Stanislav Roudavski	*Paper:* **Expanding Architectural Materiality through Dynamic Continuous Differentiation** *Artwork:* **Freeze-Volume Perceptions: Seeing Dynamic Architectural Systems through Static 3D Prints**

Topic: Architecture

Authors:

Stanislav Roudavski
University of Melbourne
Department of Architecture
Gwyllim Jahn
University of Melbourne
Department of Architecture

references:
Lynn, Greg (1999). *Animate Form* (New York: Princeton Architectural Press)
Schumacher, Patrik (2011). *The Autopoiesis of Architecture: A New Framework for Architecture* (Chichester: Wiley)

This paper discusses design challenges and potentials of hybrid physical/digital architectural environments. In this context, the notion of continuous differentiation (cf. Lynn, 1998, pp. 8-43; Schumacher, 2011) - inspired by natural environments and enabled by computation - is taken as an illustrative challenge to architectural creativity. Existing work discusses and implements continuous differentiation as a static outcome of underlying processes. This paper expands this concept by discussing differentiation that sustains continuity through time as well as through space. Dynamic material effects made possible by this approach include variable porosity, ornamentation, lighting and surface articulation. The paper's central research question asks whether architectural materiality can be expanded through this approach. To trigger critical reflection on the developing nature of architectural materiality, the paper analyses the outcomes of a particular experiment that implemented parametric geometry, interactive environment and a high-density responsive agent system in an architectural installation. The paper argues that its case-study demonstrates unique compositional potentials and contributes a productive concept for further critical discussion, experimentation and research.

Artwork:
This project consists of static and moving images describing complex agent systems and their individual states in virtual and physical environments. The systems at the centre of the project's narratives explore topographically-situated complex behaviours. The behavioural history singular moments is represented as a continuously differentiated meshes. These meshes are then used to create 3D prints. Resulting physical models act as perceptual frames that help to examine architectural-design potentials of particular system states. Used in parallel with other ways to visualise complex systems, this approach can usefully contribute to architectural design. Thus, static 3D-printed models can reveal unobvious architectural phenomena among dynamic emergent patterns generated by populations of agents. For instance, parallel traces left by groups of agents can materialise as surfaces, overlapping paths can become repeating apertures and collisions be read as volumes. In addition, tactile 3D-models can reveal spatial characteristics of complex dynamic systems that are perceptually inaccessible through two-dimensional screen renderings. For instance, depths, curvatures, volumes, focal planes and other characteristics essential in architectural composition can be perceived in 3D prints but are impeded on-screen. The proposed art project contributes to the creative discourse by demonstrating visual evidence that critically examines the implications of freeze-volume perceptions to thinking about complex systems in architecture and beyond.

Contact:
stanislav.roudavski@cantab.net

Keywords:
architectural design, agent systems, continuous differentiation, generative design, interactive architecture

Emergent Materiality through an Embedded Multi-Agent System

S. Roudavski
Melbourne School of Design, University of Melbourne, Melbourne, Australia
www.stanislavroudavski.net; stanislav.roudavski@cantab.net

G. Jahn
elsewarecollective, Melbourne, Australia
www.elsewarecollective.com; gwyllo@gmail.com

Abstract

The paper discusses the implementation of a multi-agent system as an integral component of a hybrid, digital-physical architectural environment. It contributes to the existing practice-based architectural research in two ways: 1) by describing an innovative integration of a multi-agent system for surface patterning; and 2) by discussing this integration in terms of emergent materiality. This case-study demonstrates suggestive creative approaches and observes in the field the operation of a concept that promises to be useful for future analysis, research and design.

1. Introduction: material or immaterial?

Current discourse in architecture acknowledges the increasing importance of "immaterial" phenomena, such as exchanges of information [1, 2] and simultaneously emphasises the importance of materials [3–5]. Similarly, traditional ways of working, predicated by an understanding of architecture as hierarchical assemblies of objects with set material properties, are in conflict with the growing emphasis on processual architecture [cf. 6]. These contrasting understandings complicate the notion of architectural materiality and call for further practical and theoretical investigations of hybrid, physical/digital architectural environments.

Engaging with this challenge, this paper considers how the notion of continuous differentiation [7, p. 136] – inspired by natural environments and enabled by computation – can be dissociated from the form-, object-, and hierarchy-oriented notions of architectural composition. While Lynn does talk about "the composition of stable bodies that are capable of continuous transformation and mutation" (p. 137), much existing work discusses and implements continuous differentiation as static outcomes of underlying generative processes. These outcomes are said to be continuously differentiated when they exhibit gradual transitions between contrasting states [8, p. 141], where states are understood as physically material assemblies of objects. Thus, even when working with continuous differentiation, the compositional practice focuses on the constitution, description and valuation of architectural form.

This paper seeks to engage with parallel understandings emphasising processes, events and emergent characteristics by considering how differentiation occurs in time, as well as in space. Dynamic material effects made possible by this approach include variable porosity, ornamentation, lighting and surface articulation. They manifest themselves as events or performances rather than as static objects or forms. Extending existing discourses in this area [such as 9], the paper analyses the outcomes of a particular experiment that combined complex geometry with an interactive environment and a responsive multi-agent system in an architectural installation.

2. Assemblage: provisional formations of socio-technical actors

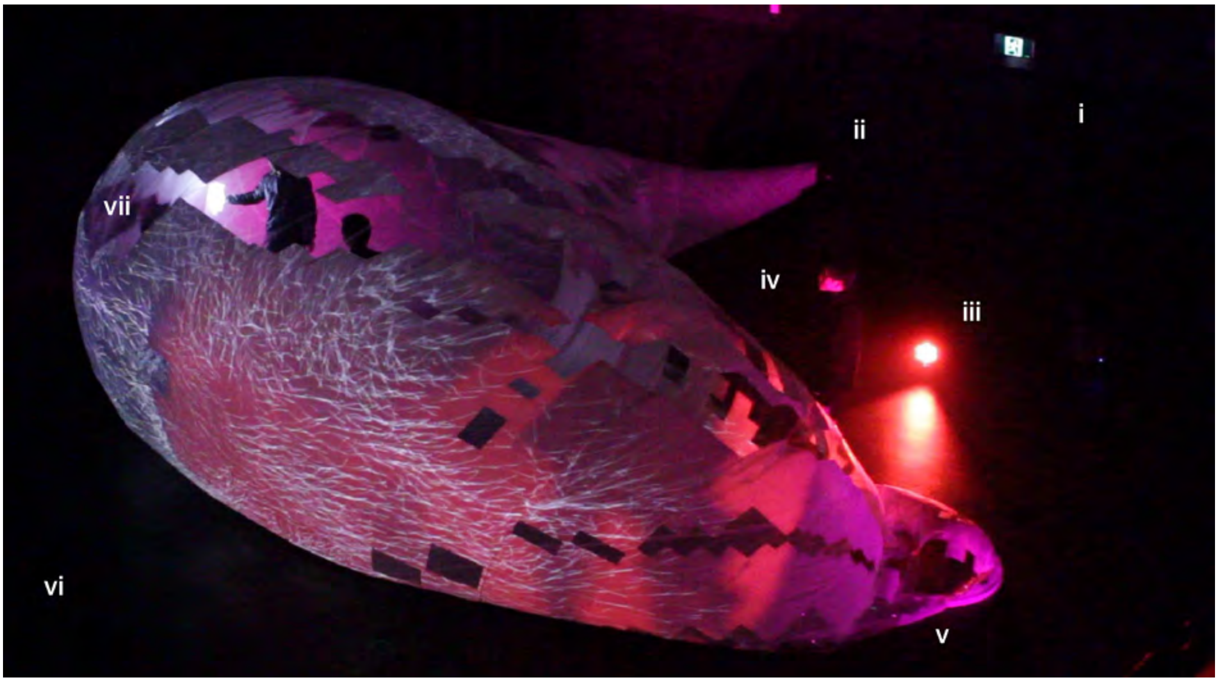

Fig. 1. Overview. i) perimeter speakers; ii) location of the fan; iii) one of the lights; iv) visitor, looking through the transparent patches; v) entrance to the inflatable; vi) towards entrance to the space and the projectors; vii) visitors carrying a lantern.

The Performative Architecture Installation discussed in this paper was designed and constructed at the University of Melbourne in 2011. It can be most productively considered as a temporary and continually regenerated open assembly of heterogeneous actors [10–13]. Within such an assembly, boundaries are unstable, fuzzy and dependant on the observers' capabilities and goals. However, the extended discussion of the overall assemblage is outside the scope of this paper. Instead, it focuses on one aspect – emergent materiality. Because this discussion of materiality would be inaccessible without a brief description of the overall system, it is provided in this section. To simplify this description, the paper identifies three formations: 1) a non-standard physical structure; 2) an interactive system; and 3) an emergent-behaviour system.

The physical structure of the installation is an organically shaped inflatable made from opaque and transparent patches. It was developed through multiple prototypes, following the principles of design through making [cf. 14] understood as "a discipline that can instigate rather than merely solve ideas" [15, p. 7]. On one hand, the parametric geometry of the structure was informed by parallel experimentation with fabrication. On the other, the form and the fabrication approaches were evaluated for their performance within the intended interactive setup.

The interactive system consists of video projectors; controllable lighting system; providing video streams for analysis of visitor behaviour; controllable speakers; light sensors; and a smoke machine. The control system was assembled in Cycling 74's visual programming software MAX running on a typical desktop PC computer. This setup enables incorporation of visitor behaviours into the overall performance and supports integration of generated effects with the physical structure and the surrounding space.

The focus of this paper is on the third formation, the emergent-behaviour system that was implemented using Processing/Java cross-communicating with MAX.

3. Emergent behaviour: a multi-agent system

The following two subsections discuss the multi-agent system employed in the installation as 1) a particular narrative structure able to produce dynamic, temporally differentiated and emergent material effects; and 2) as an embedded system that situates these effects in populated, messy and rich physical environments.

3.1. Narrative structure: agents, modes and emergent effects

Fig. 2. Narrative modes. Frames from a video showing an explosive transition from the Reflective mode (A) to the Agitated mode (B, C).

The narrative structure of the installation was developed through multiple iterations alongside its interactivity and physical structures. The primary organisational device here came not from static or moving images and not from the rules established within the programming environment but from micro narratives produced throughout the development process to capture desires, describe observed events and post-rationalise found effects. These mini-narratives (50–100 words) helped to establish temporary design criteria and supported communication between team members. Temporal in nature, they also actively encouraged thinking about continuing events instead of static snapshots of spaces or objects. No written narrative is possible within implicit (or actively developed) voice and thinking about narrators and alternative points of perception sharpened attention on the multiple co-existent foci of the interactive performance.

While design thinking benefitted from being periodically cast into the narrative form, the management of complex dynamic processes and integration of coherent and communicable design decisions through the creative team led to the chunking of the continuous interactive experience into narrative modes incorporated into a simulation of a spatial environment populated by agents.

3.1.1. Behaviour

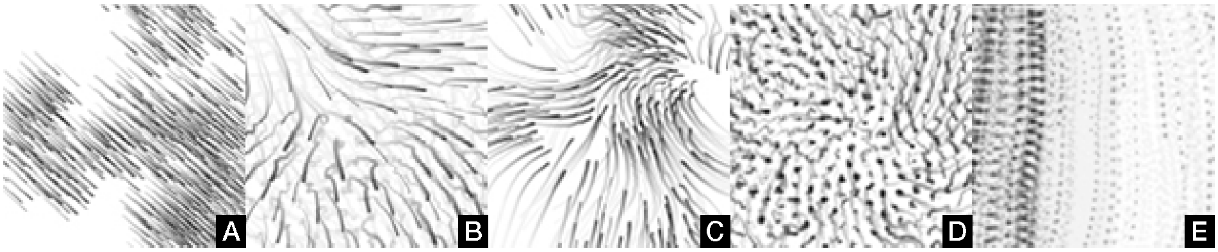

Fig. 3. Vocabulary of behaviours. Examples of emergent patterns.

This multi-agent system is operated by a basic software routine that initialises and iterates the simulation. The simulation takes form of a system composed of multiple interacting agents [cf. 16, p. 11]. Within such a system, an agent is "an entity that performs a specific activity in an environment of which it is aware and that can respond to changes." [17, p. 7]. However, the term agent is used in many heterogeneous ways, even in the artificial intelligence and artificial life communities where these ideas originated. Within Nwana's [18] typology, the installation's agents belong to the basic reactive type that acts "using a stimulus/response type of behaviour by responding to the present state of the environment in which they are embedded." (p. 209) The main characteristic of such agents is autonomy. They can perceive the environment they inhabit and act upon it. The functionality of the installation's agents was derived from the work of Reynolds [19] who defined his flocking "boids" as particles with predefined sets of behaviours allowing them to interact with other particles and their immediate environment.

The simulation behaviour of the multi-agent system is the hierarchical set of rules that defines interactions with other agents and with the environment. The Performative Architecture Installation's system adopts the basic assumptions of a Reynolds [19] flocking model: 1) each agent has an ability to perceive nearby agents; 2) each agent can perceive the whole world as a bounded dimensional space; and 3) all agents can recalculate their current state once per unit of time during the simulation.

The primary component of the internal state is the velocity vector but in extension of Reynolds, the Performative Architecture Installation's implementation stores additional data such as bin membership (see below) and previous location vectors for path rendering.

This basic implementation can be extended with rationality, ability to learn, more sophisticated internal world representation, etc. However even in its current specification, it exhibits performative characteristics that extend common possibilities of architectural materiality.

Behaviours. Agent behaviours are cumulative responses to rules. In the Performative Architecture Installation they take the form of two-dimensional movements. Rules are inaccessible to humans visiting the installation but behaviours are perceptible. Typical rules are static and global to all of the multi-agent system. In contrast, individual responses are dynamic and can be enlarged or decreased for individual agents.

Rules. Agents in the system adhere to two simple rules derived from Reynolds' boids algorithms: alignment and avoidance (Fig. 3, A, B). Each rule is conditional on the proximity of other agents and is effective for all agents within specified search radius and within the agent's grid cell. The algorithm operates as follows. For each neighbouring agent, find the distance between this agent and its neighbour. If this distance is less than the environment's threshold for a change in behaviour, modify the velocity of the agent such that the effect of the neighbour is inversely proportional to the distance between the two agents. To align two agents, the neighbours' velocity is added to that of the current agent. To avoid neighbours, the vector between the neighbour and the agent is found and added to the agent's velocity.

3.1.2. Environment

The environment that the agents occupy can include obstacles, field conditions such as wind and other phenomena. The Performative Architecture Installation implemented one environmental feature in the form of four attractors coincident with the sensor locations on the surface of the inflatable (for examples of local effects produced by these, see the project journal [20, pp. 130, 131]). In another example, an optimisation technique of spatial binning also became a perceivable feature of the environment (see, section 3.1.2.5 below).

3.1.2.1. Topology

The system's environment is a rectangular two dimensional space. It triggers both local and global changes in agent behaviours (e.g., see Fig. 6 for local changes and Fig. 4 for global changes). Local changes scale responses in relationship to specific coordinates, while global changes modify the installation's mode, affecting or substituting agents' rule sets. The environment constrains all possible agents' trajectories to two dimensions thus increasing the number of interactions between agents apparently moving in a three-dimensional space when projected on a curvilinear surface of the inflatable and thus increasing the likelihood and frequency of emergent effects (such as transitions, durations and patterns including clusters, waves, zones, grids and so on). In order to maintain the illusion of an unbounded and continuous space, topologically the environment is constrained to a sphere with agents' movement wrapping around the edges of the visible rectangle.

3.1.2.2. Modes

The system's narrative modes are (e.g., see Fig. 4):

> **Calm.** Very low intensity. The agents move with randomized low speeds and the avoidance is high. They form grid-like patterns, occasionally dispersing and reassembling. The overall effect is of quiet undulation and twinkling interrupted by brief periods of low activity that suggests potential for more dynamic behaviours (also, see Fig. 14).
>
> **Reflective.** Low intensity. Initially flocking in loose undulating clusters across the inflatable, the agents slowly blanket the fabric in a more uniformly dispersed pattern.

This state departs from the near-static equilibrium of the Calm state, but its alternating sub-states are still relatively passive (also, see Fig. 5 and Fig. 11).

Agitated. High intensity. Streams of agents race across the surface of the inflatable now and then exploding in bursts of energy (also, see Fig. 6).

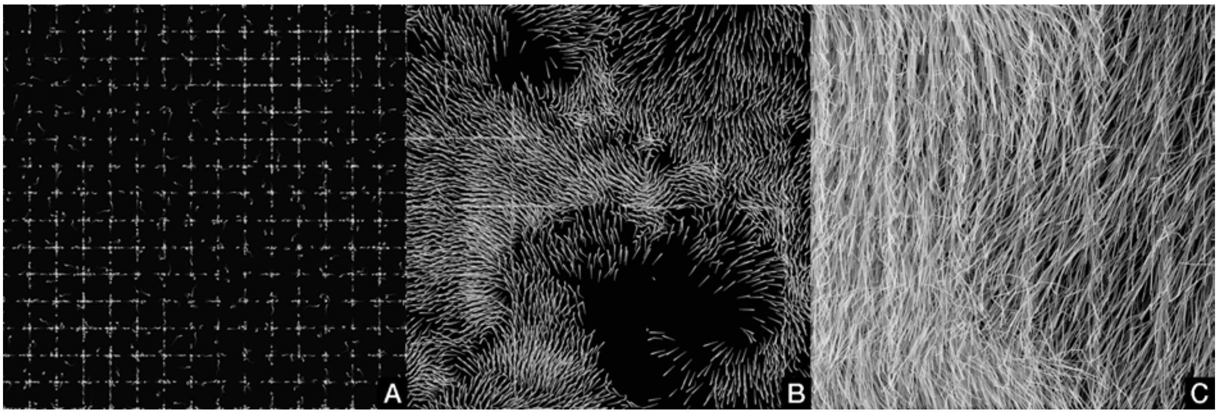

Fig. 4. Samples of modes: Calm (A); Reflective (B); and Agitated (C).

These modes were achieved through the alterations in positioning, movement and interactions between agents inhabiting a continuous field. Allen observes that in a field, “overall shape and extent are highly fluid and less important than the internal relationships of parts.” [21] His discussion of fields emphasised intervals, repetitions and seriality as primary characteristics.

When such approaches are used as metaphors or diagrams for interrelationships between objects (buildings, people, etc.), they can be productively employed as form-guiding strategies in the design process. When used in this way, they assume a utilitarian function in architects’ creative processes. The outcomes of such processes are typically static materialisations that do not openly expose their genesis or directly reflect the on-going renegotiation of spatial relationships (electronic, physical, chemical, etc.). In the Performative Architecture Installation, temporary but perceivable modes and change-vectors between modes, not objects or even relationships between them, act as primary phenomena. While these modes are pre-conceptualised and pre-specified by the designers, their behaviours are also constantly influenced by the surrounding dynamic environment. The forms of the field provide a commentary on the dynamic relationships of the site and can reconfigure these relationships by staging, framing, suggesting or discouraging particular social performances.

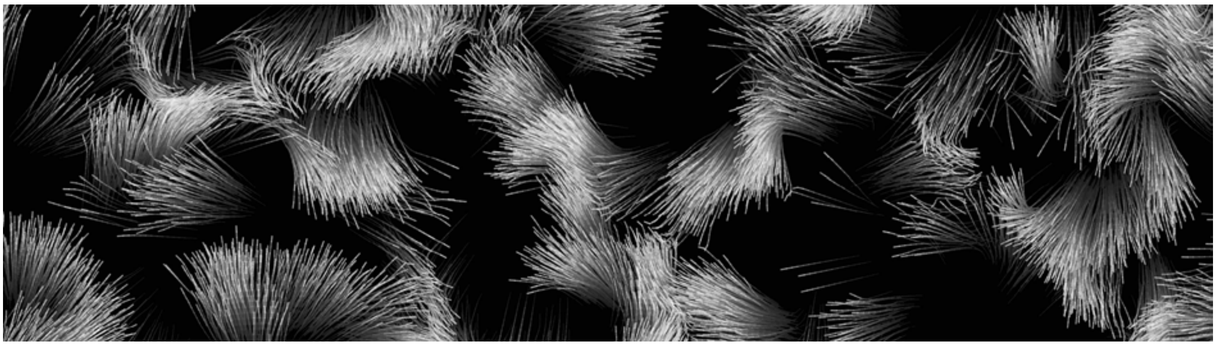

Fig. 5. Reflective mode. Chunking into brush strokes.

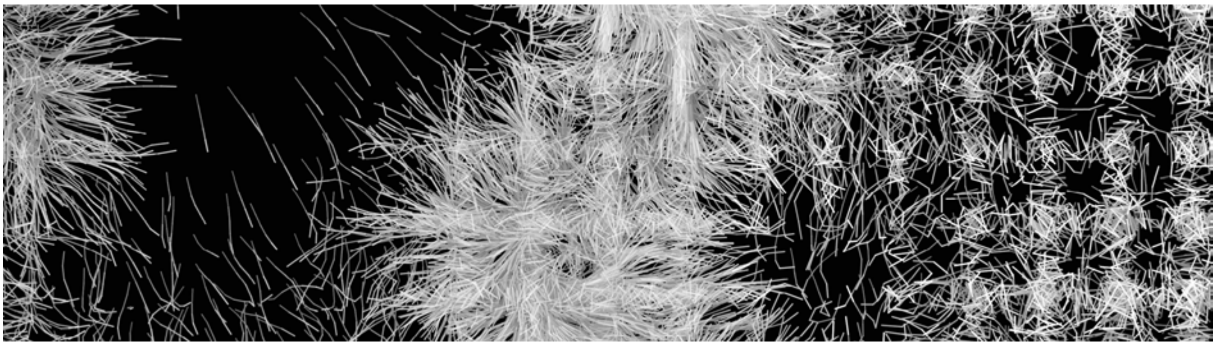

Fig. 6. Agitated mode. Visible gridding and local variations.

Technically, a mode is a predefined set of static and fluctuating parameters that scale individual behaviours of agents in a given environment. Because the parameters are quantifiable, it is possible to interpolate between and within modes to construct an infinitely differentiated parameter space.

3.1.2.3. Sub-Modes, Mode History

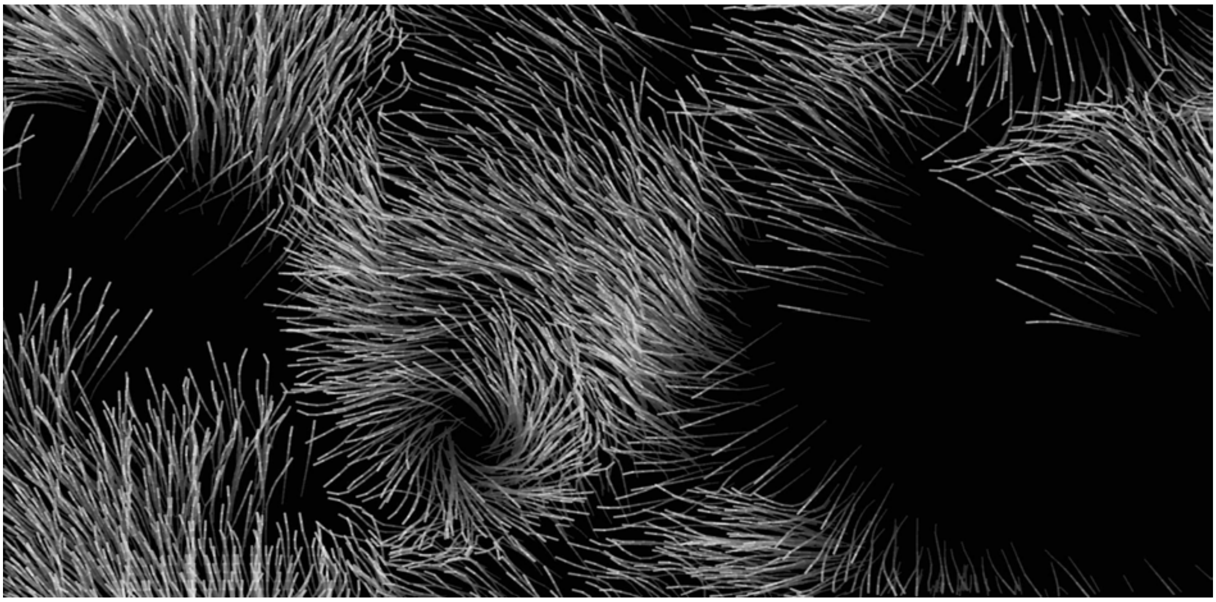

Fig. 7. Sub-mode transition. Dispersal of the chunked brush strokes into a uniformly spread field, mid-transition. Mode: Reflective.

As the environment is only capable of maintaining a single mode at any one time, each mode operates with an embedded memory of previous modes and of their duration. This memory effects the selection of parameters within the subsequent mode. Modes are capable of measuring parameter values, switching between parameter sets (sub-modes) and modifying or interpolating between parameter-set values over time (operating on mode history). Gradual changes in parameter values tend to produce perceptually smooth transitions between perceptible patterns. Such transitions can be slow, transforming the environment without advertising the change to the observers who, unless they pay special attention, can suddenly find themselves is a qualitatively different space (e.g., see transition from Fig. 5 to Fig. 7). Switching between sub-modes tends to rearrange the differentiated flow of patterns suddenly, so that the moment of transition is emphasised as a significant event (e.g., see transition from Fig. 9 to Fig. 6). The supply of various dramatic effects produced by sub-modes switching is incorporated into overarching emotional registers of the three principal modes. Sub-modes are distinguished by perceptible patterning and the rhythms of motion within constrained ranges of intensity representative of the parent mode. By contrast, the primary narrative modes are differentiated by the intensity of the behaviours they contain (see, e.g., Fig. 4).

3.1.2.4. Transitions

A transition is an externally triggered switch from one narrative mode to another (Fig. 4). There are six possible transitions: 1, 2) from Agitated to Calm or Reflective – capturing a slowly dissolving state of the last distribution produced by the Agitated mode; 3, 4) from Calm to Reflective and back – indicating the change with a heightened activity and then settling into a dispersed field; 5, 6) from Calm or Reflective to Agitated (Fig. 2 and Fig. 14) – resulting in an explosive change, with agents rapidly moving away from their initial positions, supported by dramatic lighting fluctuations and highly active audioscape. Transitions are triggered by the sensors or a computer vision system using camera-stream analyses. Both trigger types react to the visitors' behaviours. Through these triggering mechanisms, the multi-agent system becomes a participant in an open assembly that can accept events, energies and deliberate behaviours from external participants.

During a transition, the current mode with its last distribution of agents acts as an input for the subsequent mode. Hence, the character of the transition is a product of the reorganisation of agents within the environment (Fig. 8 and Fig. 14). Transitions result in a range of effects not exhibited within modes and produced by the contrasts in agent behaviours and speeds (or, to put it differently, redistributions of energy). Both transitions and sub-modes act to introduce order (or concentrated energy) in the environment by establishing gradients in the behaviour and distribution of agents and affecting the system's entropy. Gradients here are understood as energy-story phenomena, such as uneven distributions of energy in molecular systems with intensive properties (temperature, pressure, density). [e.g., cf. 22, p. 9] (Fig. 8, B, C, D) For example, some modes compress agents into smaller regions in the environment, resulting in explosive redistributions during a transition to a subsequent mode (Fig. 8, C, D and Fig. 14, B, C). Others narrow the range of search, resulting in perceptually random movement because with fewer agents found, repeated interactions between pairs occur infrequently. This change produces contrasting readings of agents' intensities and groupings (Fig. 8, A, C). Another example of a transition effect is produced when active well-defined clusters of agents of the Agitated mode become frozen as perceptually static (but slowly dissipating) partially gridded patterns (Fig. 4, A and Fig. 14, A).

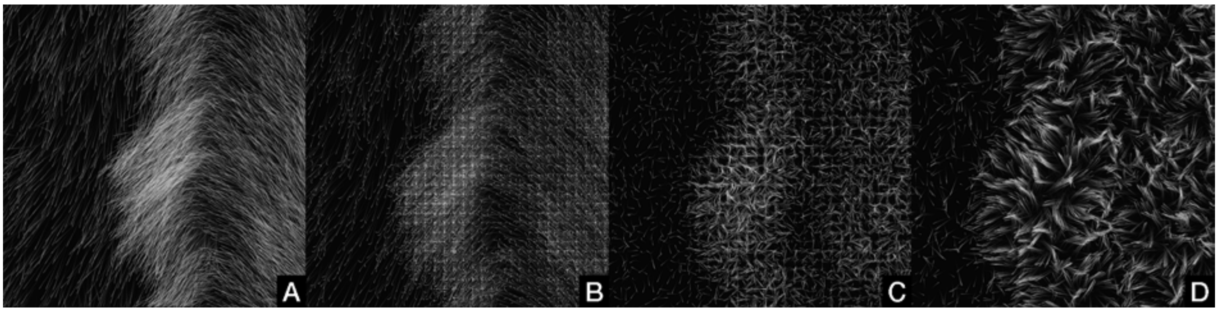

Fig. 8. Seeding. The current mode serves as a seed for the next. A, B: Agitated to Calm; C, D: Calm to Reflective.

3.1.2.5. Effects

As is evident from the above, the multi-agent system is capable of producing multiple emergent material effects. To illustrate, one such example is striation. The speed of each agent is limited to a global value. This value affects the proximity of pairs and controls the frequency of agent interaction. Consequently, high speeds tend to result in the emergence of striated patterns whereby agent velocities become averaged over the entire environment (e.g., see Fig. 9 and Fig. 8, A) By contrast, lower speeds produce more local variation through more frequent interaction between individuals (e.g., see Fig. 4, B and Fig. 8, D).

Fig. 9. Striation patterns in the Agitated mode.

Another example of an emergent effect is gridding. In this case, it is a consciously permitted visible artefact of optimization. Larger populations produce more complex and nuanced effects. The environment becomes more diverse and agents interact not only as individuals but also as groups. However, the time needed for a sequential search algorithm to update all agents increases proportionally with the population size, quickly depleting performance capabilities of a typical computer and undermining the real-time performance of the system. And some form of proximity searcher is necessary to drive behaviours. In order to increase the population size of the simulation, the system implements a simple spatial binning algorithm. The environment is partitioned into lists or 'bins' arranged as a Cartesian grid. These bins are populated by agents based on their current positions. If the next location of an agent corresponds to a different grid cell, it is removed from its current bin and added to a new one. Any subsequent proximity searches are constrained to the agents within the current bin, greatly reducing the running time of the algorithm.

In addition to accelerating the computation, and in contrast to common practice that minimises behavioural artefacts produced by the bin grids, the Performative Architecture

Installation deliberately employs it for the production of visible grids when their appearance is justified by the overarching narrative. The emergent effect of grid lines and squares is used to establish scale, emphasize curvature, strengthen the effects of perspective foreshortening and create contrasting patterning that precedes or follows fluid motion.

These effects emerge when parameters cause agents to avoid other agents within a range that is larger than the dimensions of the bins. Such conditions make grid edges visible because agents oscillate between neighbouring cells (Fig. 11 and elsewhere). The linearity of the grid contrasts with the fluid geometry of the agent paths and patterns the curvilinear geometry of the installation as grid cells distort across its surface. Grid cells also act as sub-environments, compartmentalising agent interactions in a manner that results in cell-sized flocks. Within the global environment, these flocks emerge as painterly effects because small groups of agents become more legible than individuals or large-scale patterns (Fig. 5). Visible gridding of this type is a characteristic example of a found emergent effect. Originating from a simplistic implementation (such visible gridding can be easily eliminated if neighbouring bins are included into the search); this effect was adopted and curated for meaningful incorporation into the spectrum of available material expressions.

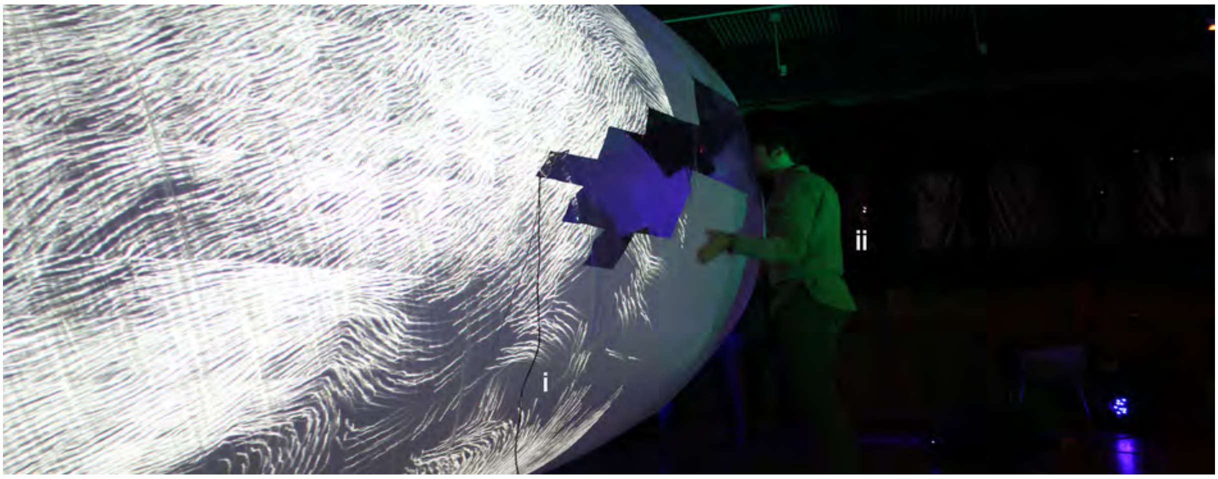

Fig. 10. Gridding 1. The patterns produced by binning, taken during design development. i) cable to the light sensor at the corner of the transparent patch, to be integrated into the skin; ii) looking and touching were encouraged.

The modes and the transitions between modes are defined in terms of bottom-up rather than top-down rules and relationships. Consequently, the resulting system always remains dynamic. Predictable at the macro scales, in terms of perceivable types of emergent effects referring to particular modes or sub-modes, the system never produces identical distributions at the level of interactions between agents and groups of agents.

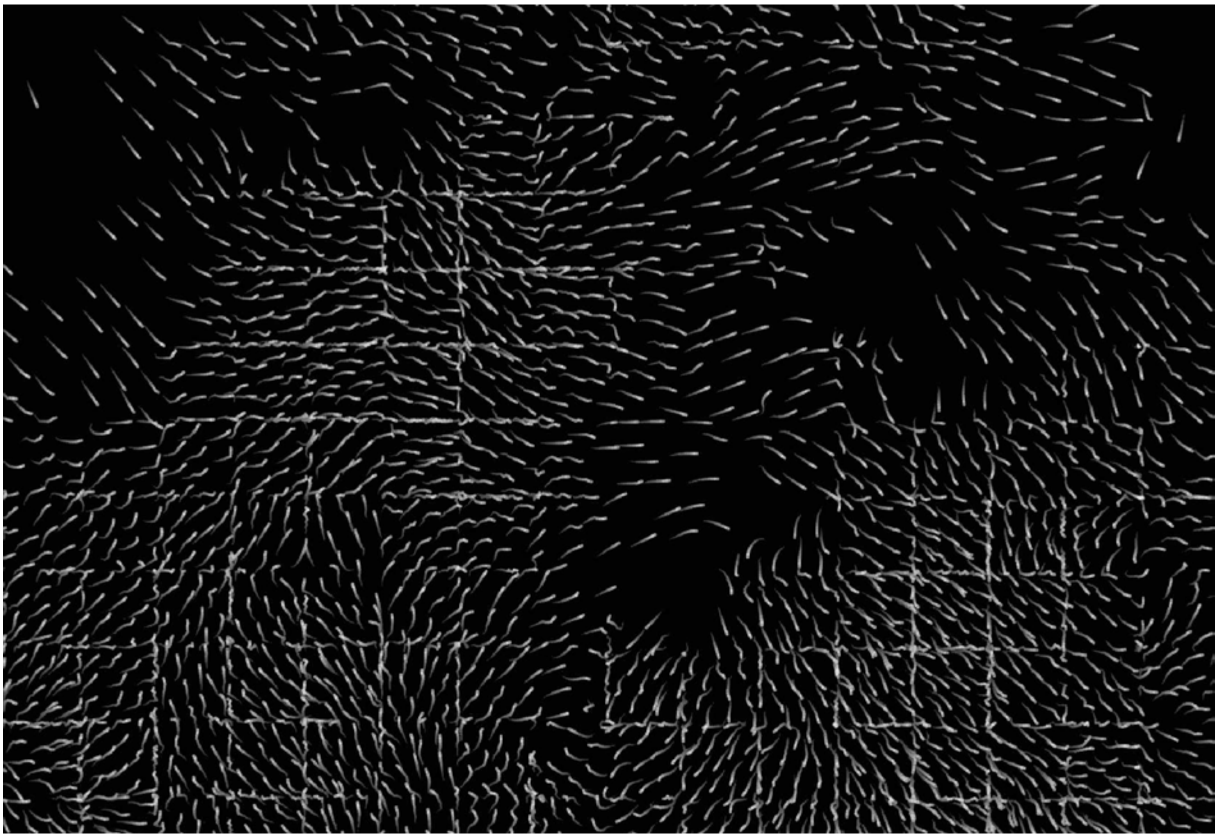

Fig. 11. Gridding 2. Appearance of the grid pattern in the Reflective mode.

3.2. Embodiment: agents in the charged space

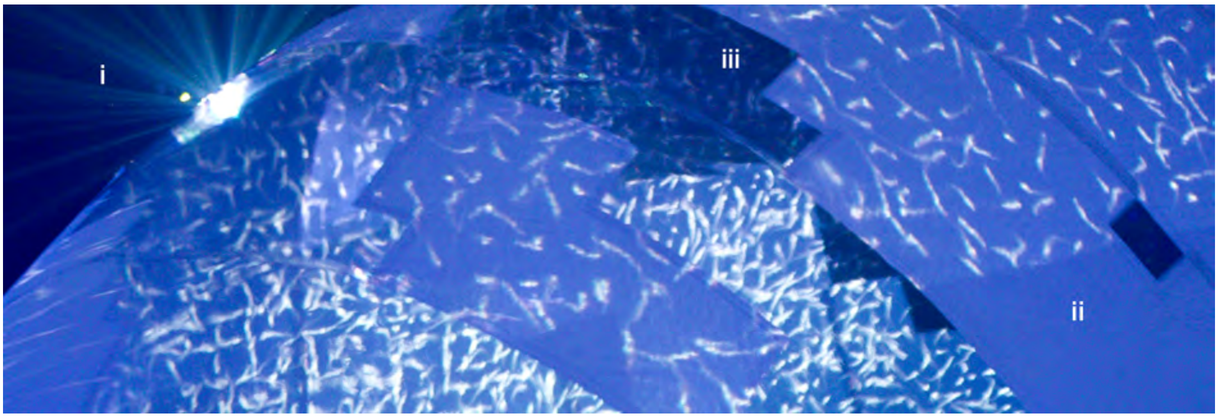

Fig. 12. Situated effects 1. The image shows volumetric light effects (i); differences in scale and sharpness; shadows (ii); and effects on the transparent areas.

In the case of the Performative Architecture Installation, the terminology of human-computer interfaces (graphic or otherwise) is too constraining. Instead, the installation can be more productively understood as a temporary and continually regenerated open assembly of heterogeneous actors. Morse [23, p. 167] describes settings hosting digital art installations as spaces charged with meaning. Visitors can traverse these spaces and the form of their itineraries constitutes an essential part of the poetics of an installation (see also the discussion of place construction in [24, e.g., p. 113]. Accordingly, the multi-agent system of the Performative Architecture Installation acquires additional and new meanings when incorporated into a situated performance. The installation's material characteristics then can be described as emergent not only because they are sustained by agent interactions but also because they become possible through enacted relationships with its hosting place, its visitors and so on.

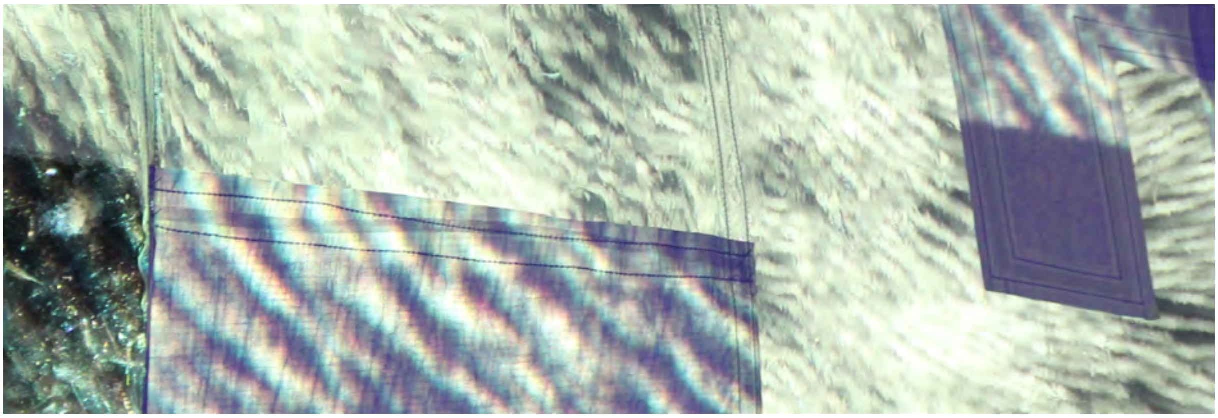

Fig. 13. Situated effects 2. Spectral effects; transparency and density; patterning and scaling.

As mentioned above, the man-machine interface included light sensors and video cameras as well as a dual video projection onto the complex shape of the inflatable structure. The transition from a computer screen to a curvilinear physical form generates effects that alter and enhance the expressive range of the agent system. The projection's integration with space, light, sound and visitors' bodies undermines the algorithmic certainties of computer code transposing it as one of many material presences into layered and much less orderly situated affordances and experiences.

Examples of such situated effects include:

Surface effects. Spectral effects: at points of foreshortening or scaling (Fig. 13). Layering: the image penetrates the patches of transparent material to appear enlarged and blurred against the opposing inner wall of the inflatable (Fig. 12 and Fig. 13).

Point-of-view effects. Secondary images on people; through transparent patches; reflections; refractions; field-of-vision effects.

Light effects. Contrasting lighting modes supporting the narrative (Fig. 2); dynamic shadows and volume effects (Fig. 12). Effects by the stationary, computer controlled lights and from the lantern carried by the visitors (Fig. 14) (e.g., reflected light and glow).

Relational effects. Multiple layers of movement involving the installation and the visitors. Multiple layers of interaction between human and non-human participants. Parallel meanings constructed by multiple participants.

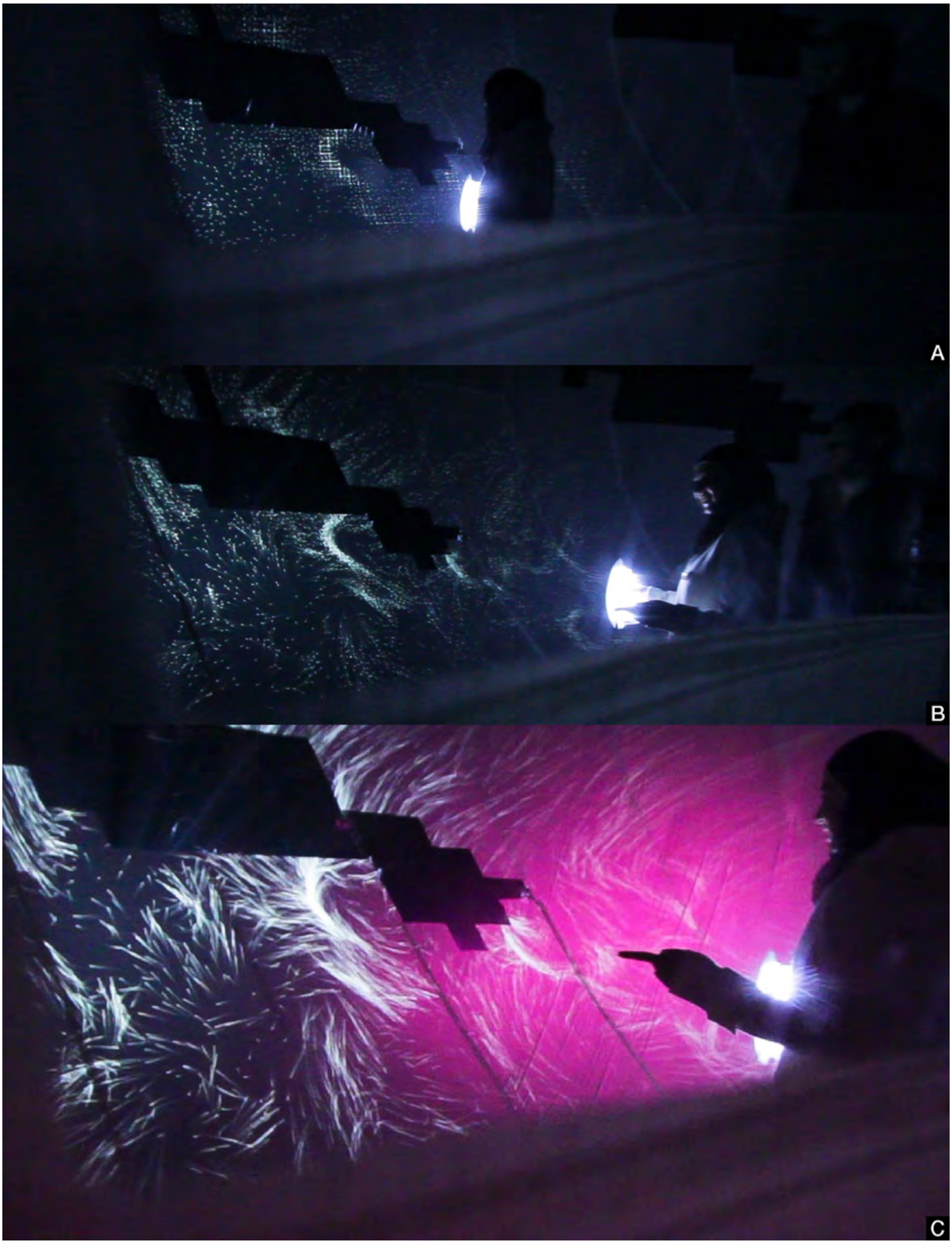

Fig. 14. Modes, lighting and atmosphere. A, B) Calm; C) Agitated.

4. Conclusion: towards emergent materiality

The examples of this paper discuss emergence as flows of matter and energy. While this emergence does not form static objects, its transient character does not prevent it from being real, material and accessible to human perception and experience. Consequently, this approach extends the current understanding of architectural materiality by providing examples of temporal continuous differentiation and emergent effects.

Primary characteristics of emergent materiality are not those described in relationship to objecthood. Instead they comprise "dimensionality, movement and duration" [25, p. v] or "intervals, repetitions and seriality" [21] as primary characteristics.

Ballard [25, p. 5] persuasively argues that "the digital machinic assemblage has specific affects and resonances that in some way distinguish it from previous (non-digital) assemblages." Machinic here refers to the mode of organization, not to the form of an object. Derived from Guattari [26, p. 39], and ultimately from Maturana and Varela [27], the term emphasises relationships between components that as (autopoietic) organisations are distinct from their materiality. The line of enquiry exploring controversial tensions between material and immaterial in architecture cannot be fully pursued in this paper (on my position in regard to their interrelationship in the case of virtual environments, see [28]). However the focus on enacted modes of organisation suggests a useful process-oriented conceptual and creative stance illuminated, for example, by Deleuze and Guattari's [10, p. 152] questions about a "body without organs": what does it do? what type it is? how is it fabricated? what are its modes? what comes to pass? what is expected and what is unexpected? with which variants and surprises?

As experienced during the practical work on the Performative Architecture Installation, the concept of emergent materiality [cf. 25, p. 172] is a good match to the designer's needs to think, talk and make architecture as on-going socio-technical performances rather than static and hierarchical compositions.

5. Acknowledgements and further information

The thinking and designing discussed above were collaborative. For further information and credits, see [20]. Additional images can be found here:

http://pas2011.tumblr.com/archive

6. References

1. Mitchell, W. J. Antitectonics: The Poetics of Virtuality. (Eds. J. Beckmann). in: The Virtual Dimension: Architecture, Representation, and Crash Culture Princeton Architectural Press, New York, 1998, 204–217.

2. Flachbart, G. and Weibel, P., Disappearing Architecture: From Real to Virtual to Quantum, Birkhäuser, Basel, 2005.

3. Kohler, M. and Gramazio, F., Digital Materiality in Architecture, Lars Müller Publishers, Baden, 2008.

4. Mori, T., Immaterial/Ultramaterial: Architecture, Design and Materials, George Braziller; Woodbridge: ACC Distribution, New York, 2002.

5. Agkathidis, A., Hudert, M. and Schillig, G., Form Defining Strategies: Experimental Architectural Design, Ernst Wasmuth, Tübingen, 2007.

6. Ednie-Brown, P., Ethico-Aesthetic Know-How: The Ethical Depths of Processual Architecture, Techniques and Technologies: Transfer and Transformation: IVth International Conference of the Association of Architecture Schools of Australasia, AASA, Sydney, Australia, 2007, 61–67

7. Lynn, G., Folds, Bodies & Blobs: Collected Essays, La Lettre volée, Bruxelles, 1998.

8. Schumacher, P., The Autopoiesis of Architecture: A New Framework for Architecture, Wiley, Chichester, 2011.

9. Moloney, J., Designing Kinetics for Architectural Facades: State Change, Routledge, Abingdon; New York, 2011.

10. Deleuze, G., A Thousand Plateaus: Capitalism and Schizophrenia, University of Minnesota Press, Minneapolis, 1987.

11. De Landa, M., A New Philosophy of Society: Assemblage Theory and Social Complexity, Continuum, London, 2006.

12. Latour, B., Reassembling the Social: An Introduction to Actor-Network-Theory, Oxford University Press, Oxford, 2005.

13. Johnston, J., The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI, MIT, Cambridge, MA; London, 2008.

14. Rust, C., Whiteley, G. and Wilson, A., Experimental Making in Multi-Disciplinary Research, Design Journal, 2000, (November).

15. Sheil, B., Design through Making: An Introduction, Architectural Design, 2005, 4(75), 5–12.

16. Fromm, J., The Emergence of Complexity, Kassel University Press, Kassel, 2004.

17. Sterling, L. and Taveter, K., The Art of Agent-Oriented Modeling, MIT Press, Cambridge, MA, 2009.

18. Nwana, H. S., Software Agents: An Overview, The Knowledge Engineering Review, 1996, 11(03), 205–244.

19. Reynolds, C. W., Flocks, Herds and Schools: A Distributed Behavioral Model, SIGGRAPH Computer Graphics, 1987, 21(4), 25–34.

20. Performative Architecture Studio, 2011, Performative Architecture Studio Journal, http://issuu.com/ertf345345/docs/pas_2011_journal (accessed 2012/11/13).

21 Allen, S., Points + Lines: Diagrams and Projects for the City, Princeton Architectural Press, New York, 1999.

22. De Landa, M., Philosophy and Simulation: The Emergence of Synthetic Reason, Continuum, London; New York, 2011.

23. Morse, M., Virtualities: Television, Media Art, and Cyberculture, Indiana University Press, Bloomington, 1998.

24. Roudavski, S., Staging Places as Performances: Creative Strategies for Architecture, PhD Thesis, University of Cambridge, Cambridge, 2008.

25. Ballard, S. P., Out of Order: Explorations in Digital Materiality, Thesis, The University of New South Wales, Sydney, Australia, 2008.

26 Guattari, F., Chaosmosis: An Ethico-Aesthetic Paradigm, Indiana University Press, Bloomington, 1995.

27. Maturana, H. R. and Varela, F. J., Autopoiesis and Cognition: The Realization of the Living, Reidel, Dordrecht; London, 1980.

28. Roudavski, S., Virtual Environments as Techno-Social Performances: Virtual West Cambridge Case-Study, CAADRIA2010: New Frontiers, the 15th International Conference on Computer Aided Architectural Design Research in Asia, 2010, 477-486