationalization of the semiology project. The first step is to make the virtual humans more realistic; besides the graphical and animation level, this implies work on the level of intelligent behaviour. The goal is to let the agents interact with their environment as much as possible like real humans, creating heterogeneous crowds that behave in a life-like manner and inhabit differently designated spaces differently [16, 17].

3.1 Crowd Behaviour Pattern Analysis

One of the most popular and simplest ways to simulate a crowd is with Reynolds flocking algorithm. In 1987, Reynolds [2] proposed Boid, a simulation of the flocking behaviour of birds, which was one of the original simulations of collective behaviour. The model is based on three simple rules: Separation, i.e. avoid getting too close to other particles; alignment, i.e. turn towards the average direction of a local cluster; and cohesion, i.e. steer towards the centre of the flock. This modelling approach is being used in the film industry to simulate animal flocks. With respect to the complexities of the human crowd behaviours, this simple modelling approach is rather too crude and superseded by other approaches. Based on the algorithm of Boids, Processing has many external libraries of mature flocking intelligent algorithms, such as iGeo. Plethora etc. The agent-based crowd simulation modelling using processing is mainly developed based on this group of algorithms.

By using processing to do the agent-based crowd simulation, the social activities here can be expressed as different types of attraction points, such as music performances, sculptures, etc. The attraction points can be imported into the model and recognized by agents. The imprint of human behavior in the activity will be seen as the "output" of the model and can be translated by scripts into useful data such as duration, density, etc. Take the student project IArch: Design Me (project team: Xuexin Duan, Vahid Eshraghi, Jie Shen, Wei You) from AA DRL Studio Patrik Schumacher & Pierandrea Angius in 2011–2013 as an example, they classified the public activities into three main types: single - attraction event, multiple - attractions event, and no-attraction event. No - attraction event is always happening on the square which has a large area but no specific event on it, so people will wonder or just pass through it. Single - attraction event is like concert or solo performance in public. multiple - attractions event is like visiting a gallery (Fig. 1).

The agent-based crowd simulation in Processing basically abstracts a person as a point, this point will have basic information such as position, speed, direction, etc. It is more suitable for a fast analysis of crowd behavior patterns or visualization of crowd trajectory in space.

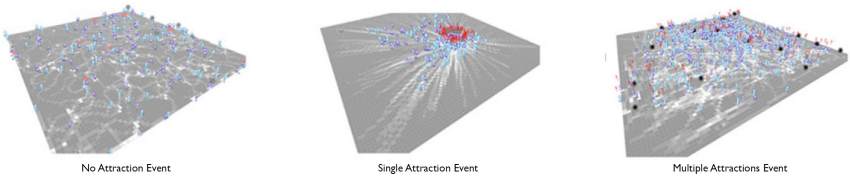

Fig. 1. IArch: Design Me project's analysis of human behavior. Besides the physical properties, agents also have social properties, such as patience, interests, etc. and based on the different types of events, the crowd will have different behaviors response, and the different values and properties will be generated as a behaviors pattern map. (credit: Xuexin Duan, Vahid Eshraghi, Jie Shen, Wei You from AA DRL Studio Patrik Schumacher & Pierandrea Angius in 2011–2013.)

3.2 Intelligent Agents

Crowd simulation in Processing has a big limitation in simulating complex behaviors, and how to visualize the human behaviors, as well as analyze different interaction between human and architectural space. Because we need to "see" the agents' actions and behaviors in the space, not as a 2D pattern representing different data, also not as characters in crowds for navigation and steering, which tend to be rather lifeless, the life-process crowd modelling should appear more social presence. Since 2011, under the parametric semiology topic, in AADRL Patrik Schumacher's studio, the research already has started on trying to make the interaction rules dependent not on physical constrains but on visually expressed information about the spaces' designation on defining the expected social situations. At an early stage, the attempt on building the link between virtual human and virtual environment is by using Miarmy or Softimage. In the IArch: Design Me project, the team introduced a furniture system as a kind of environment clue to trigger people's different behaviors in order to mutate different events. It starts from very simple interaction rules: by changing the furniture's basic parameter, such as height, to change the meaning of the furniture which can change people's different behaviours, then to achieve ordering people. The agent behavior is based on these simple rules (Fig. 2).

In the IArch: Design Me project, the scenario is fashion week which contains three sub-scenarios: opening, catwalk, and after-party. During the openings, the two curved partitions as the trigger elements give a sign to the two types of agents and guide them to enter from different entrances. When the opening ended, some agents choose to leave, some agents stay and start to chat, when the two curved partitions start to move and together with the changing on the lighting condition, agents "know" the space is mutating to another sub-scenarios: catwalk will start soon. And when the show is over, people start to leave, and the furniture is changing to a more fragmented configuration, also the changing on lighting condition helps to differentiate territories. All these give a "hint" to the agent that the after party will begin soon. As the function of spaces is conceived as dynamic patterns of social communications, by mutating the 3 sub-scenarios, we can change the communication mode. Although people are in the same physical space, because the social meaning the designer gives to the space is different, we can see how people respond to the space in different ways (Fig. 3).

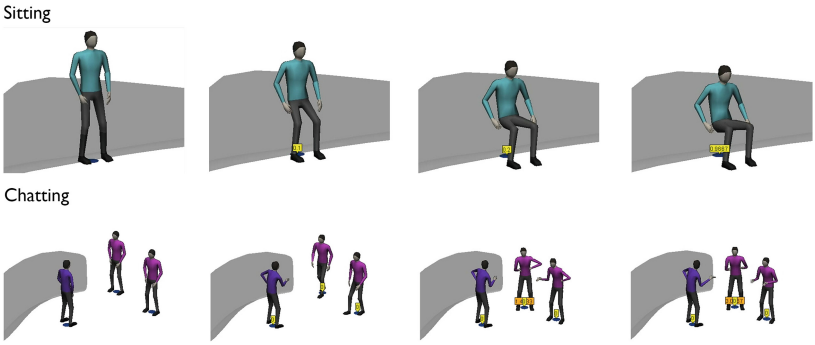

Fig. 2. The interaction rules based on the height of furniture: people will sit or start to chat beside a counter, also the agent has internal properties, like patience value, which will determine how long the agent will stay in one place or having a conversation with other agents. (credit: Xuexin Duan, Vahid Eshraghi, Jie Shen, Wei You from AA DRL Studio Patrik Schumacher & Pierandrea Angius in 2011–2013.)

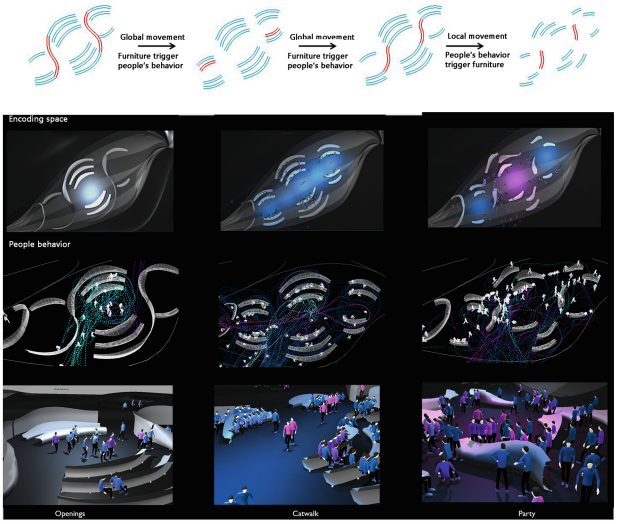

Fig. 3. IArch: Design Me furniture system: by having minimum physical changes, this furniture system can mutate the three sub scenarios. (credit: Xuexin Duan, Vahid Eshraghi, Jie Shen, Wei You from AA DRL Studio Patrik Schumacher & Pierandrea Angius in 2011–2013.)

3.3 Semantic Virtual Environment

In order to make the virtual humans have meaningful interactions in the virtual environment, the designer needs to create a semantically rich environment, as well as building up all the relevant links between agents and the environment. Recently Schumacher's AADRL studio is achieving a more complete Spatio-visual Semiological System. All semiological design must be carried out by establishing two interrelated and differentiated systems: the system of signifiers or symbols and the system of the signified or

meanings [13]. For example, in one of the student projects from Schumacher's studio (Yihui Wu, Lei Wang, and Yanling Xu 2016–2018), the team set up a Manual including an explicit vocabulary and grammar for the space. Start with simple rules, like concave configuration links to individual work, convex configuration links to group work like meeting, and by introducing other distinctions, the grammar's combinatoric power can produce many different meaningful expressions. Another aspect of the parametric semiological design method is to consider that a distinction might not be introduced as a strict dichotomy, but as a gradual gradient spectrum generated by defining the two poles. However, this method is only meaningful when we can define meaningfully corresponding gradients in the field of social meaning (Figs. 4, 5 and 6).

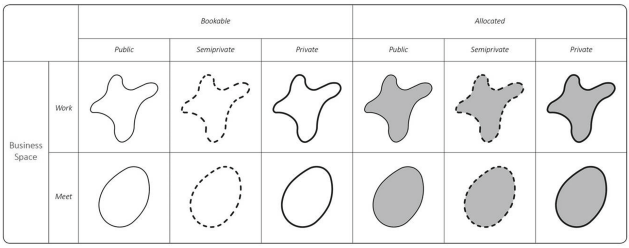

Fig. 4. Dictionary of spatio-visual vocabulary. (credit: Yihui Wu, Lei Wang, and Yanling Xu, from AA DRL Studio Patrik Schumacher & Pierandrea Angius in 2016–2018.).

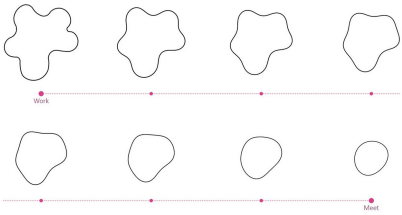

Fig. 5. The continuous spectrum of shapes can be translated to a gradient design field. (credit: Yihui Wu, Lei Wang, and Yanling Xu, from AA DRL Studio Patrik Schumacher & Pierandrea Angius in 2016–2018.).

This example of a semiological research project is intended to illustrate how a relatively complex and subtle semiological project is gradually elaborated based on a series of simple and intuitive systems of form-function association. Here, this student project, as a preliminary attempt, gives us a glimpse of the ambitions of the parametric semiological project, which is trying to create an all-encompassing and increasingly informative design language for the built environment.

4 Quantitative Analysis, Evaluation, and Optimization

The agent-based life-process crowd simulation methodology developed under the research agenda can be seen as an upgrade of the current engineer's crowd simulations. This new type of simulation is more focused on social functionality, as designers

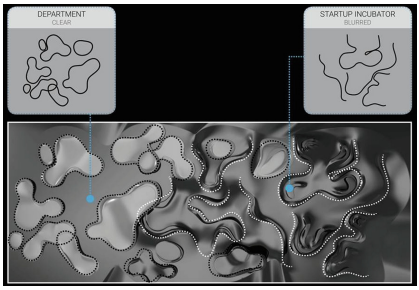

Fig. 6. The project shows one of the situations gradient spectrum, one end represents the absolute meeting situation, the other end represents the absolute individual concentrated work situation. (credit: Yihui Wu, Lei Wang, and Yanling Xu, from AA DRL Studio Patrik Schumacher & Pierandrea Angius in 2016–2018.).

treat the designed spaces as a semantically coded environment which will order people's interaction and communications. And in order to deliver a convincing semiologically informed simulation, Patrik Schumacher listed the innovations that the current research groups are working on [15]:

1. *expansion of action/behaviour repertoire*
2. *differentiation of agent population*
3. *designation dependency of behaviours*
4. *information empowered, semiology competent agents*
5. *agent decisions via dynamic utility functions*
6. *focus on social interactions and event scenarios*
7. *domain tailoring and client customization*

4.1 Methodology and Toolset

Zaha Hadid Architects ABPS group's recent research work focusses on a scientific research approach which is aiming for quantitative analysis, evaluation, and optimization in accordance with relevant social functionality criteria. The team attempts to build a methodology and toolset for a marketable, professional design service of a new quality. Their work focusses on three parts. First is the simulation: the agent-based life-process modeling. Second is the empirical validation of the model. This requires the collection and analysis of real-world data to calibrate the model. The third is the generative design which is to develop a generative design tool based on the first two parts. This paper will elaborate mainly on the first part. In order to integrate the social interaction into a heterogenous crowd simulation, the ABPS group is developing their own AI decision-making system within a software framework based on the Unity game engine.

The simulation approach contains three main parts: Agent modeling, environment modeling, and data analysis. In the agent modeling, besides the basic mobility and pathfinding using A* graph algorithm, it mainly focusses on three aspects, first is the customized action types based on different scenarios, like a base action library for the intelligent agent behavior modeling. For example, in the working scenario, it should

include basic actions like having a meeting, working at a desk, etc. Second is the agent types and internal state. All these parameters will decay based on the events and time and will influence the agent's decisions. The third aspect: the AI decision-making framework. Each agent contains an AI brain that holds a set of different actions on one hand and internal state on the other hand, based on the internal state and evaluation of the environment as well as other agents' behaviors. The whole process is dynamic and autonomous (Fig. 7).

Fig. 7. ZHA ABPS's example interface of agent types, in the working scenario, the agents can be classified into different working teams, and agents can be differentiated as team leaders who will have more meetings, and team members who will work at the desk more. And each agent contains a set of different needs parameters, like thirst, hunger, concentration, motivation to work, etc. (credit: Tyson Hosmer (team leader), Soungmin Yu, Sobitha Ravichandran, and Ziming He)

The environment modeling includes three aspects: destinations, zones, and events. The destinations are places like meeting rooms which might contain sub-goals like chairs, desks, etc. Each goal has a specific script, so the agent is aware of how to interact with it. Zones are areas that are marked by special features, e.g. the floor material or ceiling colour, which will influence the behavior of the agent, such as walking speed, etc. An event is a dynamic interaction system. There can be scheduled events or unscheduled events. In the working scenario, a scheduled event could be a team meeting which will trigger the particular team to go to the defined meeting room. Unscheduled events could be spontaneous conversations triggered by an encounter between agents based on their internal state and the location of the encounter.

The data analysis includes input data and output data. Input data include agent types, internal state parameters, global influence parameters, etc. Output data include event durations, locations, different agents' encounter counts, conversation duration, etc. All the data is correlated with the spatial features.

4.2 Scenario and Example

The ABPS team is focusing its research on office work environments, especially corporate spaces and incubator spaces, as these are the best scenarios for complex dynamic interactions in information-rich environments. In such environments, many diverse interactions happen simultaneously, and it would be very difficult to predict the occupancy and communication patterns by merely looking at the drawing and imagining scenarios. The new tool of agent-based life-process simulation assists the designers to understand the social effects of the space arrangements better, to decide, for instance, where meeting zones or social zones would be best located. The tool is not only helpful on the organizational level, but also on the articulation level. The designers can test different social codes and protocols attached to different spaces. The goal is that through this design process, designers can really create a productive, socially effective architectural order (Fig. 8).

Fig. 8. ZHA ABPS's example data analysis on Infinitus headquarter project, which shows the different social interaction patterns and analysis, such as agent perception, conversation, occupancy, history map, etc. (credit: Tyson Hosmer (team leader), Soungmin Yu, Sobitha Ravichandran, and Ziming He)

5 Discussion

The development of agent-based occupancy modelling for architectural design has started on a new promising trajectory. Patrik Schumacher's original, theoretically grounded design research programme of Agent-based Parametric Semiology outlines

a compelling new methodology that aims to upgrade the capacity of architecture to fulfil its societal function as posed anew in the context of the Post-Fordist network society. Over the last ten years, this research programme has been clearly theorized and well-illustrated in many speculative design projects at the AADRL. During the last three years, serious research and implementation work are underway at ZHA's ABPS research team, pushing this project closer to the point where it delivers a compelling new evidence-based, marketable design service.

With the development of Game AI, more and more researchers have begun to pay attention to this possibility. A productive technology transfer is underway that could massively upgrade our discipline. I believe we are witnessing a rare opportunity for architectural design research. This research is still only in its infancy and remains full of exciting challenges.

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