Snooks *Architectural Intelligence* (2022) 1:9
https://doi.org/10.1007/s44223-022-00007-8

Architectural Intelligence

RESEARCH ARTICLE Open Access

Behavioral tectonics: agentBody prototypes and the compression of tectonics

Roland Snooks*

Abstract

This research demonstrates the development of a tectonic approach to architecture through an experimental, iterative methodology. It is a synthetic approach where tectonics and form are engaged in a non-hierarchical negotiation. An architecture where expression, ornament, structure and their spatial consequences are intertwined and inseparable.

The design research posited here has been conducted over the past nine years through the sustained development of a series of architectural tectonic experiments called the agentBody Prototypes. These prototypes reify an ambition to compress surface, structure and ornament into a single irreducible assemblage. The agentBody Prototypes are a series of fourteen proto-architectural projects, or fragments, with lead design by Roland Snooks, and research, development and fabrication by the RMIT Architecture | Tectonic Formation Lab.

The paper describes the wider context of this work and includes a brief chronological overview of this trajectory, followed by a series of observations drawn from critical reflection. This paper attempts to draw out the architectural design implications that have emerged through a specific interaction of algorithmic design, and robotic fabrication.

Keywords: Behavioral formation, Multi-agent algorithms, Additive manufacturing, Wire arc additive manufacturing, Architectural tectonics

1 Introduction

This research demonstrates the development of a tectonic approach to architecture through an experimental, iterative methodology. It is a synthetic approach where tectonics and form are engaged in a non-hierarchical negotiation. An architecture where expression, ornament, structure and their spatial consequences are intertwined and inseparable.

The design research posited here has been conducted over the past nine years through the sustained development of a series of architectural tectonic experiments called the agentBody Prototypes. These prototypes reify an ambition to compress surface, structure and ornament into a single irreducible assemblage. The agentBody Prototypes are a series of fourteen proto-architectural projects, or fragments, with lead design by Roland Snooks, and research, development and fabrication by the RMIT Architecture | Tectonic Formation Lab.

The paper describes the wider context of this work and includes a brief chronological overview of this trajectory, followed by a series of observations drawn from critical reflection. This paper attempts to draw out the architectural design implications that have emerged through a specific interaction of algorithmic design, and robotic fabrication.

Each of the agentBody Prototypes, while presented as a project in its own right, should be considered part of a continuum, where the prototypes create a unified body of design research. The design of each prototype is a critical response to the failures and understandings drawn from the previous prototype - the catalyst for one prototype is created from the reflection on the last. Often these projects are exhibited in galleries and art museums, however,

*Correspondence: roland.snooks@rmit.edu.au

RMIT Architecture, Tectonic Formation Lab, RMIT University, Melbourne, Australia

they are not intended to be sculptural, but instead they are prototypes that explore specific architectonic concerns.

The agentBody Prototypes have been developed through the co-evolution of tectonic design and material/fabrication approaches. Throughout the 9 years, tectonic approaches have been developed in response to the limitations and potential of emerging advanced fabrication technologies, while new additive manufacturing approaches were developed within the Tectonic Formation Lab in response to tectonic design experiments. The mutual interaction of this process ensured a tight integration of design and construction, but perhaps more importantly the interaction of the two led to design innovation and pushed the work into new territory.

Composite fabrication approaches are essential to most of the agentBody Prototypes. These approaches involve compositing two material systems, not as layers, but as interdependent elements that created a hybrid material behavior greater than the sum of its parts - a true composite. These include sacrificial formwork strategies where structural materials, such as carbon fibre or concrete, are infused or cast into 3D printed skins (Fig. 1).

These prototypes are primarily concerned with innovative tectonics and their design implications. These imperatives are viewed through a lens of qualitative criteria and architectural potential rather than any quantifiable optimisation. However, critical to the viability, and indeed elegance, of these systems are their efficient production. Consequently, there is a constant attempt to find easier ways of building, reducing operations, minimising machine time etc. Reducing the reliance on moulds, formwork and jigs is a key aspect of this concern, and of central importance to any attempt to enable mass-customisation to compete with mass-standardisation.

Fig. 1 Unclear Cloud, 2021. Exhibited at the National Gallery of Victoria as part of the Sampling the Future Exhibition

This research demonstrates a series of shifts from laminating on moulds, to mouldless lamination, to sacrificial formwork, to directly printing structural material. These composite approaches, and responses to limitations, are mined for their design potential rather than the optimisation of a single system and its convergence to a known optimal form.

2 Context

The context within which the agentBody Prototypes have been developed includes a wider architectural community of practice and a lineage of algorithmic design developed within my practice.[1] This algorithmic lineage is articulated through the recent publication Behavioral Formation.[2] The research posited here contributes to a small, but growing, community of architectural practice engaged in experimental applications of fibre-composites, 3D printed polymer and wire-arc additive manufacturing (WAAM).

Fibre composites have a long history in architecture, dating back to the mid twentieth century.[3] More recently there has been a resurgence of interest in composites within experimental architectural practice and research. This has been driven by both a desire to build complex architectural forms and to create highly efficient structures, by architects including Greg Lynn,[4] PATTERNS,[5] and Achim Menges/ICD.[6]

Applications of 3D printed polymers to architecture are in a nascent stage. However, in addition to the pioneering work described here, architectural practices and construction-tech startups such as Archi-Union, Nagami, and Aectual have been building architectural projects incorporating printed plastic in the past several years. This work has primarily involved cladding and internal surface treatment rather than integrated tectonic applications.

Wire-arc additive manufacturing (WAAM), has emerged in the last decade as an increasingly viable approach to 3D printed large-scale metal structures.

[1] This practice over the past two decades includes the experimental research group Kokkugia (2003-2013), Studio Roland Snooks (2013-present), and RMIT Architecture | Tectonic Formation Lab (2013-present).

[2] Behavioral Formation: Volatile Design Processes & the Emergence of a Strange Specificity, published by Actar in 2021, reflected on 18 years of my architectural design research.

[3] This lineage of fibre composites in architecture can be traced back to at least the Monsanto House of the Future in 1957.

[4] Greg Lynn has developed a series of projects exploring the capacity of carbon fibre, including the RV Prototype.

[5] League of Shadows, a pavilion at SCI-Arc is part of a series of fibre composite projects by PATTERNS.

[6] The Elytra Filament Pavilion, is an example of Achim Menges/ICD's composite winding strategy, Prado et al., 2017.

While this has yet to be applied to built architecture, pioneering projects such as Joris Laarman's MX3D Bridge demonstrate the potential of this technology at a scale applicable to buildings.

A lineage of generative algorithmic design projects developed by Kokkugia over a decade (2003-2013) established the design context for the agentBody Prototypes. These algorithmic projects explored the potential of self-organisation and emergence within generative multi-agent design processes to create intricate and complex architectural form. The current tectonic research posited here was catalysed by the disjuncture between the capacity of generative algorithms to create complex geometry and the limited capacity of the construction industry to build complex forms. However, the interaction of algorithmic logic and advanced fabrication has propelled our work beyond the desire to build the digital and instead it has established an iterative approach to developing novel tectonics.

Fundamental to these projects is an algorithmic approach developed through this larger body of work - Behavioral Formation. This approach draws on the logic of swarm intelligence and the operation of multi-agent algorithms. Behavioral Formation encodes design intention within a population of semi-autonomous computational agents that interact in a self-organising process to generate emergent proto-architectural forms, structure and organisation. Within this larger generative approach two algorithmic strategies, agentBodies and Manifold Swarms, underpin the design process of the agentBody Prototypes. These strategies are described in detail in the publication Behavioral Formation: Volatile Design Processes & the Emergence of a Strange Specificity, with excerpts below.

> *"AgentBody algorithms embed tectonic geometry within algorithmic processes and algorithmic agency within geometry. We developed this reciprocal strategy through the design of intricate tectonics and complex formal articulation. The enmeshed relationship of geometry and agency establishes a self-organizing methodology in which structural, material and fabrication logic can be encoded within the geometry of the agent. This conceptualization of the agent draws on the logic of ant bridges, where it is the interconnected geometry of the ants' bodies that creates architectural or structural matter."*[7]

> *"Manifold swarms is a multi-agent strategy for the generation of emergent surface topology... This strategy is based on encoding an orientation coordinate system into the agent, which is divorced from the agent's description of its location, velocity, and acceleration. This vector orientation system enables a population of agents to communicate and align their orientation coordinates to self-organize as a surface of best fit. Through this self-organization of implied surface normals, a coherent manifold surface topology emerges from disordered clouds of agents."*[8]

The interaction of these two strategies creates an agent-based process that simultaneously generates the spatial topology and tectonics of the project. This approach is fundamental to creating an architecture where form is an expression of tectonic self-organisation. This combined methodology has become the primary design process for all the agentBody Prototypes.

3 AgentBody prototypes

This series of agentBody Prototypes has evolved through a sequence of strategies that intertwine innovative fabrication techniques and tectonic approaches. These projects are briefly outlined below predominately in chronological order. The intention here is to demonstrate the iterative nature of this design research. Each iteration of this series is an experiment that demonstrates new opportunities and limitations that are incorporated into the subsequent strategies and prototypes (Fig. 2).

3.1 Composite bodies

Fibre composites were investigated at the outset of this series of prototypes with the assumption it would be a viable approach to fabricating the agentBody tectonics that had been developed digitally and characterized by translucent skins, embedded structural skeletons and complex curvature.[9] The two composite body prototypes, Composite Swarm (2013) and Composite Wing (2014), consist of foam agentBodies that are laminated within a thin fibreglass surface. The bodies act as core material generating structural depth and corrugations to provide structural strength. Composite Swarm was developed as an attempt to compress surface, structure and ornament into a single composite. The interaction of the agentBodies generated a continuous network that was simultaneously structural and the primary expression of the project. While creating a highly efficient surface (a 1 mm thick surface supporting a 2500 mm high structure), the bodies are equally intended to operate as embedded ornament. Rather than ornamental figures applied

7 Snooks, 2021, p73.

8 Snooks, 2021, p89-90.

9 The Aalto University (2012) proposal is an example from this series of projects. Snooks, 2021, p78-79.

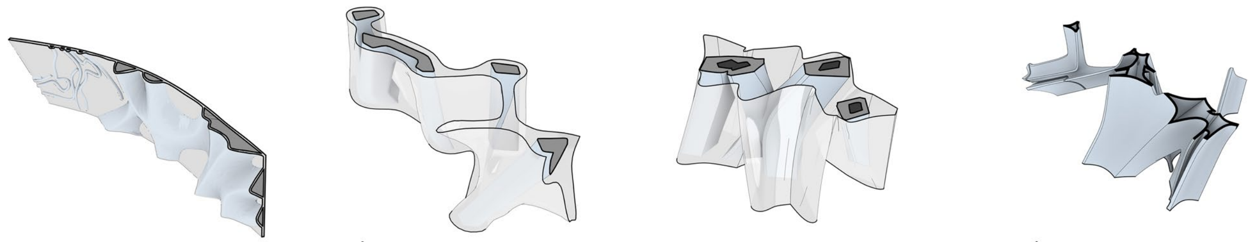

Fig. 2 Diagram of tectonic evolution. Chunk sections from four projects demonstrate significant steps in the progression of agentBody tectonics: **a** lamination of foam agentBodies (Composite Wing), **b** concrete reinforced sacrificial formwork (NGV Pavilion), **c** carbon fibre reinforced sacrificial formwork (Unclear Cloud), **d** directly printed steel structure (Remnant 1)

Fig. 3 Composite Swarm, detail, 2013

to a surface, the surface is an emergent outcome of the self-organisation and structural behavior of the bodies (Figs. 3 and 4).

Composite Swarm was fabricated through a vacuum infusion process with flexible cast polyurethane foam bodies laminated between layers of fibreglass on a CNC milled foam mould. The material behavior of the bodies, their capacity to bend but not stretch, was encoded within the algorithmic behavior of the digital bodies. This contributed to an algorithm that negotiated between structural, material, formal and spatial behaviors in the generation of a synthetic whole.

The shift in scale from Composite Swarm (7 m2) to Composite Wing (66 m2) required a shift from a complete project mould to an approach that limited the mould size and eliminated the need to expertly position the flexible bodies. The five complex curved parts that comprise the Composite Wing were laminated from a single mould. The unique profile shapes of these five parts enabled their assembly into a form without visible repetition - generating a repetition of surface character rather than a repetition of components. The shift from bespoke digital fabrication to outsourced manufacturing required a more standard fabrication technique for the foam bodies. This resulted in the selection of a CNC milled approach to replace the flexible cast foam approach used in Composite Swarm (Figs. 5, 6, 7).

Fig. 4 Composite Swarm, 2013. Exhibited at the Design Hub, Melbourne

Fig. 5 Composite Wing, 2014. Exhibited at the Design Hub, Melbourne

Fig. 6 Composite Wing, 2014. Exhibited at the Design Hub, Melbourne

3.2 Self-forming surfaces

The complexity of fabricating the Composite Wing project and the number of processes involved led to a search for a more efficient fabrication approach. Despite its structural efficiency the project had limited viability as a generalised technique due to an intensive fabrication process. Our initial response was to explore the connection of flat-sheet agentBodies to generate the surface curvature of a manifold swarm through their specific geometry and logic of connection. As the parts are connected they force curvature into the surface - a type of self-forming. This approach was first demonstrated through laser-cut steel sheets in the Laminar Bodies project (2015). Without the structural depth of the foam bodies of the composite projects, this prototype was reliant on surface curvature for strength, a shift from the micro-structuring of surfaces to generating structure through surface geometry (Figs. 8 and 9).

This strategy, developed through the Laminar Bodies project, revealed the potential for creating fibre composite surfaces without moulds. This potential was tested through the Composite Skeleton (2015) project that employed a carbon fibre skeleton laminated within a thin fibreglass skin. The carbon fibre bodies were laser-cut from flat, rigid sheets of carbon fibre, before being assembled to create a double curvature surface. A vacuum infusion technique was then used to laminate a 0.25 mm thick translucent fibreglass surface that resisted the shear forces within the prototype. The innovation of the project lies in the lamination of a surface onto a self-forming skeleton rather than a mould, eliminating the prohibitive cost of moulds for one-off composite parts (Figs. 10 and 11).

3.3 Linear assemblies

The Brass Swarm (2015) and DADA Pavilion (2015) prototypes were developed in response to the increasing compression of the previous prototypes to thin surfaces. The projects are assembled from robotically bent metal rods, which assemble into thick fibrous manifold swarms. Each body is composed of four rods that were fabricated through a multi-robot rod bending technique. An empirical understanding of the limitations of the fabrication technique was developed through iterative testing. This understanding was then encoded within the agentBody algorithm to ensure the algorithmic transformations of each agentBody remained within the limits of fabrication. This enabled a highly volatile[10] generative process to maintain an automated generation-to-fabrication workflow (Figs. 12 and 13).

3.4 Sacrificial formwork - cast concrete

Within this lineage of agentBody prototypes, the composite projects flattened the agentBodies to surfaces while the linear rod-based projects resisted surface. A sacrificial formwork strategy was developed to negotiate between these two extremes by inverting the process of the composite projects. Rather than laminate a skin over the network of agentBodies comprising the skeleton, sacrificial formwork involved 3D printing a thin skin within which a structural skeleton is cast (Figs. 14, 15 and 16) (Snooks, 2018, p100-113).

This strategy was developed through a series of small prototypes that culminated in the design of the Sacrificial Skin public art project (2016) and NGV Pavilion (2016). This process removed the need for moulds and subtractive manufacturing techniques. Instead, a highly efficient fabrication approach is posited that is capable of negotiating between skin and lattice. This approach leverages the capacity of 3D printing to fabricate highly complex geometries, and the efficiencies and structural capacity of cast fibre-reinforced concrete (Fig. 17).

[10] The role of volatile algorithmic design strategies is discussed in more detail in: Volatile Formation, Snooks, 2012.

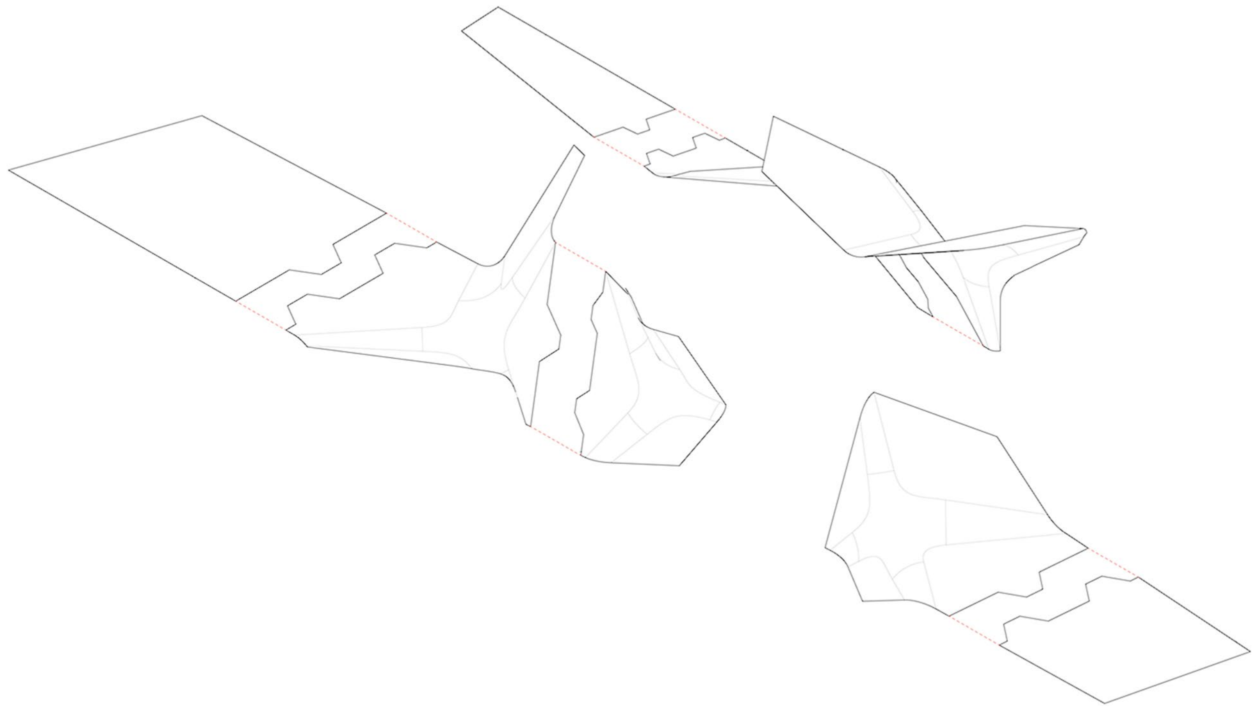

Fig. 7 Composite Wing, composite mould diagrams

3.5 Sacrificial formwork - infused carbon

This sacrificial formwork logic has more recently been extended from casting concrete to infusing carbon fibre. This strategy involves polymer skins with an intricate network of conduits printed within. The conduits provide the sacrificial formwork for the carbon fibre infused skeletons. This strategy was first explored through the Cloud Affects (2019) project, exhibited at the Shenzhen Biennale, and refined in the Unclear Cloud (2021) project exhibited at the National Gallery of Victoria. In contrast to the cast concrete sacrificial formwork projects, these prototypes have a loose fit of skin to structure. The lamination of the structural skeleton shifts between the front and rear surfaces of the skin, creating a pattern of reinforcement that shifts in focus throughout the form. A series of technical printing innovations were required to enable the complex geometry and topology of these projects including non-parallel and start-stop printing. While these are modest innovations in themselves, they have significant design implications, enabling complex topologies, and increased geometric freedom. Cloud Affects was printed in thirteen parts, each infused with

Fig. 8 Laminar Bodies, 2015. Exhibited at the Adam Gallery, Wellington

Fig. 9 Laminar Bodies, 2015. Exhibited at the Adam Gallery, Wellington

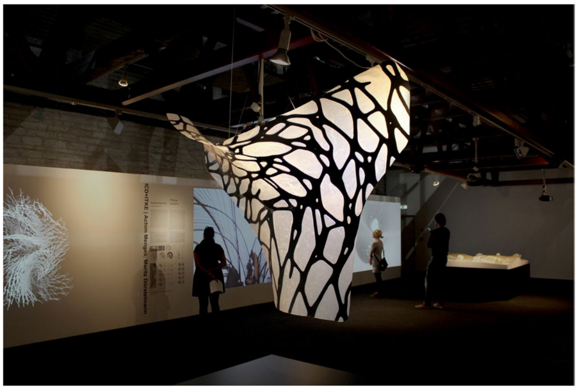

Fig. 10 Composite Skeleton

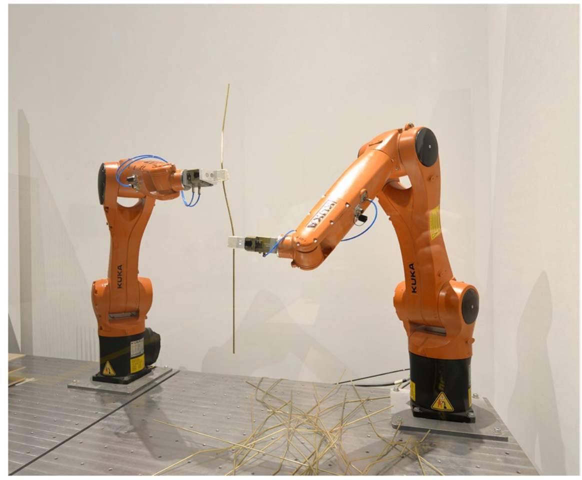

Fig. 13 Robotic bending of Brass Swarm rods

Fig. 11 Composite Skeleton

carbon fibre, before being mechanically fixed together into a single assembly. Due to issues of tolerance and structural continuity, this assembly logic was reconsidered in the subsequent Unclear Cloud project, which was assembled into five discrete chemically fused assemblies. The joints between these parts were CNC milled to address tolerance issues before being glued together. This enabled the assemblies to each be infused with continuous carbon fibre elements to eliminate structural discontinuities (Figs. 18, 19, 20, 21, 22, 23).

This fibre infused sacrificial process evolved further through the Composite BioForms project. A fundamental shift in this project was to move the fibre conduit to the surface of the prototype where it could be accessed from the exterior. This eliminated certain difficulties related to infusing the structural skeleton within the skin. The project also marks a shift from petrochemical products to biodegradable materials. Composite BioForms is part of a series of prototypes exploring the implications of 3D printed wood-bioplastic composites, recycled plastics

Fig. 12 Brass Swarm, 2015

Fig. 14 Sacrificial Formwork diagram

Fig. 15 Sacrificial Formwork prototype: fibre-reinforced concrete is cast into a 3D printed polymer skin

and mycelium. The project reconsiders the construction of sandwich panels, employing 3D printed twin skins with a core of mycelium grown within the cavity. The compressive strength of the mycelium core is balanced with the tensile capacity of hemp fibre/bio-resin infused conduits embedded within the skin.

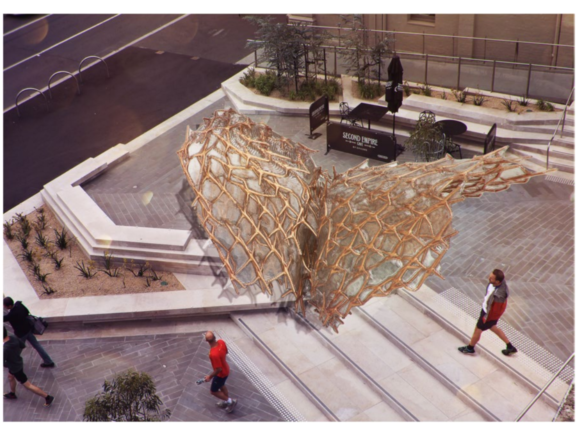

Fig. 16 Sacrificial Skins, 2016

Fig. 17 NGV Pavilion

3.6 Wire arc networks

Over the past 4 years, the Tectonic Formation Lab has been developing metal 3D printing strategies using wire-arc additive manufacturing (WAAM). This approach involves the layer-by-layer deposition of molten metal using cold metal transfer technology and industrial robotics. The lab has explored the application of this technology to create both agentBody structural networks and a hybrid fabrication strategy integrating folded sheet metal and WAAM (Figs. 24 and 25).

The Wire-Arc Facade (2021) prototype explored this hybrid strategy where metal was printed directly onto fabricated steel components. This approach leverages the comparative advantage of WAAM to create the complex geometry parts of the facade, while planar elements are fabricated directly using folded sheet metal. WAAM requires a base plate to print a part onto, which is later cut off and discarded, this hybrid strategy instead uses the folded sheet base plate as part of the agentBodies within the facade.

Fig. 18 Cloud Affects, 2019. Shenzhen Biennale

Fig. 19 Cloud Affects, detail

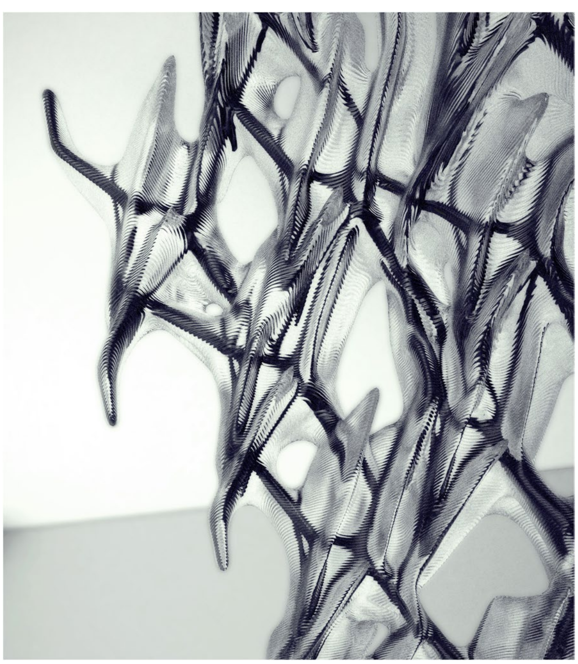

Fig. 20 Polymer/Composite study

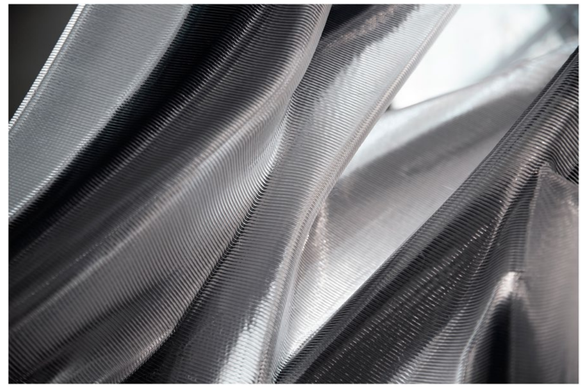

Fig. 21 Unclear Cloud, details

The previous agentBody fabrication strategies predominantly relied on printing sacrificial formwork within which structural networks of agentBodies were cast, or reinforcing foam agentBody networks with composite fibre skins. However, the structural capacity of WAAM printed steel enables a structural agentBody network to be directly printed. This was first tested in the Unclear Cloud project with two WAAM printed agentBodies connecting the polymer/carbon fibre agentBodies to the concrete base (Figs. 26 and 27).

This strategy was explored at a larger scale recently with the design of a series of architectural agentBody assemblies titled the Remnants of a Future Architecture. The first of these, Remnant 1 (2022), designed by Roland Snooks with research and fabrication by the RMIT Architecture | Tectonic Formation Lab and FormX Technologies, demonstrated the capability of this approach at an architectural scale. The project is printed in 15 steel agentBodies which are welded into 4 larger assemblies that are mechanically connected. A non-parallel printing strategy was developed to enable the layers of the print to follow the flow of the geometry. This ensured that none

Fig. 22 Unclear Cloud, details

Fig. 23 Unclear Cloud

of the connections between printed parts occur across the grain, and created a continuity of form and texture (Fig. 28, 29, 30).

4 Reflections and discussion

The chronological description above is an attempt to explain this body of work as a continuously evolving experiment, where the prototypes are not developed in response to an external context or an a priori set of assumptions or beliefs. Instead, these projects have created their own internal logic. An architectural position has emerged from the projects, one of contested tectonics. This is an anti-purist position, one that resists known types and convergence to essentialist models, in favour of an experimental non-linear approach. Non-linear feedback between, and compression of, conflicting imperatives in the work is employed as a methodology for hybridising or synthesising tectonics. This creates blurred conditions and ambiguous relationships within almost all aspects of the work spanning the computational, material, and tectonic. This body of work seeks to integrate: geometry and procedure, volatility and control, digital and material, part and whole, discrete and continuous, and structure and expression. Ultimately this is about embedding design intention within all aspects of the project's formation rather than deferring to known types and sequential processes.

Fig. 24 Wire-Arc Facade, 2021

4.1 Geometry and procedure

The agentBody algorithmic approach differs from many generative algorithmic strategies as it doesn't operate with a sequential relationship of procedure and geometry. Many algorithmic strategies directly generate patterns (the self-organisation of surfaces, curves or point clouds), which are appropriated by architects as proto-architectural geometries. The agentBody strategy embeds specifically designed geometry within the algorithm and algorithmic behavior within this geometry. This combines emergence and intention[11] and resists the indexical output of algorithms which leads to algorithmic design becoming an act of selection rather than experimentation. To work through self-organising processes that lead to emergence isn't about deferring control, but instead about changing the nature of authorship by embedding intention within volatile systems.

4.2 Discrete and continuous

The interaction of repetition and variation plays an important role in the conception, computational design and robotic fabrication of these projects. The algorithmic design logic is based on a repeated agentBody component that varies within a limited range. This variation is based on an agent's specific conditions and interaction with adjacent agents. These are discrete parts that computationally interact to create complex assemblages. The reading of these as discrete parts or continuous networks is blurred and shifts between projects from the Brass Swarm where the agentBodies maintain their discrete

[11] The relationship of emergence and intention operating within this wider body of work is discussed in more detail in the introductory chapter in Behavioral Formation, Snooks, 2021, p8-20.

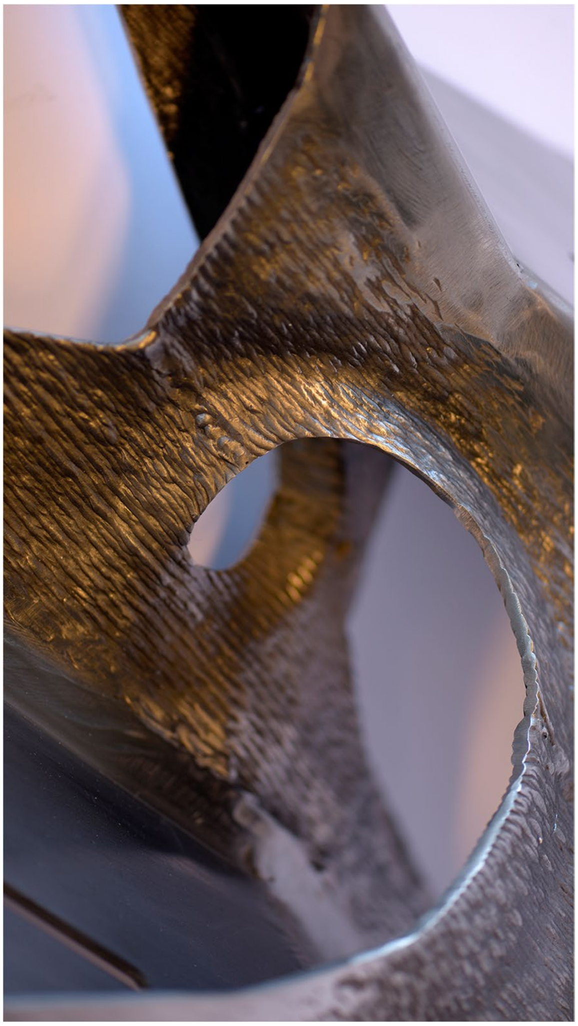

Fig. 25 Wire-Arc Facade, 2021

Fig. 26 Unclear Cloud, WAAM printed agentBody detail

form, to Composite Skeleton where the agentBodies blend into a continuous network. These projects are conceptually and computationally equivalent, however, minor shifts in the articulation of the joints that connect the bodies shift the reading between discrete or continuous. The most interesting projects in this lineage are those which maintain a tension between these two conditions. For example, within Unclear Cloud, the repetition of the bodies is recognisable, albeit with a blurring of one body into another.

This issue of the blurred connection has significant tectonic implications for the projects, particularly with regard to the joints between parts. While being scaled so that the individual agentBodies can be fabricated as discrete elements, this is not necessarily relevant to the construction logic, as the division between physical parts (as opposed to digital agentBodies) is typically defined by the logic of fabrication and assembly rather than the logic of the discrete computational entity (agentBody). This can be understood through the following examples of the agentBody Prototypes. The Composite Skeleton geometry is divided into parts that are digitally unrolled and laser cut from flat sheet material based on developable geometry rather than body joints. The divisions on the 3D printed projects, which blur their agentBody connections, typically respond to where joints can be most easily located for printing. The extent of each foam inlay part laminated within the Composite Wing is determined by boundaries of mould curvature and machine bed size. In all of these examples, pragmatic concerns relating to fabrication drive the subdivision of the geometries into fabricated parts which don't directly relate to the digital connection of agentBodies. This frees the articulation of the connection, or intersection, of discrete digital agentBodies to be tectonically articulated as an ambiguous relationship, neither discrete nor continuous. This questions whether a position within the contemporary dichotomy

Fig. 27 Unclear Cloud, WAAM printing proces

Fig. 28 Remnants of a Future Architecture (Remnant 1), 2022

of the discrete and continuous[12] can be reversed by a seemingly minor change in detail.[13]

The tectonic logic described above is presupposed by the capacity to create seamless fabrication joints. This is certainly possible in the WAAM printed projects and some of the composite projects where the joining techniques are an extension of the fabrication technique (welding and laminating). This logic is more problematic with the translucent plastic printed projects where joints can be minimised but are never seamless. This points to a future alternative approach to jointing, where the joints are articulated or expressed, not as continuous or alternatively discrete breaks, but as features in themselves.

4.3 Structure and expression

The agentBody Prototypes integrate structure and formal expression into a single compressed tectonic assemblage. The non-linear operation of multi-agent algorithms negotiates between numerous different behaviors to enable the design process to be conditioned, rather than led, by quantifiable criteria such as structural analysis. This results in an intertwined relationship of form, structure and spatial characteristics where one doesn't have priority over another.

The agentBody algorithms are encoded with structural behaviors, which negotiate with other design behaviors creating a geometric excess that operates with relative structural efficiency. In contrast to many contemporary applications of composites,[14] this work is not focussed on the lightness of its fibre-composite structures.[15] Instead, it is focused on the design implications of using such a malleable structural material. While the surfaces of the earlier fibre composite agentBody projects took advantage of this to create complex surface form, the carbon fibre sacrificial formwork projects evolved an entirely new tectonic logic from the capacity to infuse this

[12] Gilles Retsin posits the 'discrete' in opposition to the prevailing concern for continuity within digital architecture in *Disrete: Reappraising the Digital in Architecture*, an edition of AD, edited by Retsin (Retsin 2019).

[13] This is not to suggest there isn't a polemic distinction between the work of a younger generation of architects who are championing the 'discrete' and that of architecture's digital turn (as defined by Mario Carpo - Carpo, 2012). Instead, the intention is to point out that architecture is far more ambiguous than the polarising framing of this dichotomy.

[14] Achim Menges and the ICD have made significant contributions to the application of composites in architecture, in part through their series of ICD Pavilions which explore extremely lightweight approaches to fibre composite construction (Dörstelmann et al., 2015).

[15] Architecture, unlike the aerospace industry, typically has less advantages in reducing the weight of the building, when many of the loads on buildings (such as wind loads) are unrelated to its mass.

Fig. 29 Remnants of a Future Architecture (Remnant 1), 2022

Fig. 30 Remnants of a Future Architecture (Remnant 1), 2022

material within complex networks of conduits embedded within printed skins.

A set of formal characteristics have emerged from these projects which resist the convergence to pre-defined optimal types. The obsession with optimisation within contemporary digital construction leads the form of projects to converge on known optimal forms such as vaults, domes, arches.[16] Recourse to these predefined types positions architectural form as subservient to structural optimisation. The work posited here is based on a belief that architecture is a cultural, rather than scientific, pursuit and the form of architecture must respond to a broad spectrum of concerns rather than a singular quantifiable imperative. Through these projects, an architectonic language has developed that expresses an open-endedness and privileges the fragment (of something larger) over complete, definable forms. A language of wings, bodies and networks has evolved through a negotiation of algorithmic behavior, fabrication limitations, material properties, tectonics logic and formal design intention.

The scale of the agentBodies within these projects are influenced by design criteria relating to the legibility of the part and the emergent, self-organised character of the whole, as well as fabrication limitations and structural behavior. Importantly the scale of form and the individual agentBodies are intended to blur the relationship between form and articulation establishing a condition of *form as tectonics*, rather than *form articulated by tectonics*.

5 Conclusion

These prototypes are fragments of an unbuilt architecture - experiments in tectonic strategies for the future deployment in building projects. We have made the first steps in deploying these approaches in architectural projects, such as SensiLab[17] and Building 515,[18] however, these remain at the level of architectural component - walls.

[16] Philippe Block and the BRG at ETHZ exemplify this pursuit of the pure articulation of structural forces within form. Block's work focuses on optimal compression structures that largely converge to vaulted forms.

[17] SensiLab Studio (2017) is a meeting room designed by Studio Roland Snooks with 3D printed translucent polycarbonate walls. Snooks, 2021, p152-155.

[18] Building 515 Studios (2020) consist of two 3D printed studios designed by Studio Roland Snooks that sit within a larger architectural project, for the RMIT Design School, designed in collaboration with PMA and Zilka Studio.

The real ambition for this approach is to reconsider the relationship between, form, structure, ornament and their spatial implications and define a tectonic approach to architecture where these are all expressions of a cohesive tectonic logic and process of formation.

Acknowledgements
The projects were led by Roland Snooks with research, development and fabrication by RMIT Architecture | Tectonic Formation Lab. A list of the project team for each design project is listed below. For a complete list of project partners and fabrication teams please refer to detailed credits at www.tectonicformationlab.com and www.rolandsnooks.com
Composite Swarm, 2013, RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, James Pazzi, Marc Gibson.
Composite Wing, 2014, Studio Roland Snooks.
Roland Snooks, Cam Newnham, Drew Busmire, Amaury Thomas, Pei She Lee.
Laminar Bodies, 2015, RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, Ashan Perera, Ben Verzijl, Andres Rivera.
Composite Skeleton, 2015, RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, Cam Newnham.
Brass Swarm, 2015, RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, Cam Newnham, Ben Verzijl.
NGV Pavilion, 2016, Studio Roland Snooks.
Roland Snooks, Marc Gibson, Matt Kohman, Susanna Brolhani, Venkatesh Natarajan.
Sacrificial Skins, 2016, RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, Marc Gibson, Matt Kohman.
Cloud Affects, 2019, RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, Hesam Mohamed, Charlie Boman, Nic Bao, Gavin Bufton, Caitlyn Parry, Marc Gibson, Dasong Wang.
Unclear Cloud, 2021, Roland Snooks + RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, Hesam Mohamed, Charlie Boman, Marc Gibson, Nic Bao.
Remnants of a Future Architecture (Remnant 1), 2022, Roland Snooks + RMIT Architecture | Tectonic Formation Lab + FormX Technologies.
Roland Snooks, Charlie Boman, Nic Bao, Ron Ellazam, Daniel Ridout, Alan Kim.
Wire-Arc Facade, 2021, RMIT Architecture | Tectonic Formation Lab.
Roland Snooks, Charlie Boman, Alex Walzer.

Author's contributions
The conceptualisation, methodology and writing of this manuscript was undertaken by Roland Snooks. The author(s) read and approved the final manuscript.

Funding
No funding was received to assist with the preparation of this manuscript.

Availability of data and materials
Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Competing interests
The author has no competing interests to declare that are relevant to the content of this article.

Received: 16 May 2022 Accepted: 27 June 2022
Published online: 03 August 2022

References
Dörstelmann, M., Knippers, J., Koslowski, V., Menges, A., Prado, M., Schieber, G., & Vasey, L. (2015). ICD/ITKE research pavilion 2014–15: Fibre placement on a pneumatic body based on a water spider web. *Architectural Design, 85*(5), 60–65.
Carpo, M. (Ed.). (2012). *The Digital Turn in Architecture 1992 - 2012*. Wiley.
Prado, M., Dörstelmann, M., Solly, J., Menges, A., & Knippers, J. (2017). Elytra filament pavilion: Robotic filament winding for structural composite building systems. In A. Menges, B. Sheil, R. Glynn, & M. Skavara (Eds.), *Fabricate: Rethinking design and construction* (pp. 224–233). UCL Press.
Retsin, G. (2019). *Discrete: Reappraising the digital in architecture*. Wiley.
Snooks, R. (2012). Volatile Formation. In F. Roche (Ed.), *Log25*. ANYCorp.
Snooks, R. (2018). Sacrificial Formation. In A. Wit & M. Daas (Eds.), *Towards a robotic architecture*. Oro Editions.
Snooks, R. (2021). *Behavioral formation: Volatile design processes and the emergence of a strange specificity*. ACTAR.

Publisher's Note