Guest-edited by GILLES RETSIN

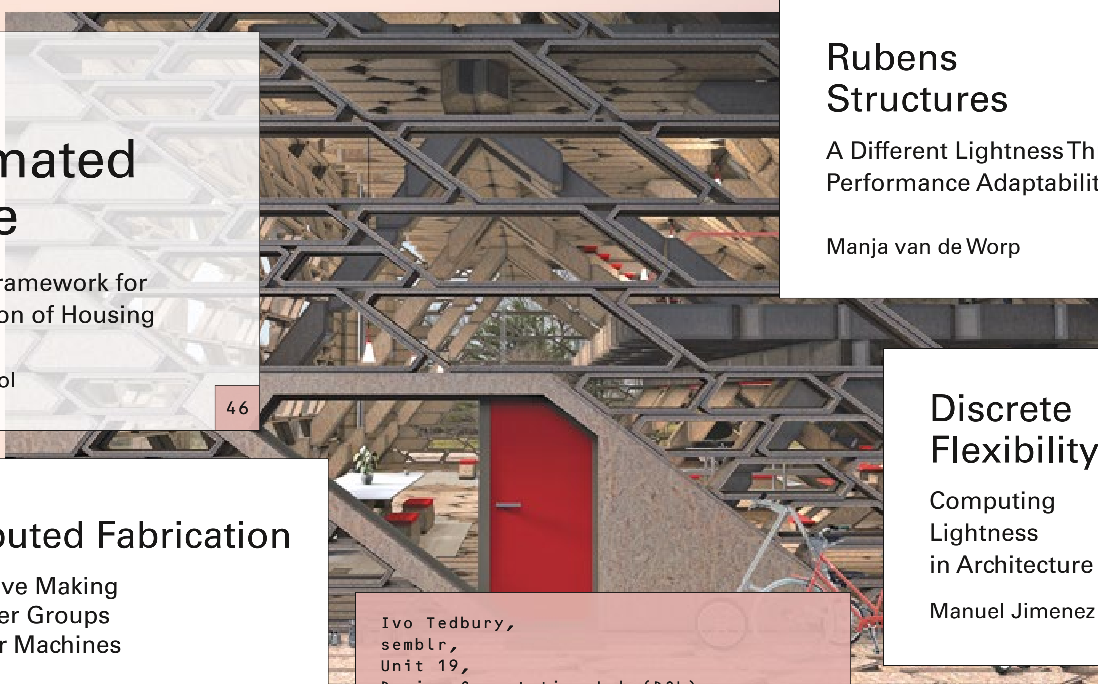
DISCRETE

REAPPRAISING THE DIGITAL IN ARCHITECTURE

ARCHITECTURAL DESIGN

March/April 2019
Profile No 258

Gilles Retsin Architecture, Tallinn Architecture Biennale Pavilion, Tallinn, Estonia, 2017



Ivo Tedbury, semblr, Unit 19, Design Computation Lab (DCL), Bartlett School of Architecture, University College London (UCL), London, 2017

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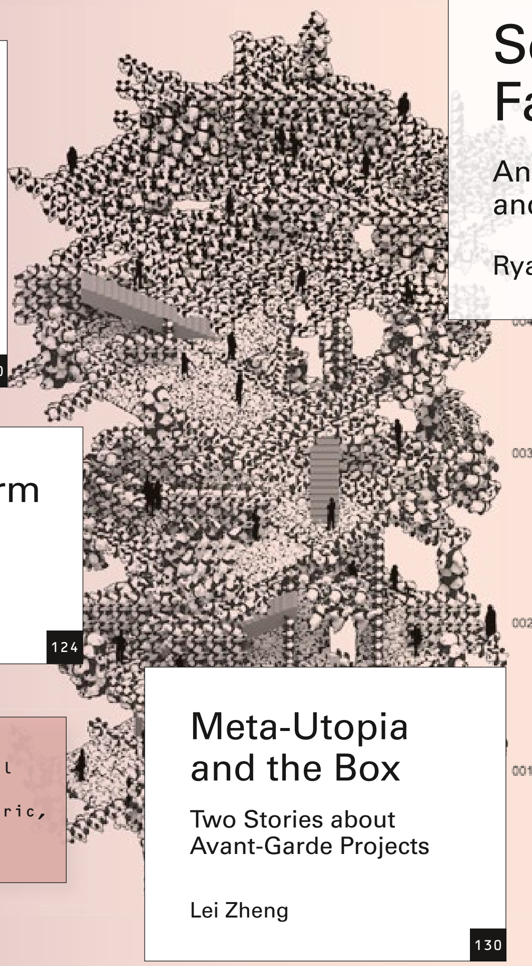
M Casey Rehm / Kinch, *Automatic Ginza*, '3-Ways' exhibition, A+D Museum, Los Angeles, California, 2018



Quirkd33 (Ryan Vincent Manning with Fabian Partoll and Alexander Gasser), Panda Hut: Exploded Isometric, Soft Discrete Familiars, 2018

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Inside front cover: Daniel Koehler, Martin Danigel, Jordi Vivaldi Piera and David Kienpointner, City in a Building, City as a Building and City as an Element of Architecture, University of Innsbruck, Austria, 2016–18. © Daniel Koehler and David Kienpointner

Page 1: EZCT Architecture & Design Research with Hatem Hamda and Marc Schoenauer, Studies on Optimization: Computational chair design using genetic algorithms, 2004. © Philippe Morel/EZCT Architecture & Design Research, photo Ilse Leenders

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ABOUT THE

GUEST-EDITOR

GILLES RETSIN

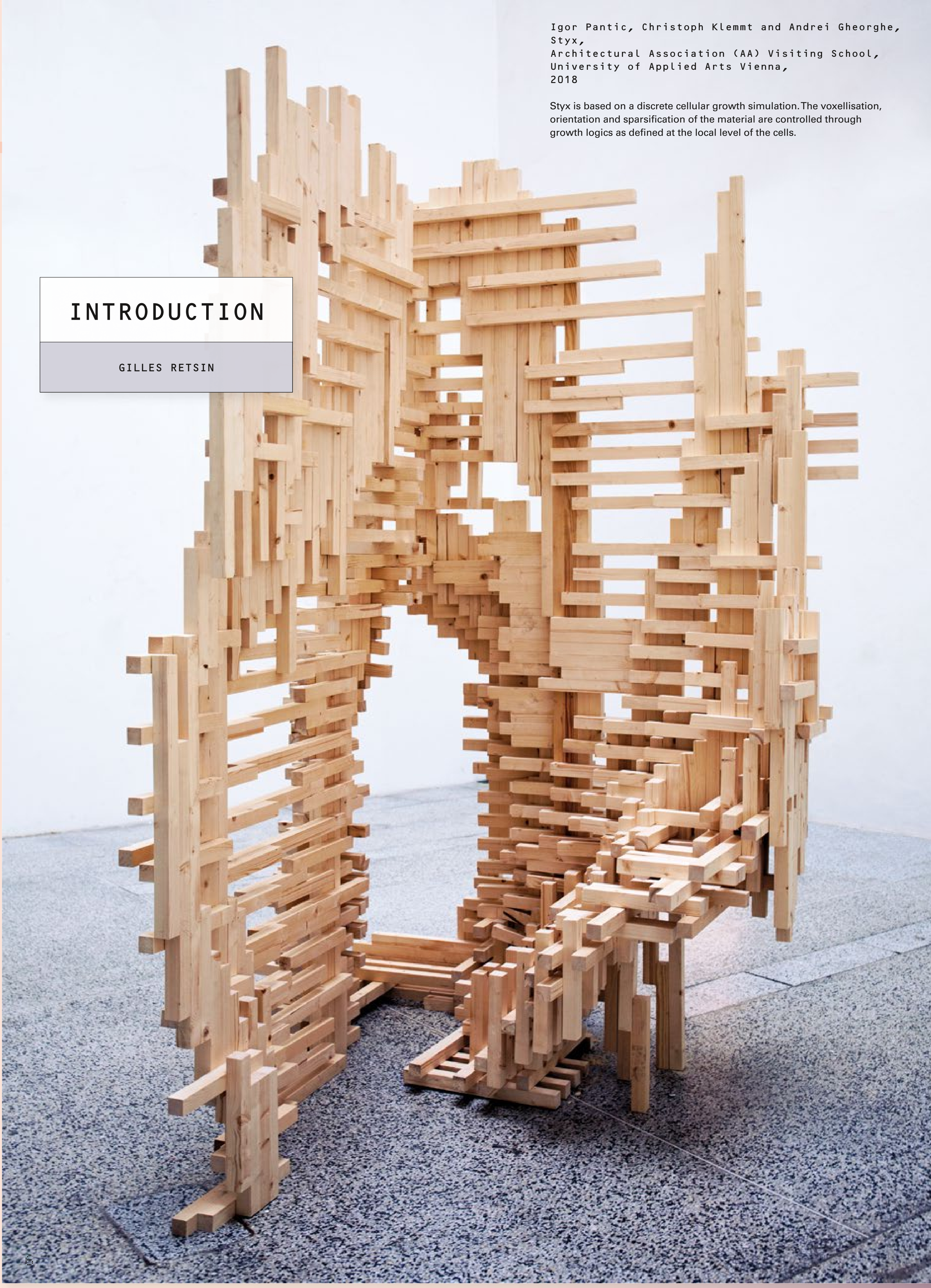
Originally from Bruges, Belgium, Gilles Retsin is an architect and designer living in London. He studied architecture in Belgium, Chile and the UK, where he graduated from the Architectural Association (AA) in London. Trained in Germany, Switzerland and the UK, his expertise in the newest digital design and fabrication technologies is combined with a deep interest in the core principles of architecture. His critical discourse reflects on the role of the digital in architecture while also speculating on automation, political issues and aesthetics.

He is a lecturer and Programme Director of the B-Pro MArch in Architectural Design at the Bartlett School of Architecture, University College London (UCL). He is also co-founder (with Mollie Claypool, Manuel Jimenez García and Vicente Soler) of the UCL Design Computation Lab, which develops robotic technologies, design strategies, software and new construction methods, and has also developed a provocative agenda on fully automated mass housing. The lab has become recognised through its design research and B-Pro Research Cluster 4 teaching agenda, which has focused on Discrete design methods, robotic assembly and large-scale 3D printing. Within the framework of the lab, Retsin has published and co-authored academic work on design methods and robotic fabrication.

In 2013 he founded his practice Gilles Retsin Architecture, which has mainly focused on cultural projects and small to large housing. He won the 2017 competition for the Tallinn Architecture Biennale Pavilion with his proposal for an abstract, Maison Dom-ino-like assembly. The practice has also received awards for its schemes such as the New National Museum in Budapest (2014), Community Centre in Liepāja, Latvia (with Isaïe Bloch, 2014) and Nuremberg Concert Hall (with Stephan Albrecht, 2018).

Retsin has developed a unique and recognisable aesthetic, while his projects are also invested in prefabrication, engineered timber construction and automation. Before founding his own practice, he worked as a project architect for Christian Kerez in Zurich, for example on the proposal for the Museum of Modern Art in Warsaw.

His work has been acquired by the Centre Pompidou in Paris, and he has exhibited internationally at, among others, the Museum of Art and Design in New York, the Vitra Design Museum in Weil-am-Rhein, Design Exchange Toronto and the Zaha Hadid Gallery in London. He has lectured and acted as a juror and guest critic at numerous universities and institutions worldwide. His work has also been published in academic journals and conference papers, and featured in mainstream media such as *Wired*, the BBC, *Fast Company* and *Mashable*.



Igor Pantic, Christoph Klemmt and Andrei Gheorghe,
Styx,
Architectural Association (AA) Visiting School,
University of Applied Arts Vienna,
2018

Styx is based on a discrete cellular growth simulation. The voxellisation, orientation and sparsification of the material are controlled through growth logics as defined at the local level of the cells.

INTRODUCTION

GILLES RETSIN

DISCRETE ARCHITECTURE IN THE AGE OF AUTOMATION

Why is the digital in architecture in need of a rewrite, as suggested by the title of the issue? The short answer is, of course, it should not be. Every other industry invests huge efforts into digitalisation and automation – as a matter of life or death in the 21st century. However, the past decade, following the 2008 financial crisis, has in fact seen a backlash against the digital in architecture. Following about two decades of optimistic and celebrated experimentation, the digital in architecture was suddenly understood to be affiliated with the troublesome neoliberalism that caused the crisis.[1] Post-2008, architects, institutions and curators evacuated themselves from the digital, finding refuge in a variety of new and neo trends and obsessions, ranging from austerity-chic to neo-postmodernism, from object-oriented ontology to the so-called post-digital.

The group of architects, educators and thinkers brought together in this issue of AD under the flag of the Discrete are equally critical of the paradigm of continuity and the last two decades of digital work. For them, the narrow focus of early digital architects on formal continuity, mass-customisation, style and craft is problematic and disconnected from the pressures of our current world. However, rather than merely rejecting the digital, this new discourse understands that architecture cannot just remain analogue in an increasingly digital world. Post-digital, image-, object- or affect-driven architectural culture seems indeed equally, if not even more so ill-equipped to face the impeding challenges. In fact, the architectural profession at large seems embroiled with neoliberal practices. In his book *Four Walls and a Roof* (2017), Dutch architect Reinier de Graaf successfully exposes the harsh reality, precarity and total lack of power of architects in late capitalism.[2] As Peggy Deamer points out, unpaid labour, an abusive culture of internships and a troubling gender gap seem to define the 21st-century economic reality of working in the architectural profession.[3] Struggling with its service-oriented economic model, defenceless against more powerful developers and market forces, many architects rightly see better futures in other industries such as tech, games, film or fashion.

Panagiota Spyropoulou, Hyein Lee, Pooja Gosavi and Pratiksha Renake, MickeyMatter robotically assembled chair, B-Pro Research Cluster 4, Bartlett School of Architecture, University College London (UCL), 2016

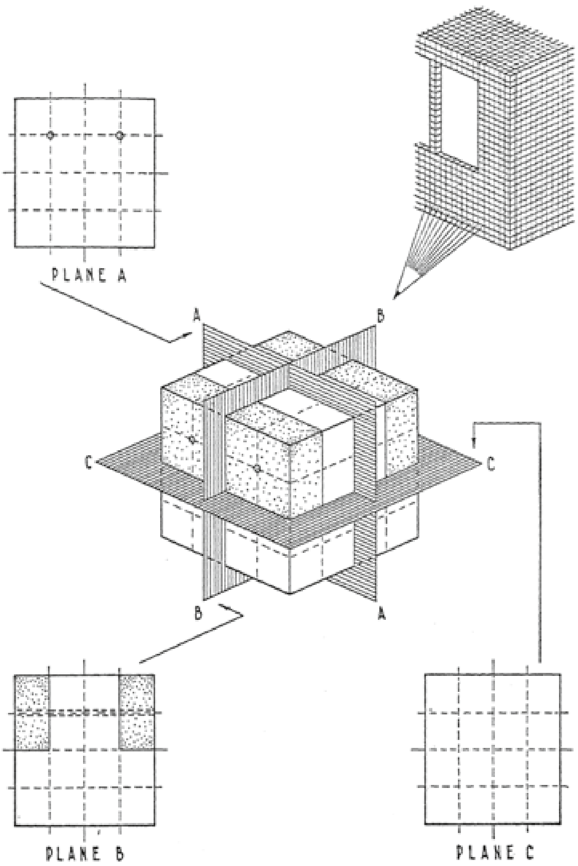
Robotic assembly is most efficient when using repeating, serialised elements. MickeyMatter looks into the use of a spherical, rounded element that allows for a certain tolerance during the assembly process. Although making use of serialisation, the chair demonstrates a substantial amount of differentiation in the organisation of the elements.

Computational Parts

Set within this post-2008 context, defined by a crisis of late capitalism, the Discrete is an emerging body of work that seeks to redefine the entire production chain of architecture by accelerating the notion of discreteness in both computation and the physical assembly of buildings. It asserts that a digital form of assembly, based on parts that are as accessible and versatile as digital data, offers the greatest promise for a complex yet scalable open-ended and distributed architecture. Moreover, it situates itself in the pragmatic and immediate real, realising that the digital is already ubiquitous and part of the everyday. As seems to be a tradition of most architectural tendencies or movements, the term 'Discrete' is perhaps not the most appropriate denomination to be able to cover the content. 'Discreteness' is a notion that comes from the sciences, referring to what is individual and separate. It is the opposite of the continuous, that which is uninterrupted and seamless. In architecture, it is traditionally through the notion of 'part-to-whole' relations, what contributor Daniel Koehler refers to as 'mereology',[4] that a discussion about continuity and discreteness enters the discipline. These part-to-whole relations can be continuous, as is the case in a concrete shell, or they can be discrete, as in a timber log cabin.

Another simple analogy is that mortar is continuous, whereas bricks are discrete. However, the term came most prominently to the forefront in architecture through computation. Computation operates essentially with discrete data, whereas the analogue operates with continuous data. As Mario Carpo points out, the past two decades of spline-driven design explorations, focused on continuity, were essentially not using computers in a computational way.[5] The notion of a computational discrete is, however, not new, but in fact precedes the last two decades of continuity. 'Coding the World', a 2018 exhibition at the Centre Pompidou in Paris, showed a large history of computational – and therefore Discrete – work in architecture, art and design since the 1950s.

More recently, discrete design techniques and algorithms have also been used by architects working intensively with computation, which Carpo refers to as the 'second digital turn'.[6] And it is probably here that the shift towards the agenda advocated in this AD is most clearly observed. The contributors to the issue are not interested in discreteness as merely another computational process, but see it as crucial in terms of a production chain and its social implications. For this emerging generation, discreteness cannot be representational; to be effective it needs to have physical, material and economic properties as well.



Alfred Farwell Bemis,
The total matrix of the house, Cambridge, USA,
1936

In 1936, the Massachusetts Institute of Technology (MIT) published Bemis's *The Evolving House*, a book that introduced 'rational design' for prefabricated housing construction. Combined with an ambitious, in-depth economic study of the production of housing, he suggested a radical overhaul of construction, based on pixel-like cubical modules.

Dafni Katrakalidi, Martha Masli,
Mengyu Huang, Man Nguyen and Wenji Zhang,
AssemblerAssemble,
B-Pro Research Cluster 4,
Bartlett School of Architecture,
University College London (UCL),
2018

AssemblerAssemble proposes a relative robot that has the same geometry as the elements it assembles. This 1:1 prototype shows elements made out of cheap oriented strand board, which are then connected with steel joints.

This thus represents a shift from Carpo's digital turn, which is invested in exploring heterogeneity and extreme resolution, to one focused on an economy of reality. The Discrete is willing to trade a few degrees of resolution, formal differentiation and 'excitement' for scalability, impact and agency, for example, to rethink the production of housing. It is also willing to trade elegant but academic material optimisation for large amounts of cheap materials if that will increase access and efficiency. It is not afraid of seriality, long straight lines, bulky elements, unfinished forms, raw materials – or even boxes, the old enemy of both Postmodernism and the digital. If it is about the relations between parts (the deep structure or quality) then the amount of parts (the mere quantity) does not necessarily matter. The Digital Discrete is not the only tendency today experimenting with the basic building blocks or rules of architecture. Since the project of continuity has run out of steam, there seems to be a more general interest in fundamentals. Rem Koolhaas proposed an extreme discretisation of architecture at the Venice Architecture Biennale in 2014, with doors, windows and escalators as elementary particles, but practices such as Ensamble Studio, Christian Kerez or Sou Fujimoto also show a keen interest in researching the fundamental building blocks of architecture.

Sou Fujimoto Architects,
Serpentine Gallery Pavilion,
London,
2013

This study model for the Serpentine Gallery looks at the three-dimensional organisation of a gridded space. It suggests a completely organic, cave-like space without any notion of traditional architectural parts or elements; although phenomenologically continuous, it remains assembled and aggregated.

Ensamble Studio,
Cyclopean House,
Brooklyn, New York,
2015

Architects such as Ensamble Studio design through rethinking the production of architecture itself. The Cyclopean House was prefabricated in Madrid and consists of lightweight foam-aluminium composite beams that can be quickly assembled. It shows an affordable model of construction that has great potential to be automated and scaled.

Moving On From Craft

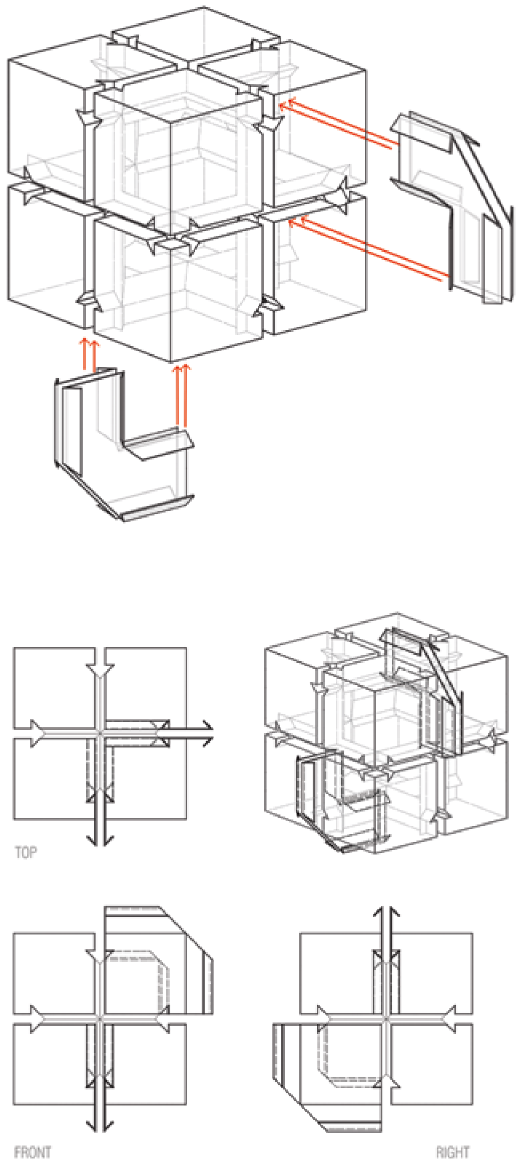
With the omnipresence and ubiquity of digital media, the Discrete is interested in the economy of reality. Similar, in fact, to the post-digital, it understands that the digital is a given, a normal part of the texture of the everyday that urgently and immediately needs to be mobilised in architecture if it wants to escape its current precarity as a relevant cultural force in society. Operating under the regime of continuity and variability, the past two decades of research into digital fabrication have never positioned themselves in respect to scalability. Digital fabrication entered the discourse under the framing of a neo-medieval 'digital craft' – the art of making beautiful and unique things, lost in industrial mass-production, but newly made accessible by digital machines.[7] The immediate implication of digital craft is the culture of the artisan, innocent, small-scale folk practice. Not dissimilar to the early digital, the 19th-century Arts and Crafts movement also advocated a return to craft. The likes of William Morris and John Ruskin mourned the loss of ornament, patina and texture while at the same time radically failing to understand the ability of industrial mass-production and standardisation to bring quality housing and radical new architecture to the masses, as Modernism did.

In this sense, a comparison can be made with Modernism – which in fact many of the authors in this issue are not shy of, some referring to the Discrete as 'a positive departure' from it,[8] or what Emmanuelle Chiaponne-Piriou calls an 'accelerated structuralism (pp 78–85). Not unlike Modernism, in respect to mechanisation, the Discrete wonders if we can find both a social and artistic project in the cold, efficient contemporary reality of automation, mass-production and digital production that defines our society. However, as Philippe Morel argues (pp 14–21), the science underlying the Discrete is not Modernist, but computational. The notion of the part in the Digital Discrete is therefore radically different from that of the prefabricated elements of Modernism – the categories of universal types, optimised for a specific use. Instead, the architectural part becomes a generic particle, a versatile, data-like building block. In short, the Discrete ambitiously seeks to use the digital to redefine the entire production chain of architecture, not in a hyperbolic future, but in the immediate, pragmatic now. This ambition requires more than an engagement with the mere surface and image of architecture; rather, it demands an in-depth endeavour with the bones of architecture, its elementary particles.

Daniel Koehler, Rasa Navasaityte, Junyi Bai, Anna Galika and Qiuru Pu, Mereologies – Project Blockerties, Large City Architecture, B-Pro Research Cluster 17, Bartlett School of Architecture, University College London (UCL), 2018

Blockerties 'hacks' the economic logic of blockchain ledgers to organise patterns of private and shared spaces. The project demonstrates not only an interest in part-relations, but also opens up discussions about the digital economy and the housing question.

The Discrete ambitiously seeks to use the digital to redefine the entire production chain of architecture



A Discrete Paradigm for Design and Production

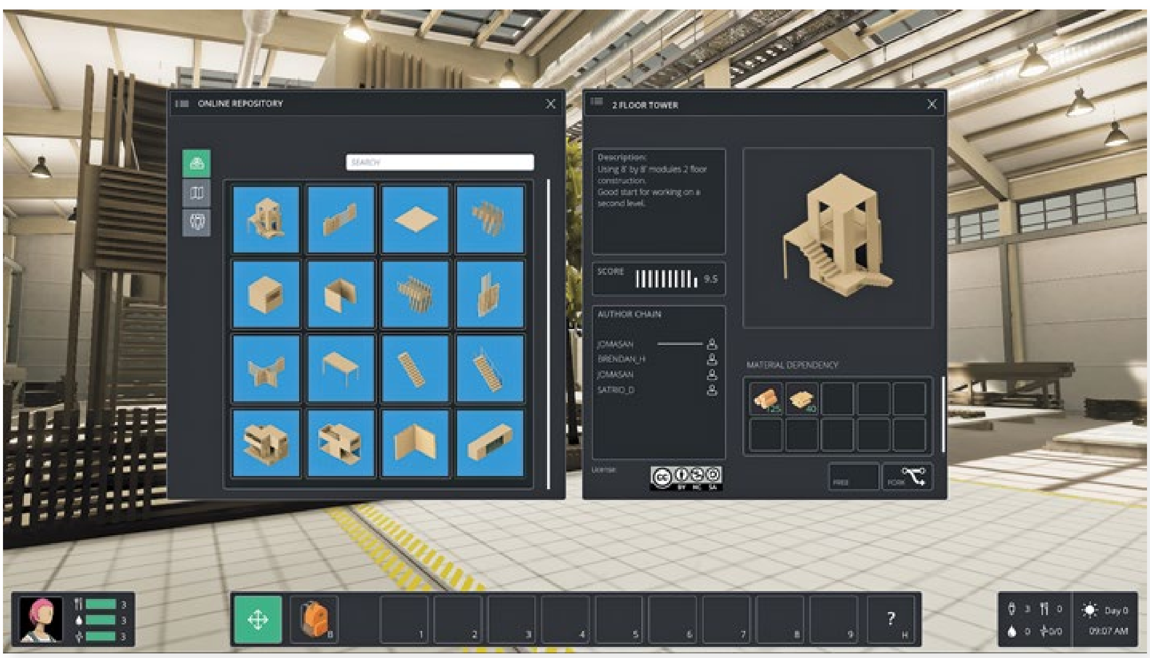
At the origins of the Digital Discrete, Morel and his practice EZCT are rethinking digital production beyond mass-customisation and variability, as a system of discrete production intrinsically linked to computation. Most exemplary of this approach is their Universal House (2012) proposal based on pixel-like, generic building elements. Jose Sanchez (pp 22–9) connects this notion of the discrete building block to an explicit social dimension and position on the democratisation of both design and production, laying the cornerstone for the aforementioned generational shift in attitude towards the digital. Criticising the parametric jigsaw puzzle, Sanchez advocates the discrete part as a scalable and accessible technology. At a perhaps more architectural level, Daniel Koehler (pp 30–37) works on a mereological framework. In his work, computation shifts from a process external to architecture, to architecture itself. His research further reinforces the understanding of parthood conditions in the Discrete – that of parts that exist independent of the whole.

Philippe Morel/EZCT Architecture & Design,
Universal House,
2012

left: Morel's project for a Universal House proposes modular, pixel-like discrete elements that can be slotted together with joints. It introduces parts that no longer have any relation to the whole, nor any predefined meaning or function.

Jose Sanchez,
Screenshot of Common'hood marketplace,
2018

below: In the computer game Common'hood, users are able to set up a digital production chain to build housing. The game is based on notions of Discrete design and production while also engaging a social agenda about housing and democratisation of production through digital fabrication.

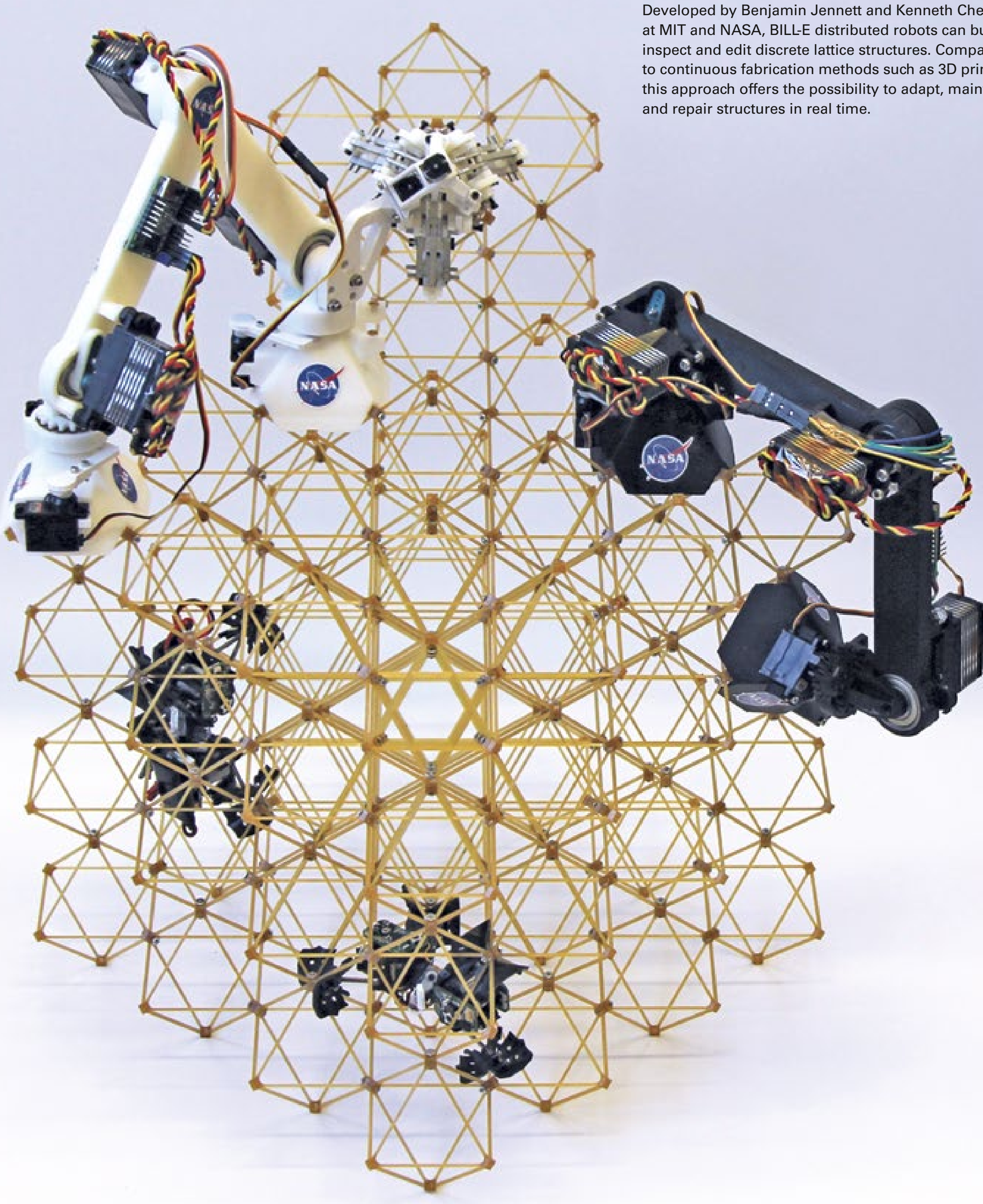


Nathan Melenbrink and Justin Werfel,
Robotic Ecosystem,
Wyss Institute,
Harvard University,
Cambridge, Massachusetts,
2018

A swarm of robots coordinates using only local environmental cues to collectively build a network of erosion barriers as a scheme for adaptive coastal protection. The robots make use of serialised materials that can be organised into site-specific structures.

MIT Center for Bits and Atoms
and NASA Ames Research Center,
BILL-E robotic platform,
2017

Developed by Benjamin Jennett and Kenneth Cheung at MIT and NASA, BILL-E distributed robots can build, inspect and edit discrete lattice structures. Compared to continuous fabrication methods such as 3D printing, this approach offers the possibility to adapt, maintain and repair structures in real time.



Similar to post-capitalist thinker Paul Mason, the Discrete looks at the digital as a post-capitalist technology that has the fundamental ability to democratise and decentralise production.[9] This position is further articulated in my own work (pp 38–45), which focuses on the necessity of a discrete syntax, both as the key to automation and as a radical architectural quality. Mollie Claypool (pp 46–53) further articulates a political stance on automation and discreteness, explicitly referencing accelerationist and xenofeminist thinkers in describing a digital framework for mass-housing and domesticity.

Maria Yablonina and Achim Menges (pp 62–9) offer an insight into the world of discrete, distributed robots, an approach that resonates with the work of Justin Werfel and Nathan Melenbrink at the Wyss Institute for Biologically Inspired Engineering at Harvard University. Similarly, researchers at MIT's Center for Bits and Atoms and NASA have developed a platform for distributed robots for assembly[10] and inspection[11] of discrete lattice structures,[12] which are currently being investigated for building large-space structures.[13] This approach is argued to be more efficient than continuous methods such as 3D printing.

Engineer Manja van de Worp (pp 54–61) suggests how the granular assemblies of the Discrete challenge the traditional understanding of structural design. Manuel Jimenez García (pp 70–77) connects the Discrete to an interest in material behaviour, inflatables and flexibility situated in a history of rapidly deployable structures, and Emmanuelle Chiappone-Piriou (pp 78–85) writes up a prospective history of the Discrete, through the changing notion of the part in recent architectural history, from elements to units, cells and eventually unassigned bits of data. She situates the Digital Discrete as a continuation of the work of digital mavericks like Nicholas Negroponte and John Frazer, but also roots it further back to 20th-century Modernism.

Mario Carpo (pp 86–93) identifies remarkable similarities between the young computational architects in this issue and the architecture of Kengo Kuma, which is also based on an interest in architectural qualities of the open-ended, the blurry, the non-figural and aggregational. Computational design processes based on continuity were often intrinsically referential, with an indexical relation to natural algorithms. The shift to more implicit rules in the Discrete can be seen in the work of M Casey Rehm (pp 94–101) and Immanuel Koh (pp 102–9). What constitutes an architectural whole is redefined and is no longer a product of parametric causality, linearly derived from a series of inputs. Architecture emerges from abstract part–part relations, to the extreme discretisation of statistical pixel values. Ryan Vincent Manning (pp 118–23) and Viola Ago (pp 110–17) explore an unapologetic aesthetic interest in seriality and repetition – one based on stuffed animals and the other on lines. Their work indicates that the Discrete is not stylistic or homogeneous. Marrikka Trotter (pp 124–9) explores the limits of the notion of scale with a debate about a more philosophical approach to discreteness. Lei Zheng (pp 130–35) addresses the utopian character of this issue of AD, questioning the limits of its supposed pragmatism. She critically reflects on scalability and confronts the Discrete with the notion of the simple box as the ultimate efficient and scalable device.

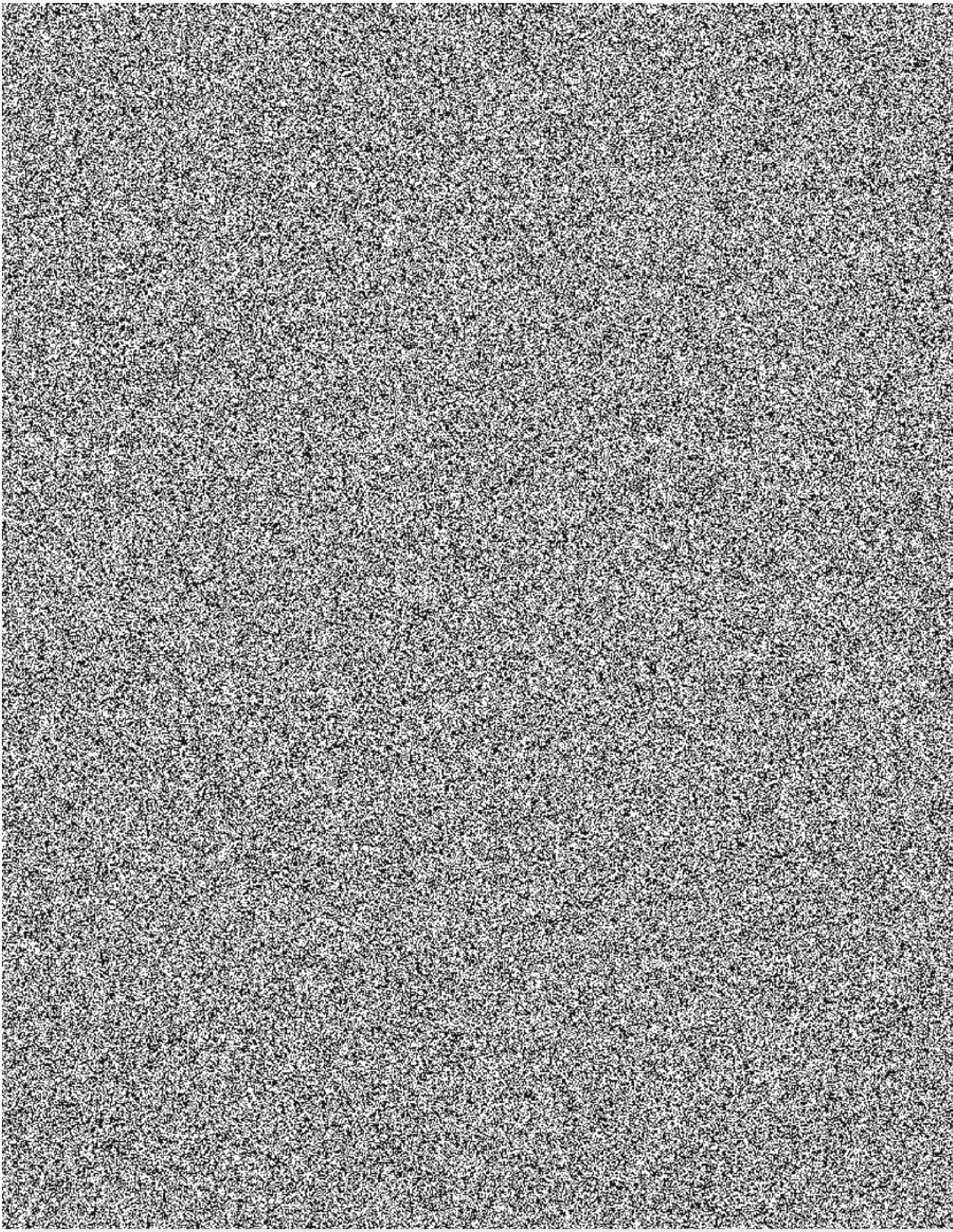
Reappraising the digital in architecture therefore ultimately means reappraising architecture

A New Platform

This AD explores a vast spectrum of topics, from design experiments to urban models, tectonics, aesthetics, robotics, material organisations and economic scenarios. Through research into automation and housing, the digital is no longer just about formal sophistication, but also its potential social impact. Breaking away from mere form and complacent style, it starts to map out and identify a territory of the digital that remains fundamentally devoted to design and research, but is also able to engage with conversations about the social, political, cultural and economic consequences. In doing so it tries to establish a new platform for the digital in architecture, enabling accessibility, distribution, efficiency and scalability. Reappraising the digital in architecture therefore ultimately means reappraising architecture itself as a driving cultural force in the 21st century. AD

Notes

1. Matthew Poole and Manuel Shvartzberg, *The Politics of Parametricism*, Bloomsbury (London), 2015, p 19.
2. Reinier De Graaf, *Four Walls and a Roof: The Complex Nature of a Simple Profession*, Harvard University Press (Cambridge, MA), 2017, pp 5–15.
3. Peggy Deamer, Preface, *The Architect as Worker*, Bloomsbury (London), 2015, p xxvii.
4. Daniel Koehler, *The Mereological City: A Reading of the Works of Ludwig Hilberseimer*, Transcript Verlag (Bielefeld), 2016, pp 8–15.
5. Mario Carpo, 'Breaking the Curve: Big Data and Design', *Artforum*, February 2014; www.artforum.com/print/201402/breaking-the-curve-big-data-and-design-45013, and Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*, MIT Press (Cambridge, MA), 2017.
6. *Ibid*.
7. Mario Carpo, *The Alphabet and the Algorithm*, MIT Press (Cambridge, MA), 2011, p 44.
8. Daniel Koehler, *op cit*.
9. Paul Mason, *Post Capitalism: A Guide to Our Future*, Allen Lane (London), 2015, pp 164–76.
10. Benjamin Jenett and Kenneth Cheung, 'BILL-E: Robotic Platform for Locomotion and Manipulation of Lightweight Space Structures', in *25th AIAA/AHS Adaptive Structures Conference*, Grapevine, Texas, January 2017.
11. Benjamin Jenett and Daniel Cellucci, 'A Mobile Robot for Locomotion Through a 3D Periodic Lattice Environment', in *Proceedings of the IEEE International Conference on Robotics and Automation*, Singapore, May/June 2017.
12. Christine E Gregg, Joseph H Kim and Kenneth C Cheung, 'Ultra-Light and Scalable Composite Lattice Materials', *Advanced Engineering Materials*, 20 (9), 2018, p 1.
13. https://gameon.nasa.gov/projects/automated-reconfigurable-mission-adaptive-digital-assembly-systems-armadas/.

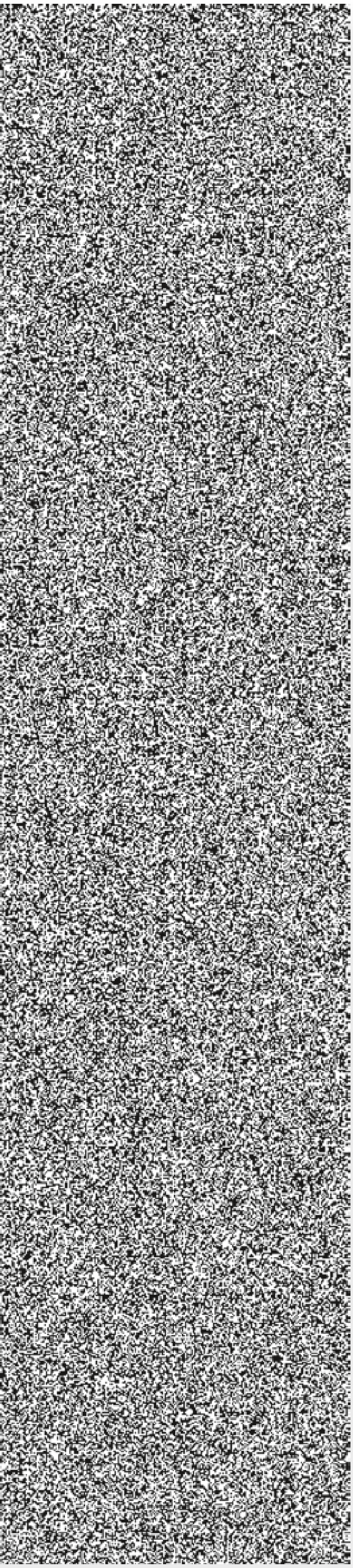


Philippe Morel

The Origins of Discretism

Thinking Unthinkable Architecture

What most differentiates the Discrete from previous architectural paradigms? Architect and theorist **Philippe Morel**, who co-founded Paris office EZCT Architecture & Design Research, examines related evolutions in theory and practice. The key, as he sees it, is a break away from anthropomorphism and rationalism, resulting in a truly computational architecture that is free from human-imposed parameters.



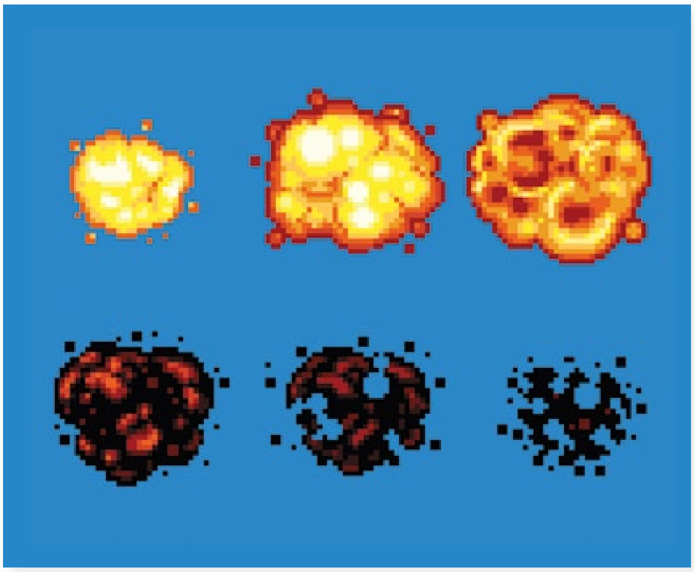
Philippe Morel,
Quantum Gray,
2014

Design experiments generated with a true random number generator (based on quantum physics), directed against the usual concepts of order and composition. The aim is to reach an architecture that is neither geometrical nor even based on other usual aesthetics of the informal. The current world based on strong inequalities should be looking for 'perfect inequality' rather than for a false and unachievable equality.

Just as there are odors that dogs can smell and we cannot, … why then … does the remark, 'Perhaps there are thoughts we cannot think,' surprise you? Evolution, so far, may possibly have blocked us from being able to think in some directions; there could be unthinkable thoughts.

— Richard W Hamming, 1980[1]

Such a title might imply a desire to establish a genealogy of 'Discretism'. Yet it is not so, as this work has already been established or undertaken in the history of science and technology or in the history and theory of architecture.[2] Indeed, the focus of this article is not the origin of an aesthetics – that of pixels and voxels, or that relating to discretisation in general – but simply computation's annexation of all aspects of everyday life, including architecture. Such a takeover is at the origin of 'computationalism': a new way of seeing the world, a new global (artificial) mindset as well as the endpoint of 600 years of rationalism. Paraphrasing Kevin Kelly, for whom 'to demand that artificial intelligence be humanlike is the same flawed logic as demanding that artificial flying be birdlike, with flapping wings',[3] the question of architecture beyond any mimesis (including biomimicry) and beyond humanly thinkable thoughts and aesthetics now needs to be addressed.

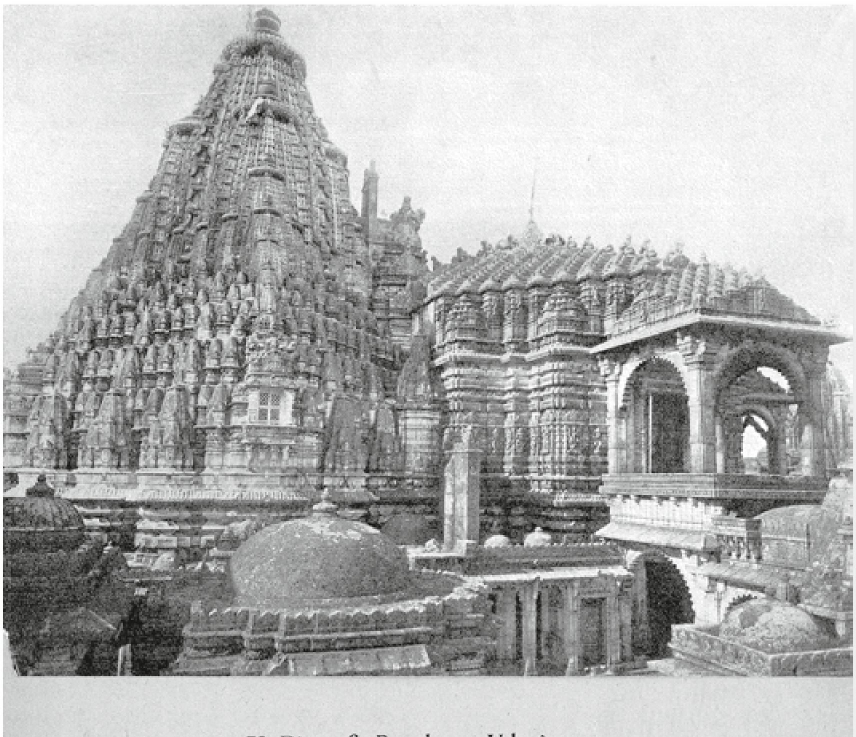


Video game explosion animation

Computer graphics not only defined a new visual culture, but also new fields of knowledge in applied mathematics (as digital geometry) that precisely deal with discrete maths problems. What matters is that all discrete maths animations as this one in a video game are not representations; they always are fully-fledged simulations (therefore computations).

In Search of Foundations

Determining the exact origin of Discretism, defined here as a mere recognition of the unreasonable effectiveness of the computer in science, is not essential.[4] For Jean-Jacques Rousseau, returning to the origin was only an analytical tool, the natural state being one that 'perhaps never existed, which probably never will exist, and yet one that we need to understand in order to judge our current state properly'.[5] Similarly Leon Battista Alberti refused the specious debates concerning origins – 'Let's leave aside the debate of philosophers who seek the ultimate origin of colors[6] to focus instead on the rules of architecture[7] and the need to acquire positive knowledge', and 'We must constantly strive … to acquire science, by seeking the frequentation of men and things that make it possible to return home more scholarly'.[8] Evoking the origins of Discretism requires acknowledgement that discretisation has become essential in all scientific fields, leading to a phenomenology of discreteness that is only the manifestation of the primacy of the non-human superintelligence currently under construction.[9]


72. Die große Pagode von Udepûr

Great Pagoda of Udaipur,
Rajasthan,
India,
17th century

The Great Pagoda of Udaipur reveals the diversity of architectural traditions. Western architecture is deeply associated with the metaphysics of geometry, the dominance of which before the advent of the computer can hardly be denied. On the contrary, non-Western architectural culture, in which discrete entities were more common, shows us that forms can be based on fields of mathematics for which classical geometrical continuity is not the most important aspect. Illustration from Bruno Taut, *Die Stadtkrone*, Eugen Diederichs Verlag (Jena), 1919.

Let us at least acknowledge that our whole scientific era – modern then postmodern – was built on the primacy of the notion of foundation. If we give foundation a philosophical meaning, it acquires a metaphysical nature; if we are content to give it a scientific meaning, then it acquires a mathematical and physical status. These foundations are axioms or 'laws' that are grouped together in the form of theories. In each epoch of great social and technical transformation, the development of new foundations and new theories generally occurs without the latter coming systematically before or after the phenomena they are supposed to describe. As for the most revolutionary technology of the 20th century – the computer – it is not possible to separate theory and practice, as expressed by the title of one of the most important scientific events of the last century, the lecture series entitled 'Theory and Techniques for Design of Electronic Digital Computers' held from 8 July to 31 August 1946 at the Moore School of Electrical Engineering at the University of Pennsylvania.[10]

The 19th century is often seen as the golden age of classification that Google ended,[11] but behind classification lay a hidden search for foundation. Philosophers, biologists, chemists, physicists and more obviously mathematicians pushed to the extreme a Renaissance-inspired paradigm of scholarly rigour, seeking the foundations of almost everything not sufficiently theorised. Evidence of this can be found in the non-Euclidean geometry, logic, analysis, biology, engineering, painting or philosophy of the time, and in numerous titles of works ranging from Antoine Augustin Cournot's *The Origin and the Limits of the Correspondence Between Algebra and Geometry* (1847)[12] to Andrey Kolmogorov's *Foundations of the Theory of Probability* (1933)[13] to name a few.

This unbridled search for secure foundations of human knowledge would find its climax in the 1930s, on the one hand with the publication in 1936 of Alan Turing's 'On Computable Numbers, with an Application to the *Entscheidungsproblem*',[14] which in a rather ironic way does not make reference in its title to this same foundational problematic, and on the other hand with Kurt Gödel's work on formally undecidable propositions,[15] which put an end to an ultimate axiomatic 'dream' of everlasting foundations inherited from Gottlob Frege and David Hilbert,[16] a dream later described by Jean-Yves Girard as 'transparentist'.[17] Transparenticism is also well illustrated by the purist painting of Le Corbusier, whose Maison Dom-ino (1914–15) is the Turing machine of architecture, but also, with similar philosophical aims, within Elementarism and Suprematism. Regardless of the false failure of absolute reductionism, a 'failure' supposed to derive from Gödel's 'negative' results in logic and computability theory, far from preventing science from accurately describing reality, in practice these outcomes helped to increase the power of all our scientific tools. Associated with advances in mathematics, theoretical and practical breakthroughs in physics have given computers new status since the mid-1940s. Indeed, to be able to run rigorous computations (with quantified and controlled error rates) with a precision adjusted to the bits of information that can easily be added to represent ever larger numbers, is a quite dizzying step in the history of science and technology, which are now inseparable.

Although we know that we cannot demonstrate everything in mathematics and that we must be content with approximate solutions to certain physical problems, in practice our progress is immense. In 1936, the same year that German philosopher and founder of phenomenology Edmund Husserl, in *The Origin of Geometry*,[18] addressed the difficult relation between the world and our perception and knowledge of it from the point of view of human experience, Turing described in his article an entirely abstract machine that would explode all human perception of the world and all comprehension in a classical sense. From that day on, human beings would no longer converse with geometric objects – forms still present little more than 20 years ago with Gregg Lynn's work, in the Husserlian tradition where 'rather than violating the inadequate stasis of exact geometries, writing in architecture must begin with an adequate description of amorphous matter through "anexact yet rigorous" geometries'.[19] Now it is computers that talk to other computers via petabytes of discrete data over which we have no more hold. We have now entered an era in which the calculations made or realised by all humanity accumulated over millions of years to predict the evolution of a natural phenomenon are operated in a fraction of a second thanks to generalised discretisation. The essential elements at the heart of all modern science – comprehension of the laws of causality and the extraordinary mathematical complexity of this – seem henceforth to escape even the brightest scientists' minds in favour of the raw power of the most abstract machines ever produced: CPUs (or GPUs, NPUs, etc).

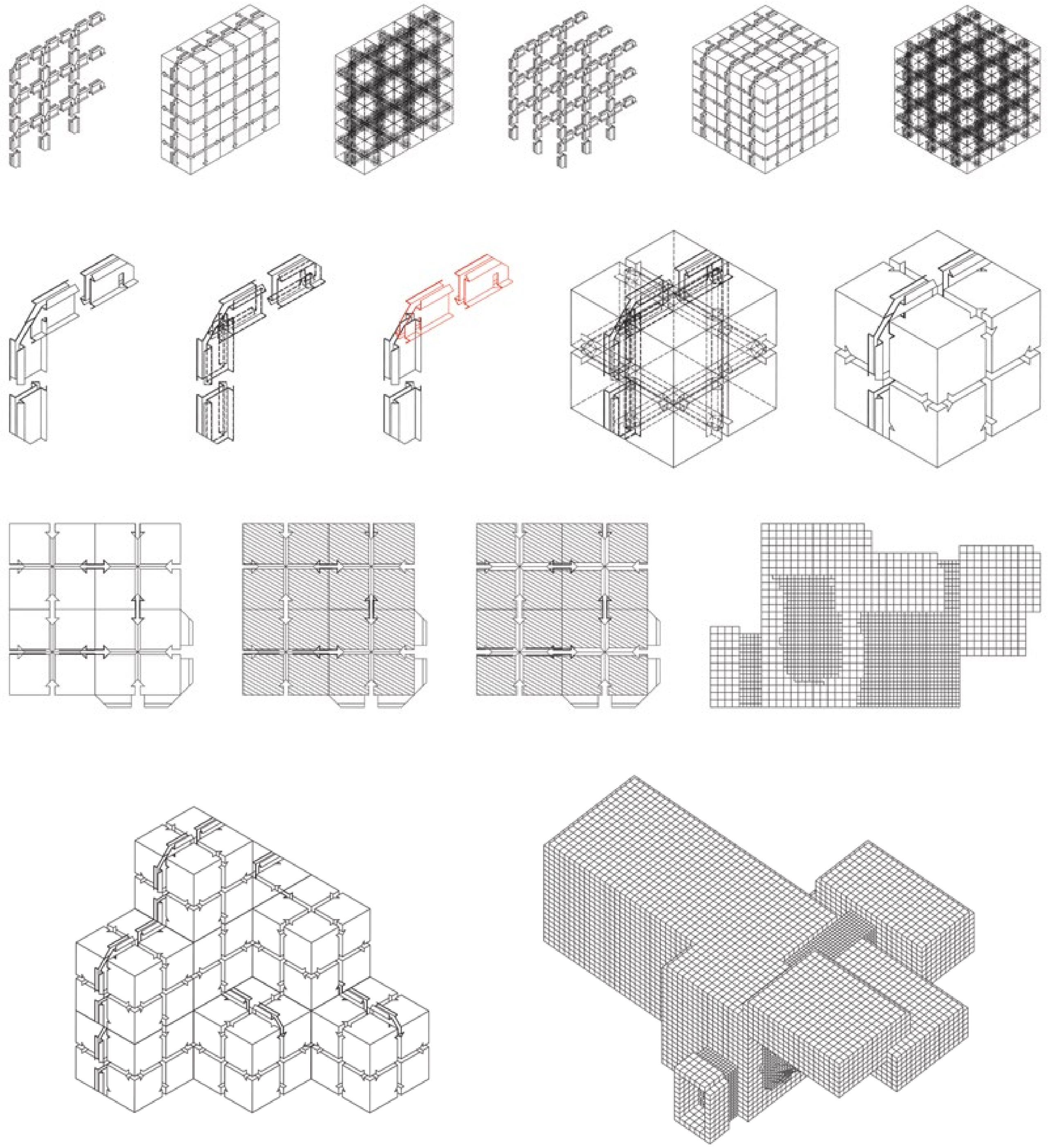
The Supremacy of Effectiveness

Beyond the question of style, as theorised, for example, by Patrik Schumacher with Parametricism,[20] what the origins of Discretism refer to is a set of theoretical and practical advances, logical and physical, in pure and applied mathematics (including the invention of the finite elements method) that have brought humanity into the era of effectiveness. As philosopher of science Paul Humphreys

This image can be viewed in the print edition of the issue

Invader,
Rubik Origine,
2006

The Origin of the World as seen by artist Invader, part of the 'Rubikcubism' series he produced to explore the link between pixels and mosaics, simultaneously paying tribute to the greatest artworks of all time, in this instance Gustave Courbet's *L'Origine du monde* (1866). This piece exemplifies how our relationship to the world, the phenomenology of which is now based on discrete entities, is merely a matter of resolution. The finer the resolution, the closer is our relation to object and truth. Cubes on panel, 66 x 82.5 x 5.5 cm.



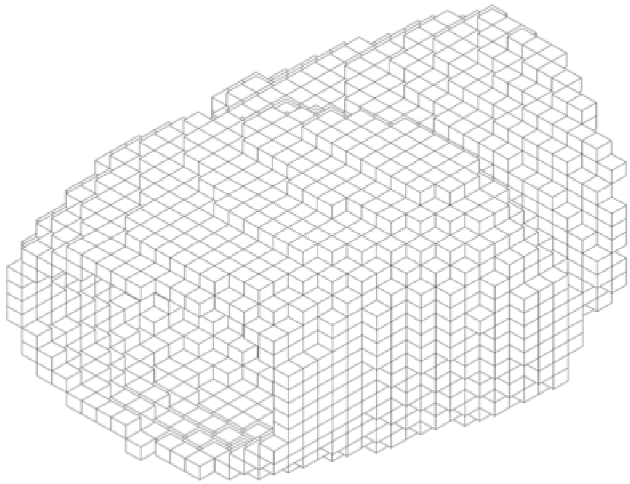
Many of today's architects suggest that the introduction of the computer has modified architecture only marginally, as upcoming artificial intelligence would also do.

Philippe Morel/EZCT Architecture & Design,
Universal House,
2009

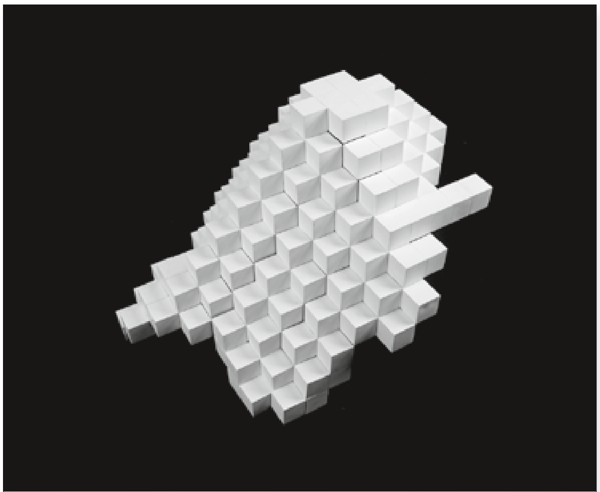
The Universal House is based on a fully integrated building system made of self-interlocking discrete blocks that can be plugged in any direction, as for the cladding panels.

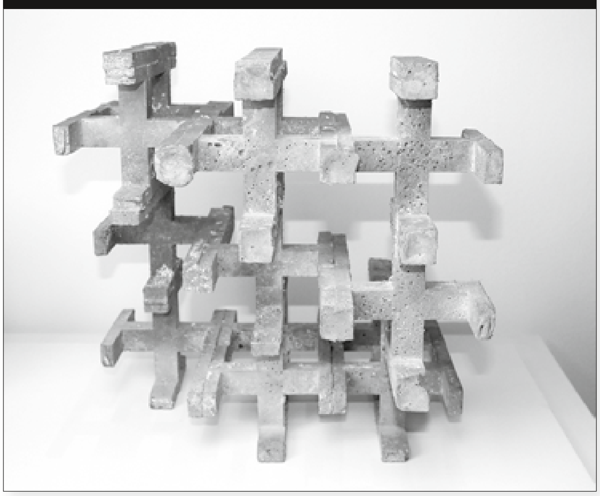
EZCT Architecture & Design Research,
FRAC Centre Pavilion Design competition entry, 2012

The unbuilt pavilion, intended for the ArchiLab 2013 exhibition 'Naturalising Architecture' at FRAC in Orléans, France, makes use of EZCT's U-Cube universal building components that can be plugged in any direction while blocking all degrees of freedom to create rigid assemblages.



Conceptual model (material: synthetic plaster) of a discrete plane in response to the FRAC pavilion competition. Contrary to standard continuous planes, discrete planes are based on the general properties of Digital Geometry (itself based on the sole use of discrete sets).



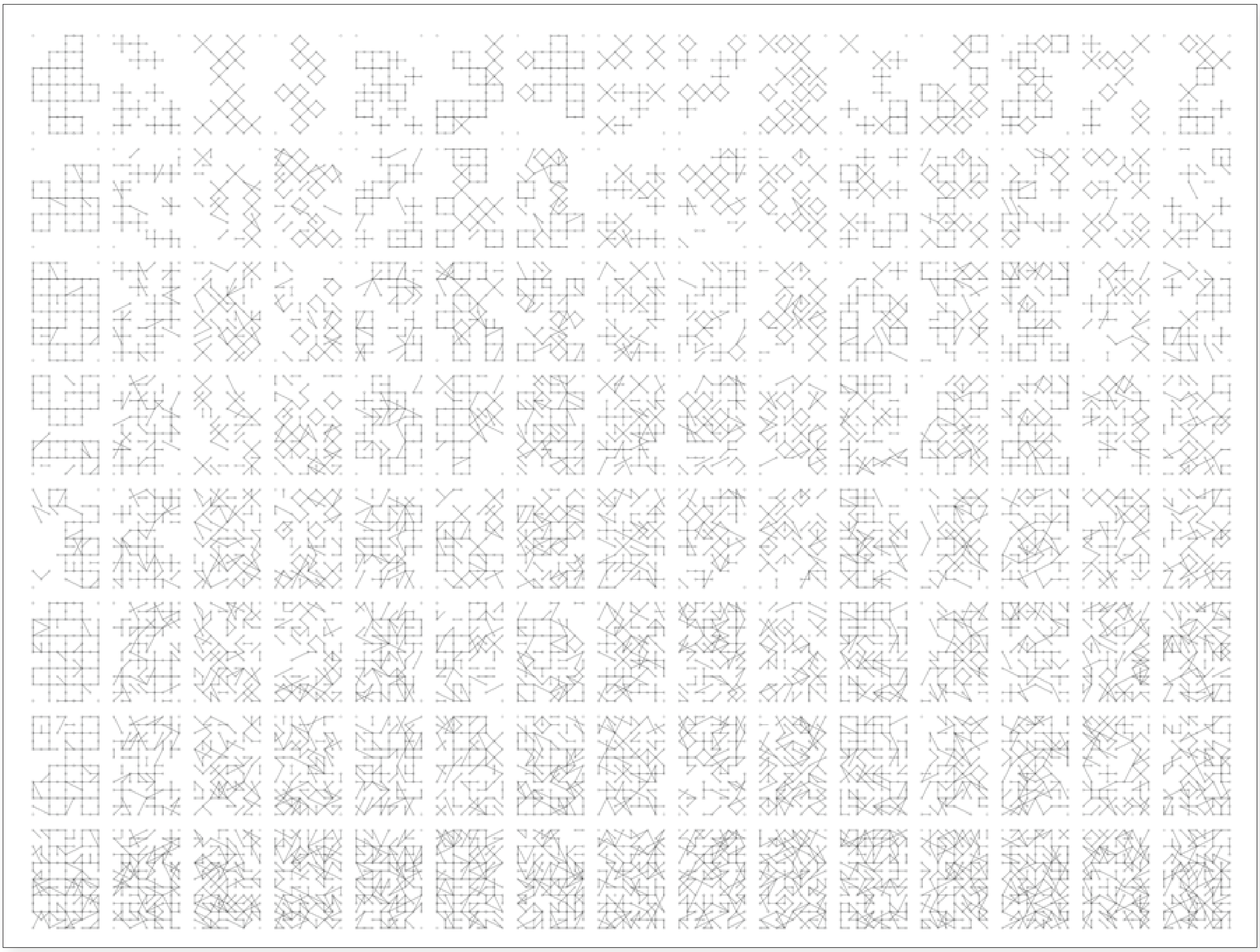


Three-dimensional structural mesh made by pouring ultra-high-performance fibre-reinforced concrete into U-Cube building components.

reminds us,[21] what is important now are the quantitative origins of qualitative change we are currently experiencing. As humans who invented logics, algebra and arithmetic, we are prisoners of an anthropocentric vision. We mistakenly think that calculations made by machines are like our own. We most often evaluate what is produced by computers, including architecture, according to criteria defined by what we knew and could do before. As Marcel Duchamp once supposedly said of Andy Warhol: 'When someone decides to put fifty boxes of Campbell's soup on a canvas, it's not the optical point of view that preoccupies us. What interests us is the concept that puts fifty boxes of Campbell on a canvas.' Indeed, the similarities that may exist between the architecture of the Discrete and 'human' architecture should not deceive us. Yet this is what 'neo-neo-rationalist' architectural idealism (the 'post-digital'), political or neo-positivist biomimetic architecture does, the latter only reproducing the intelligence of nature in the image of Renaissance anthropomorphism.

In fact, any future architecture will be massively generated by computational procedures that are already the result of a (proto) superintelligence. That this evokes various criteria, parameters and concepts associated with artificial intelligence is not important. Moreover, this artificiality is not, as in the case of current AI, purely technical. Superintelligence is artificial in every sense of the word; it refers to hybrid intelligence, both human and artificial, the effectiveness of which comes from the very possibility of making symbolical and numerical computations via a prior formalisation. It is thus an 'artificial general intelligence' (AGI) that will have succeeded in integrating all existing knowledge, giving birth to a concept of intelligence with both theoretical and practical efficiency, further reinforcing the criterion of Turing universality while removing the anthropomorphism or biomimicry of the famous 'Turing test'. Indeed, the objectives of this test, to demonstrate the possibility of an artificial intelligence at least equivalent to human intelligence, or more modestly to address criteria of intelligence, have been diverted to reintroduce a perfectly outdated anthropomorphism. In the field of architecture this anthropomorphism has been and is still regularly replaced by a biomimicry whose main asset is that it makes the extraordinary performance of computers and software ordinary and acceptable to the greatest number.

Under the pretext of possibilities for humans to carry out certain calculations or certain deductions, many of today's architects suggest that the introduction of the computer has modified architecture only marginally, as upcoming artificial intelligence would also do. The focus on the origin in general and on the origin of the calculation in particular turns us away from the evidence. Under the pretext of the human origin of the calculation we are led to believe that the rules of rationalism are still applicable. But computationalism implies the impossibility of going back to the beginning of computational procedures for which most operations escape us (even if theoretically speaking we would be able to run our computation backwards). Behind each petabyte of data are hidden other petabytes, behind each algorithm, approximation and rounding operation are hidden thousands, millions or billions of other algorithms, approximations and rounding operations. Behind each step of a computation within a sequence certainly finite but that gigantic dimensions make infinite with regards to any human faculty, hide trillions of trillions of discrete states that act as trillions of trillions of partial 'explanatory' causes.



EZCT Architecture & Design Research,
Studies in Recursive Lattices:
Genetic algorithms-based lattices
study in Mathematica,
2012

The lattices study gave birth to the first ultra-light UHPC 3D lattice and later to the creation by EZCT co-founder Philippe Morel of the large-scale 3D-printing company XtreeE, pursuing his investigations into advanced uses of ultra-high-performance concrete.

EZCT Architecture & Design
Research with Hatem Hamda
and Marc Schoenauer,
Studies on Optimization:
Computational chair design
using genetic algorithms,
2004

Chair Model 'T1-M' after 860 generations (86,000 structural evaluations). Characterised by its 'smoothness', 'T1-M' is one of the most 'evolved' chairs within the series of 25.

If, mathematically speaking, beginnings (causes) and ends (effects) do exist in finite-state machines, these concepts are no longer of any practical use, since they completely escape all perceptual capacities and therefore all phenomenological analysis. To take note of the definitive exit from rationalism for the benefit of computationalism is, among other aims, what this essay proposes. It invites us to embrace a new age of science, an 'automatic (post)history'. More prosaically, it calls for a new realism, by measuring the 'difference between what is possible to calculate in principle and what can be calculated in practice'.[22] Indeed, 'from the point of view of scientific knowledge, the relevant predictions are those that can be made in practice and not those that can only be made in principle'.[23] As Paul Humphreys has recalled, considering 'the response that computational science introduces nothing new into science' is a major misunderstanding. … The idea that an unaided human could "in principle" provide a numerical solution to the equations needed to predict weather patterns … a week from today is a complete fantasy.'[24] Indeed, the most crucial parameter of any scientific process of today is computational. Rather than wrongly speculating on such or such qualitative, essentialist, metaphysical or foundational aspect of what architecture is about – in the most traditional and boring way – it is far more interesting to pay attention to the new naked truth that architecture, when it has become fully computational, does not depend on any 'old' intrinsic parameters as these parameters were created by humans.

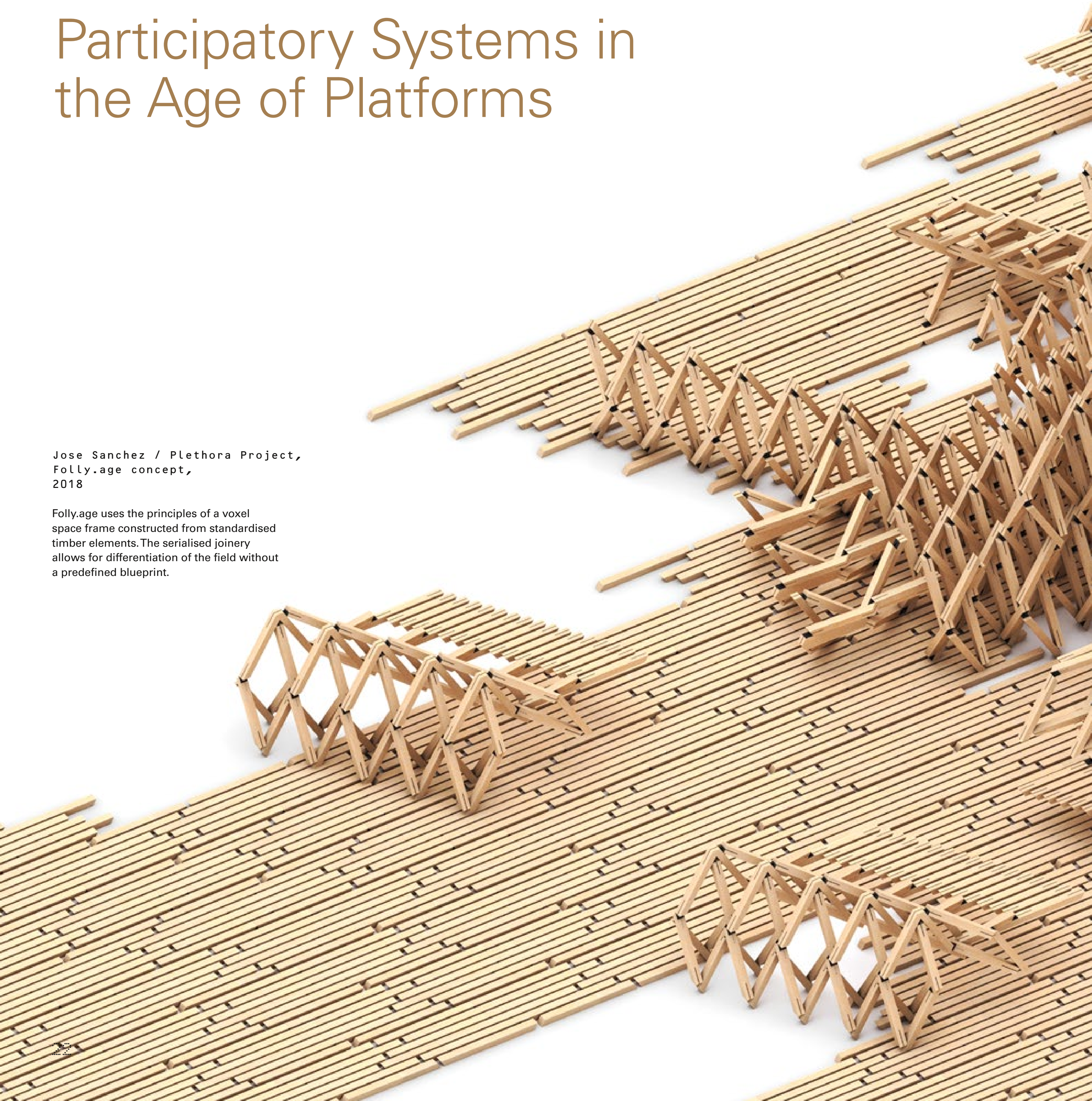
Recalling R Hamming, as quoted at the beginning of this article, 'evolution, so far, may possibly have blocked us from being able to think in some directions', including in the domain of architecture. 'There could be unthinkable thoughts' and there could be an unthinkable architecture. Therefore, the task of any architect is not about using computers to replicate or to automatise what has already been thought and produced, it is about allowing computers to reveal a fully new form of architectural intelligence that we humans are unable to conceive. It is useless to make use of machines that operate at teraflop speed for the replication of what humans can compute at the rate of 10^{-2}. Machines that operate 10^{14} times faster than humans, therefore 'in regions of (computational) speed far beyond the capacities of humans'[25] shall logically give birth to a kind of architecture that is also beyond our usual capacities. Such an architecture is still to be produced. ꝺ

Notes

1. Richard Wesley Hamming, 'The Unreasonable Effectiveness of Mathematics', *American Mathematical Monthly*, 87 (2), February 1980, p 89.
2. For example in the exhibition 'Coding the World' (curators Frédéric Migayrou and Camille Lenglois), Centre Pompidou, Paris, 2018, in the work of Mario Carpo in *The Second Digital Turn: Design Beyond Intelligence*, MIT Press (Cambridge, MA), 2017, or more recently Roberto Bottazzi in *Digital Architecture Beyond Computers*, Bloomsbury (London), 2018, and in Migayrou's essay 'Le digital en propre ou l'arrogance du discret', in *Architectures Expérimentales 1950–2012*, Editions HYX (Orléans), 2012, pp 69–73.
3. Kevin Kelly, 'Better Than Human: Why Robots Will – And Must – Take Our Jobs', *Wired*, 24 December 2012: www.wired.com/2012/12/ff-robots-will-take-our-jobs/.
4. See Eugene Wigner's famous essay 'The Unreasonable Effectiveness of Mathematics in the Natural Sciences', *Communications on Pure and Applied Mathematics*, 13 (1), 1960, pp 1–14 and its numerous variations including Alon Halevy, Peter Norvig and Fernando Pereira, 'The Unreasonable Effectiveness of Data', *Intelligent Systems*, 24 (2), May 2009, pp 8–12.
5. In Rousseau, Foreword to *Discours sur l'origine et les fondements de l'inégalité parmi les hommes* (*Discourse on the Origin and Basis of Inequality Among Men*), 1755.
6. Leon Battista Alberti, *De la peinture* (*De pictura*) [1435], Macula Dédale (Paris), 1992, pp 84–5.
7. Leon Battista Alberti, *De re aedificatoria*, VI 2, folio 79v, cited by Jean-Marc Mandosio in F Furlan (ed), *La classification des sciences et des arts chez Alberti* (from *Leon Battista Alberti: Actes du congrès international de Paris 10–15 avril 1995)*, J Vrin (Paris), 2000, p. 675.
8. Leon Battista Alberti, *De iciarchia*, I, cited by Jean-Marc Mandosio in *La classification des sciences et des arts chez Alberti*, *op cit*, p 660.
9. See Nick Bostrom, *Superintelligence*: *Paths, Dangers, Strategies*, Oxford University Press (Oxford), 2014.
10. Among the 48 lectures, John von Neumann's 'New Problems and Approaches' led to the writing of his 'General and Logical Theory of Automata', later published in Lloyd A Jeffress (ed), *Cerebral Mechanisms in Behavior: The Hixon Symposium*, John Wiley & Sons (New York), 1951, pp 1–31.
11. See Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*, MIT Press (Cambridge, MA), 2017.
12. Antoine Augustin Cournot, *De l'origine et des limites de la correspondance entre l'algèbre et la géométrie*, Librairie Hachette et Cie (Paris), 1847.
13. First published in English in 1950. Andrey Kolmogorov, *Foundations of the Theory of Probability*, trans Nathan Morrison, Chelsea Publishing Company (New York), 1950.
14. Alan M Turing, 'On Computable Numbers, with an Application to the *Entscheidungsproblem', Proceedings of the London Mathematical Society*, 2, November 1936, published 1937.
15. Kurt Gödel, 'Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I' (On Formally Undecidable Propositions of Principia Mathematica and Related Systems I), *Monatshefte für Mathematik und Physik*, 38 (1), 1931, pp 173–98.
16. Patricia Blanchette, 'The Frege-Hilbert Controversy', in Edward N Zalta (ed), *The Stanford Encyclopedia of Philosophy*, Fall 2018; https://plato.stanford.edu/archives/fall2018/entries/frege-hilbert/.
17. Jean-Yves Girard, *Le fantôme de la transparence*, Editions Allia (Paris), 2016.
18. Written in 1936, first published in entirety in *Husserliana, vol. VI*, Martinus Nijhoff Publishers (The Hague), 1954, as a chapter of *Die Krisis der europäischen Wissenschaften und die transzendentale Phänomenologie: Eine Einleitung in die phänomenologische Philosophie* (The Crisis of European Sciences and Transcendental Phenomenology: An Introduction to Phenomenological Philosophy).
19. In Greg Lynn, 'Probable Geometries: The Architecture of Writing in Bodies', *ANY #0*, 1993, pp 44–9.
20. See Patrik Schumacher, *The Autopoiesis of Architecture: A New Framework for Architecture*, John Wiley & Sons (Chichester), 2010.
21. Paul Humphreys, *Extending Ourselves: Computational Science, Empiricism, and Scientific Method*, Oxford University Press (Oxford), 2007.
22. Vincent Ardourel, *Du calcul sur ordinateur à la mécanique discrète*, Vrin (Paris), 2018, p 10.
23. *Ibid*.
24. Paul Humphreys, *op cit*, p 52.
25. *Ibid*.

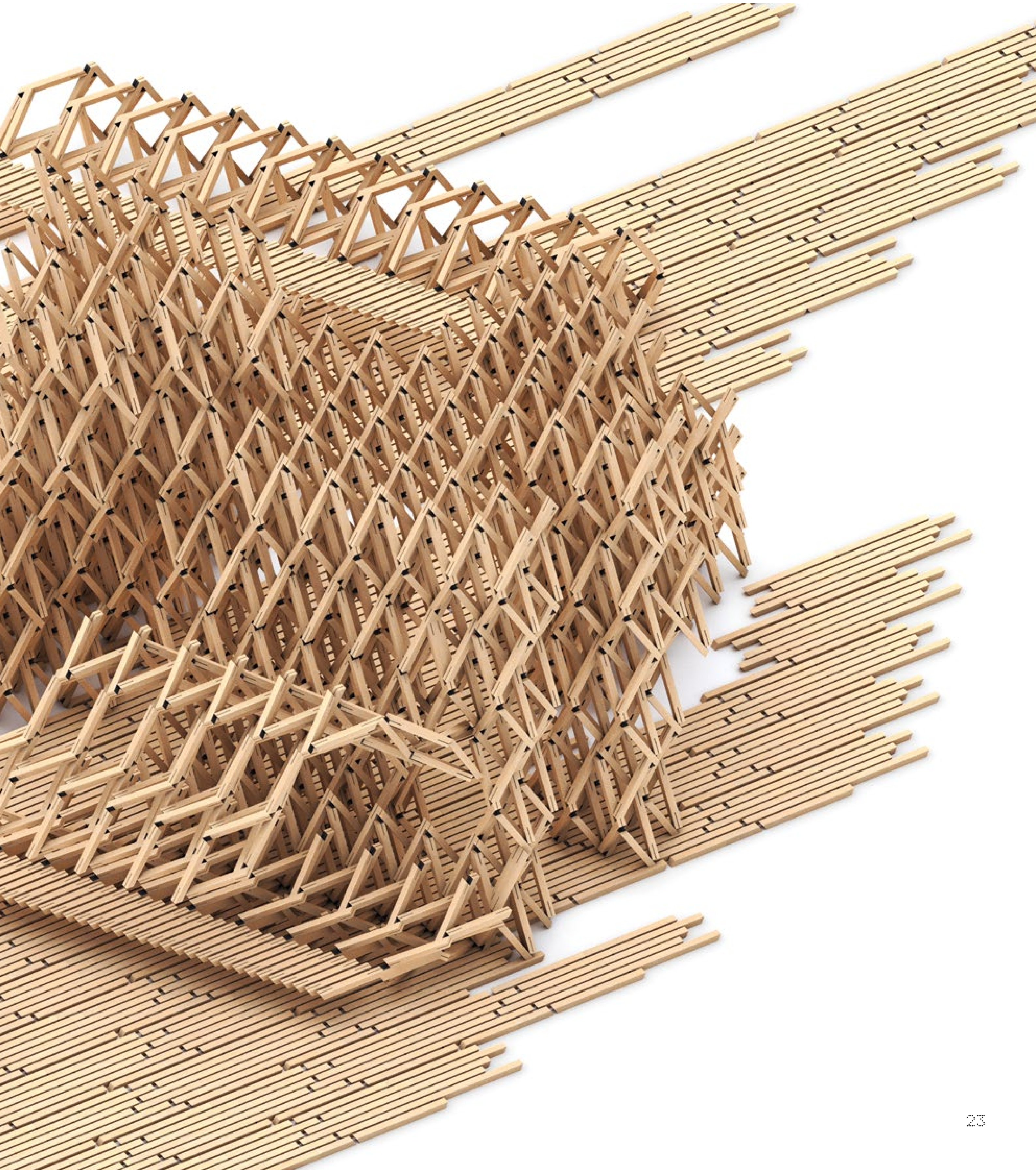
Architecture for the Commons

Participatory Systems in the Age of Platforms



Jose Sanchez / Plethora Project,
Folly.age concept,
2018

Folly.age uses the principles of a voxel space frame constructed from standardised timber elements. The serialised joinery allows for differentiation of the field without a predefined blueprint.



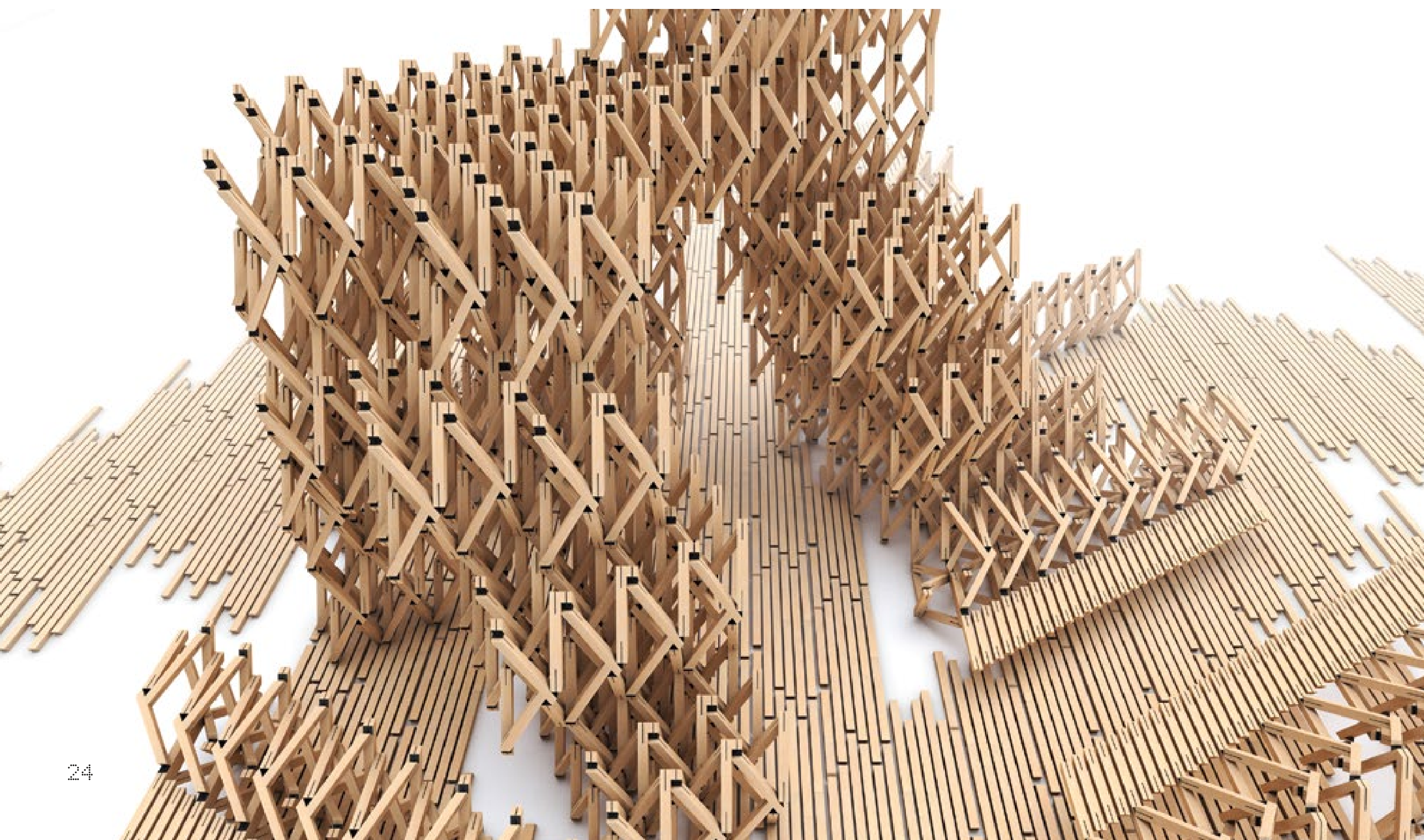
Does the Discrete offer a pathway to a more equitable architecture? **Jose Sanchez**, director of the research and learning initiative the Plethora Project and Assistant Professor at the University of Southern California (USC) School of Architecture in Los Angeles, laments the exclusivity of parametric design, and argues why the Discrete could be the answer. Two combinatorial assembly projects and a gaming platform that he has been involved in creating serve as practical illustrations of the possibilities of social engagement that this new paradigm presents.

Discrete architecture emerges out of a critique of the ideologies that are associated with the practice of nonstandard parametric architecture. The convergence of technology and machinery necessary to achieve such architectural paradigms plays into a narrative of practices and institutions with privileged access. Foregrounding technological progress oblivious of its social counterpart, the parametric agenda contributes to raising the barrier of entry into the architectural profession and ultimately to reinforcing asymmetries in a field that is dominated by a concentration of power and capital within only a handful of firms.

In this sense, Discrete architecture is inevitably linked to the social and the possibility for a larger number of smaller enterprises to coexist. The Discrete tectonic paradigm privileges autonomous units, parts that are not subsidiary members of a whole. Parts can be recombined into multiple permutations identifying an open-ended tectonic field condition. The scale of such parts is relevant and again linked to a social structure that is able to manufacture, handle, recombine and deploy them. Without this social backbone, the Discrete can be misunderstood as a response to the fatigue of the smooth continuity of parametric design and fall into the stylistic dialectic established by its proponents.

Jose Sanchez / Plethora Project, Folly.age concept, 2018

Pavilion proposal based on a metallic joint that operates as a kit of parts enabling the combinatorial arrangement of a large open-ended field.



Dissolution of Tectonics

Since its popular adoption in the 1990s, computer-aided design has evolved to become a design paradigm with a clear set of principles. It could be argued that the denomination of 'nonstandard' as presented by Frédéric Migayrou at the first exhibition devoted to architecture, computation and fabrication, at the Centre Pompidou, Paris, in 2003,[1] established a critical mass of interest and innovation that over the years has become known as parametric design. The foundation of this movement is linked to advances in digital fabrication and design software, challenging the tradition of serialised production that is the legacy of the Industrial Revolution. Under the logic of parametrics, it is possible to mass-differentiate and -customise designs, as fabrication technology does not rely on repeating identical units to achieve economies of scale. Computer-numerically controlled (CNC) routers, laser cutters and 3D printers establish file-to-factory protocols, and as Mario Carpo argues, can execute bespoke designs without any additional cost.[2]

Patrik Schumacher has claimed that architecture has entered the new epochal style of Parametricism with an unprecedented degree of freedom for architectural form.[3] At the same time, architects such as Neri Oxman[4] and Greg Lynn[5] celebrate the 'dissolution of tectonics' as the building fabric of design and architecture has become more fluid and continuous, eliminating the necessity of parts, where matter can be controlled at an infinitesimal degree of precision by accumulations and intensifications of material properties at a microscopic scale.

In opposition to the continuity of the parametric design agenda, the notion of the Discrete breaks from a tradition of mass-customisation of a singular building, attempting to reconstruct the commons through distributed knowledge and design production. The Discrete recognises a fundamental flaw in the economics of parametrics: parametric manufacturing scales linearly, meaning that the rate of production and costs will always operate at a constant rate. Traditionally, serialised technology has worked within the economics of zero marginal cost,[6] where initial investments are returned with the diminishing cost of every unit produced and trend towards zero. This economic model understands that units need to address an economy of scale, and therefore use standardisation. Through its cultural adoption, parametric design has proved itself a style that breaks the standardisation of legacy manufacturing and caters for the growing needs of a global elite who have been able to accumulate large portions of capital. At the same time, parametrics is not equipped to scale and engage the growing needs of the field of architecture at large, rendering itself incapable of allowing mass adoption or representing diverse sections of the population. This issue is set aside as advocates of parametrics champion the unprecedented 'architectural freedom'[7] that such a paradigm has provided. Parametrics has inevitably relied on a trickle-down economic model to slowly propagate any design innovation. It is in this sense that parametrics has become a symbol of the neoliberal practices happening worldwide, a form of technological progress, that loses sight of a social counterpart, and that gives evidence of current inequalities and asymmetries, only sustained by large accumulations of capital.

The metallic joint prototype was developed in collaboration with architects Diego Pinochet and Felipe Véliz in Santiago, Chile, with the aim of maximising standardisation to allow a large range of permutations.

The Discrete Proposition

The Discrete agenda has been a conscious attempt to subvert this trend and offer an alternative; this new paradigm attempts to reconsider serial repetition as an economy of scale[8] that can deliver fabrication, customisation and adaptability with scalable principles. The project does not intend to return to serialised production of identical units or cookie-cutter solutions, but rather rely on combinatorics and permutations of purposefully designed parts to achieve customisation and adaptation.[9] The project stands for 'a defence of parts', understanding the social and economic implications of their potential extinction under the parametric regime.

Reconsidering part-to-whole relationships is a return to the interest in mereology, as has been argued by Daniel Koehler.[10] In a traditional parametric model, a design (a whole) is post-rationalised into parts by a series of steps going from abstraction to fabrication documents. This follows the model of a jigsaw puzzle, where parts, often all different, have been optimised to only perform a specific role. In a Discrete model, on the other hand, the parts acquire autonomy and define a system or field condition that can stand independently of the whole. Wholes, from a Discrete perspective, need to be understood as patterns – 'non-holistic sets' or 'open wholes', that are able to grow or shrink in adaptation to their context. They define an open-ended field condition that can find multiple states of equilibrium. Parts, on the other hand, need to be conceived to perform not only one unique role, but rather a multiplicity of possible encounters with other parts. Parts indeed become more generic but capable of encapsulating fabrication and structural logic.

The foundations of this approach can be linked to Ian Bogost's notion of 'unit operations'. For Bogost, meaning emerges from the coupling of units without belonging to a larger holistic system. In Bogost's view, the units do not lose their autonomy once they take part in systemic relations. His distinction between wholes and multitudes allows for the existence of units without any overarching structure. As he explains: 'A world of unit operations hardly means the end of systems. Systems seem to play an even more crucial role now than ever, but they are a new kind of system: the spontaneous and complex result of multitudes rather than singular and absolute holisms.'[11]

The result of these principles is 'granular assemblies' that make evident their capacity to grow and shrink. While granularity could be understood as a tectonic condition, it encapsulates the autonomy and spontaneous interactions of units. The idea of assemblies addresses the properties of reconfigurability of parts and potentially their reversibility. It describes a temporal condition, one of a contingent configuration.

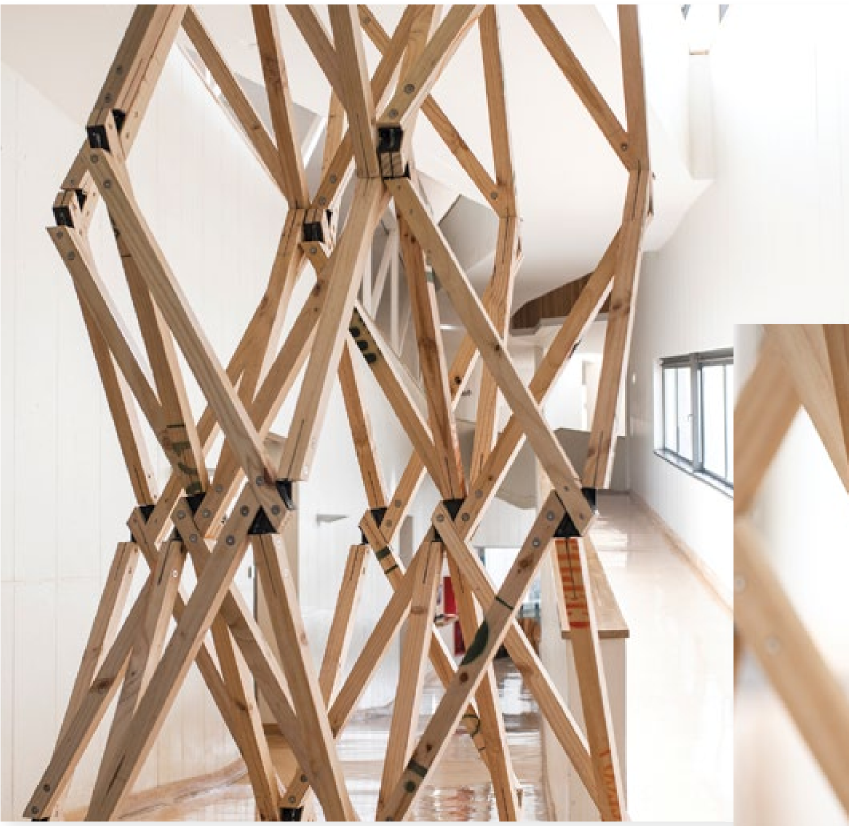
These 'contingent configurations' or patterns, as described above, are special arrangements of parts that acquire cultural meaning and value. Here is where Discrete architecture can provide a fundamental innovation to architecture and improve upon the parametric paradigm; patterns define an immaterial data structure for architecture, one that could be shared digitally and socially propagated. This data structure emerges from the geometric logic of units. Patterns become a highly adaptable and flexible format for design to emerge as a participatory enterprise, as they offer a vast search-space for architectural assemblies to emerge out of social permutations. This is aligned with a wider agenda for architecture to reclaim a broader literacy and social adoption, expanding the range of architectural production. The Discrete agenda withdraws from a 20th-century tradition of designing a singular building instance, promoting instead the design of combinatorial building systems that can be deployed in a multiplicity of instances.

Many of these ideas were put to the test in the Bloom project, a collaboration with Alisa Andrasek in 2012, where one identical unit was mass-fabricated for a later open combinatorial assembly in the hands of a social system. Bloom utilised injection moulding to serially produce, at an affordable cost, thousands of identical units that had been engineered to allow for a large range of design patterns out of their combinations. While the project team was able to anticipate some of the design permutations that would have a strong architectural impact in the development of a pavilion, the crowd, through the act of playing with the pieces, was able to generate a myriad of novel patterns and evolve the strategies for installing the structure. Each time it was assembled at a new site, the arrangement was different, adapting to local conditions and utilising the creativity and interest of the multitude engaged in it. The Discrete paradigm, from this perspective, is fundamentally tied to its capacity for social adoption and for an initial design to take a multiplicity of configurations defined as patterns. By shifting the focus from the virtual multiplicity offered by parametric designs (that are often only materialised as a singular outcome), Discrete design can conceive of tectonic systems that are pre-engineered for an open-ended architecture.

Jose Sanchez and Alisa Andrasek,
Bloom,
London,
2012

Initially presented at the London 2012 Olympics, Bloom explored the recombination of its components as a form of play in the hands of a large crowd of users.

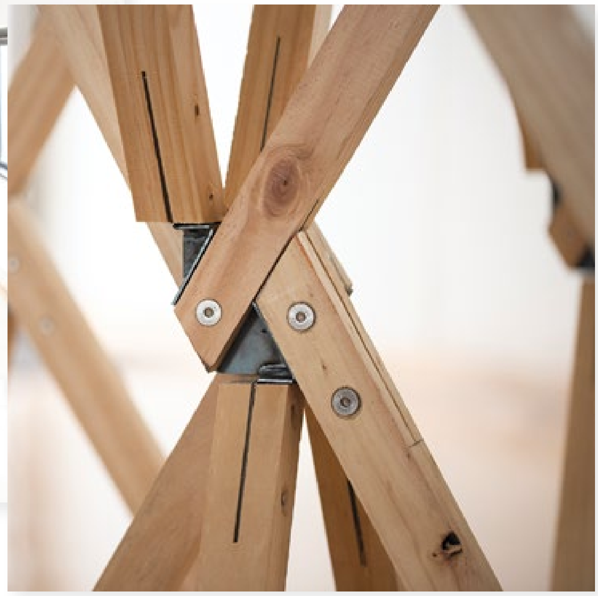
The Bloom project was founded on the idea of serialising thousands of identical components that could be fabricated at an affordable cost and recombined in different locations.



Jose Sanchez / Plethora Project, Folly.age prototype, 2018

left: Fabrication prototype developed with the support of Diego Pinochet and Felipe Véliz to test the rules of aggregation and assembly in a voxel configuration.

below: The vectorial orientation of the wood is defined by the orientation of the metallic joint.



Platform Design

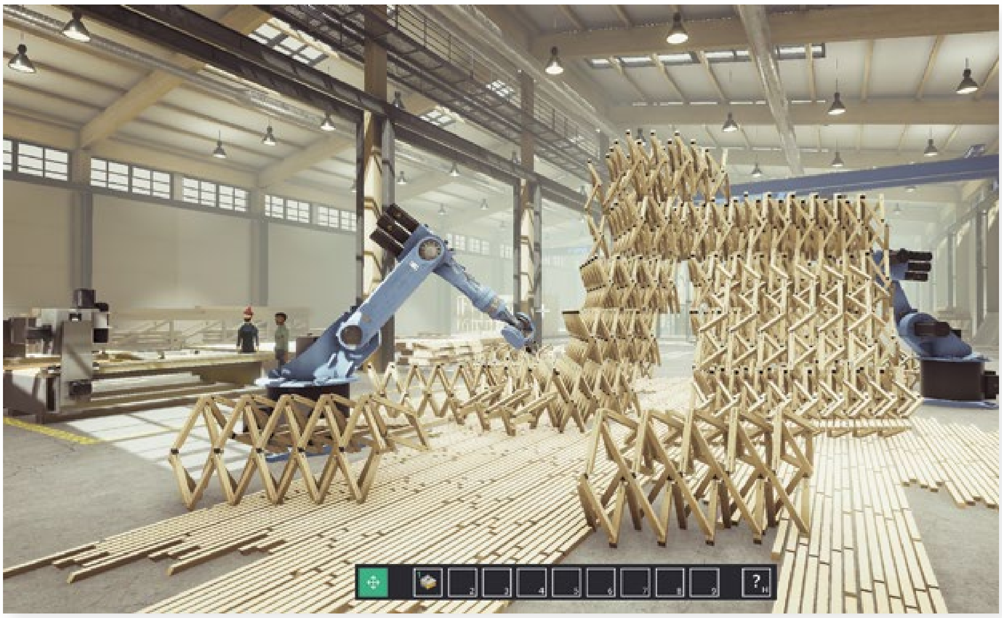
Once the foundations of a Discrete paradigm are understood, reconsidering the role of parts in the constitution of an open-ended whole, and design as the development of valuable and meaningful patterns, it becomes evident that the mechanisms for openly and socially developing such patterns acquires critical relevance. The development of digital platforms in the form of web repositories (as is the case with open-source projects) or video games is linked to the interest of allowing for generic building parts to find cultural and contingent patterns in the hands of a social system. The paradigm understands a feedback loop between tectonics and culture, emphasising the role of access allowing for a diversity of voices to participate in the definition of value systems.

Building upon the notion of patterns developed by Christopher Alexander,[12] Discrete architecture conceives of tectonic patterns as a transient and idiosyncratic synthesis of resources, knowledge and access. Patterns establish a fundamental design claim, as argued by César Hidalgo, present in the principles of informational entropy: information-rich patterns are rare and therefore valuable.[13] The value that emerges out of Discrete architecture, in this sense, has less to do with the value adjudicated by arbitrary gatekeepers or by those who have accumulated capital, but is more about a social coupling, a collective consensus of which arrangements resonate more closely with their social occupation. Design can become massively accessible through the participation of users via websites and video games, where relevant patterns are inevitably scarce and acknowledged as design contributions. It is the ethical imperative of platforms to track authorship and ownership and not become mechanisms for the extractivism of value in the form of data, as we have seen with contemporary social networks.

Discrete architecture can be critiqued as a series of formal and manufacturing constraints, a regression from a pure compositional freedom, but these constraints are purposeful in allowing social affordances, allowing for a massive number of recombinations in the hands of multitudes. Discrete architecture has been designed to be socially propagated while being manufactured with scalable and accessible technology. In Folly.age by Plethora Project, a research project that began in 2017, the design development has closely followed the guidelines of the Discrete agenda presented above, emphasising an interest in working with abundantly available materials. Folly.age proposes the design of a kit of metallic joints that can dictate the vectorial orientation of 5-by-5-centimetre (2-by-2-inch) wooden battens, allowing for a voxel arrangement and a series of spatial configurations. While most of the project uses standardised and inexpensive wooden battens, the geometry of the joints opens up a new search-space of architectural configurations. Here the kit-of-parts strategy is proposed in opposition to the parametric jigsaw-puzzle model. The kit contains three different joint variations that can be mass-produced as identical copies. These units, in their combinatorial correlation, are able to describe thousands of possible encounters, leaving the architectural field open-ended. No single instantiation of the project exhausts the possibilities of the system. Here reversibility and reconfiguration serve as mechanisms for local adaptation.

Jose Sanchez / Plethora Project,
Virtual warehouse facility,
2018

right: Part of a new video-game title currently being developed by Plethora Project, this real-time video-game interface allows users to design and simulate the fabrication of Discrete architecture projects. Such interfaces create large social platforms for the design and reconfiguration of discrete architectural assemblies.



Jose Sanchez / Plethora Project,
Block'hood video game,
2016

below: Block'hood was the first video-game interface developed by Plethora Project for the study of collective architectural engagement using real-time interactive platforms.

While the Bloom project made an explicit claim of assimilating the architectural unit with a toy to enable gameplay, Folly.age allows this design process to occur digitally. Plethora Project has been developing research in video-game technology with projects such as Block'hood in 2016, in the interest of allowing massive social recombination of parts to happen within digital platforms.[14] Gaming platforms have become a central medium to socialise complex simulations including architectural design. They offer the capacity to profoundly change the dialogue that architects are able to establish with a client or audience, moving beyond a simple parametric slider in a website or sampling colours from a Pantone chart. The challenge is to communicate architectural design opportunities and constraints, generating a dialogue that can facilitate collective architectural production while allowing for the ethical allocation of authorship, ownership and compensation.

Rethinking the Socio-Economic Implications of Design Frameworks

Discrete design is a theoretical framework that is fundamentally aware of a multi-actor economy and the interdependence of firms and individuals that make architecture possible. Technological and disciplinary progress cannot be at the expense of its social counterpart. Far from a rhetoric of exclusion, Discrete design offers a participatory framework for collective production, placing at the centre the design of open-ended tectonic systems that encapsulate knowledge.

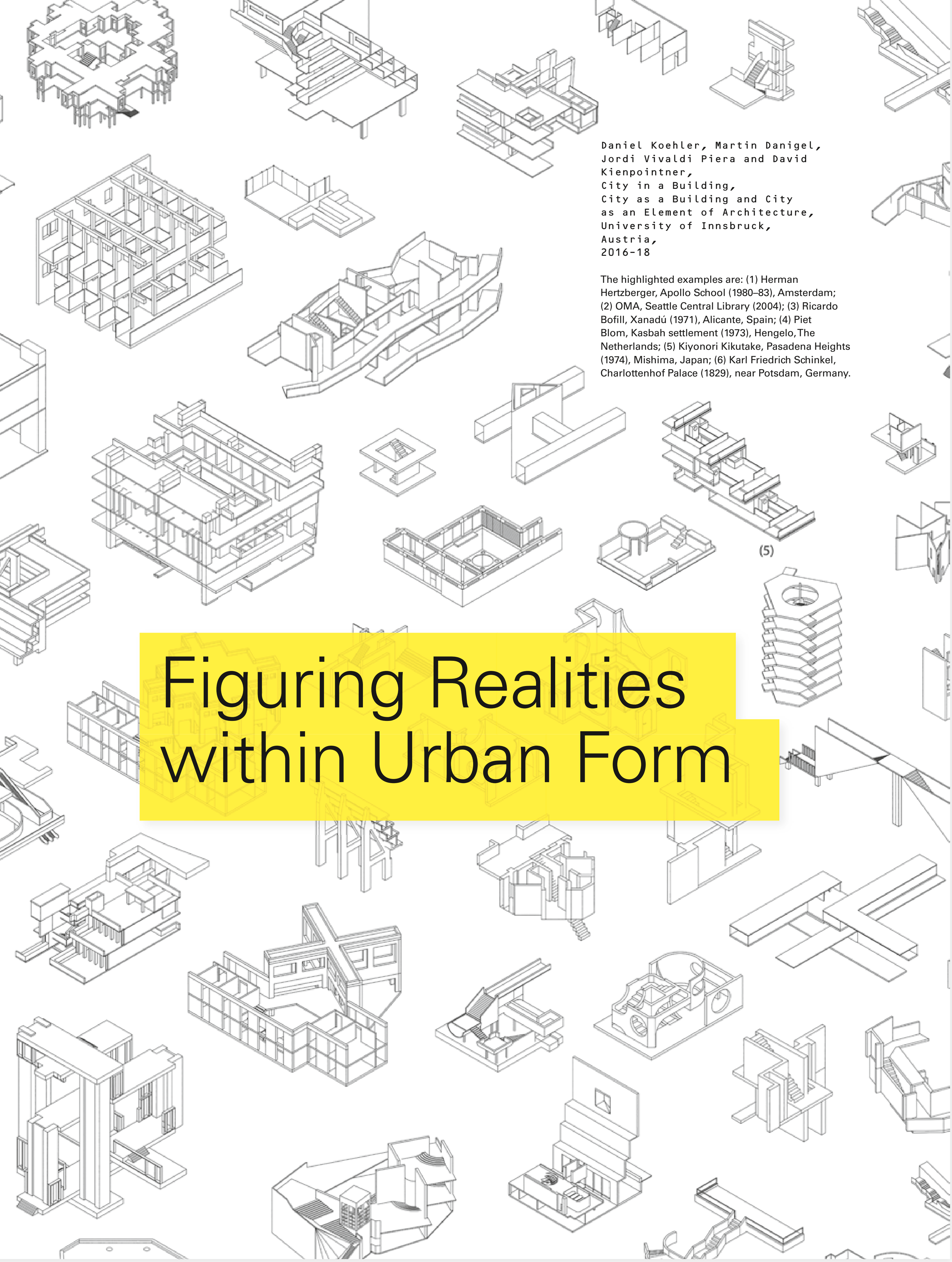
Notes

1.Frédéric Migayrou, *Architectures non standard*, exhibition catalogue, Editions Du Centre Pompidou (Paris), 2003.
2. See Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*, MIT Press (Cambridge, MA), 2017.
3. Patrik Schumacher, 'The Historical Pertinence of Parametricism and the Prospect of a Free Market Urban Order', in Matthew Poole and Manuel Shvartzberg (eds), *The Politics of Parametricism: Digital Technologies in Architecture*, Bloomsbury Academic (London), 2015, pp 19–44.
4. Neri Oxman, 'Structuring Materiality: Design Fabrication of Heterogeneous Materials', in Rikva Oxman and Robert Oxman (eds), *AD The New Structuralism: Design, Engineering and Architectural Technologies*, July/August (no 4), 2010, pp 78–85.
5. Greg Lynn (ed), *AD Folding in Architecture*, 2nd revised edition, John Wiley & Sons (Chichester), 2004.
6. Jeremy Rifkin, *The Zero Marginal Cost Society*, St Martin's Griffin (New York), 2014.
7. Schumacher, *op cit*.
8. Jose Sanchez, 'Polyomino: Reconsidering Serial Repetition in Combinatorics', in *Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, Los Angeles, 23–25 October 2014, pp 91–100.
9. Jose Sanchez, 'Combinatorial Design, Non-Parametric Computational Design Strategies, in *Proceedings of the 36th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, Ann Arbor, Michigan, 27–29 October 2016, pp 44–53.
10. Daniel Koehler, *The Mereological City: A Reading of the Works of Ludwig Hilberseimer*, Transcript Verlag (Bielefeld), 2016.
11. Ian Bogost, *Unit Operations: An Approach to Videogame Criticism*, MIT Press (Cambridge, MA), 2006.
12. Christopher Alexander, Sara Ishikawa and Murray Silverstein, *A Pattern Language*, Oxford University Press (New York), 1977.
13. César Hidalgo, *Why Information Grows: The Evolution of Order, from Atoms to Economies*, Basic Books (New York), 2015.
14. Jose Sanchez, 'Temporal and Spatial Combinatorics in Games for Design', in *Proceedings of the 35th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, LOCATION, Cincinnati, Ohio, 19–25 October 2015, pp 513–23.

Discrete design offers a participatory framework for collective production, placing at the centre the design of open-ended tectonic systems that encapsulate knowledge

Daniel Koehler

Mereological Thinking



Daniel Koehler, Martin Danigel, Jordi Vivaldi Piera and David Kienpointner, City in a Building, City as a Building and City as an Element of Architecture, University of Innsbruck, Austria, 2016-18

The highlighted examples are: (1) Herman Hertzberger, Apollo School (1980–83), Amsterdam; (2) OMA, Seattle Central Library (2004); (3) Ricardo Bofill, Xanadú (1971), Alicante, Spain; (4) Piet Blom, Kasbah settlement (1973), Hengelo, The Netherlands; (5) Kiyonori Kikutake, Pasadena Heights (1974), Mishima, Japan; (6) Karl Friedrich Schinkel, Charlottenhof Palace (1829), near Potsdam, Germany.

Figuring Realities within Urban Form

Mereology offers an approach to considering the city through its composing parts. **Daniel Koehler** – co-founder of the architectural research practice Lab for Environmental Design Strategies (lab-eds), leader of an Urban Design research cluster at the Bartlett School of Architecture, University College London, and a postdoctoral research associate at the University of Innsbruck in Austria – sets out its philosophical background and explores how it can be applied in this field.

Using analogies, architectural elements are considered as vessels of meaning: as representations. Therefore, architecture as a spatial practice is primarily discussed as a device of transforming one representation to another. Herein lies also its 'analogy' to computation, defined as the transformation of a bit of information from one state to another. It can be seen as the virtue of the digital debate rendering building parts as transformative devices:[1] as computational vessels of meaning. Accelerating the postmodern discourse, the increasing performance of digital technologies was primarily used to increase the parts of a building, and thus also its analogies. Conveniently, digital methods enhanced the resolution of functional patterns. By breaking down human actions into increasingly smaller parts, computational performance allowed the design of a much more accurate, differentiated and harmonious whole.[2] Critically, the resolution offered dissolution. Microscaled parts liquefied any signifier when they were arranged as a multiplicitous mass of particles into a blob.[3] For convenience or criticality, the acceleration of analogical thinking concluded the building as a purely representative space: as a placeholder to be used or to be thought with. Strangely enough, both strategies ignored the physical body itself, as if architectural form were only the result of a process. Thought and form became exchangeable, either shrinking the human condition to a behavioural pattern or shrinking architectural meaning to groovy shapes.

Beyond Quantities

But, as has already become part of architectural history, advancing resolution had its second turn.[4] In the end, a computation is not a solitary function but framed by two states, or data assets: the input and the output. With increasing quantity and complexity, it is not the transforming calculus that is decisive, but its input and output: the states at its side, the quantity of these states, and the character of their distribution. Building on such an insight, in popular science literature one stumbles today upon a more refined use of the term 'computation', describing it as a pattern in the space–time arrangement of data.[5] Describing computation beyond algorithmic action is a conclusive step, looking at the current dominant artificial intelligence (AI) research that relies on large datasets and neural networks. So too, today's social media platforms building on the internet cannot be explained by viewing the TCP/IP protocol as the performative calculus, but rather by looking at the number of links and nodes shared with it: in short, big data.[6] Shifting to a higher order of computation means shifting (again) to composition.

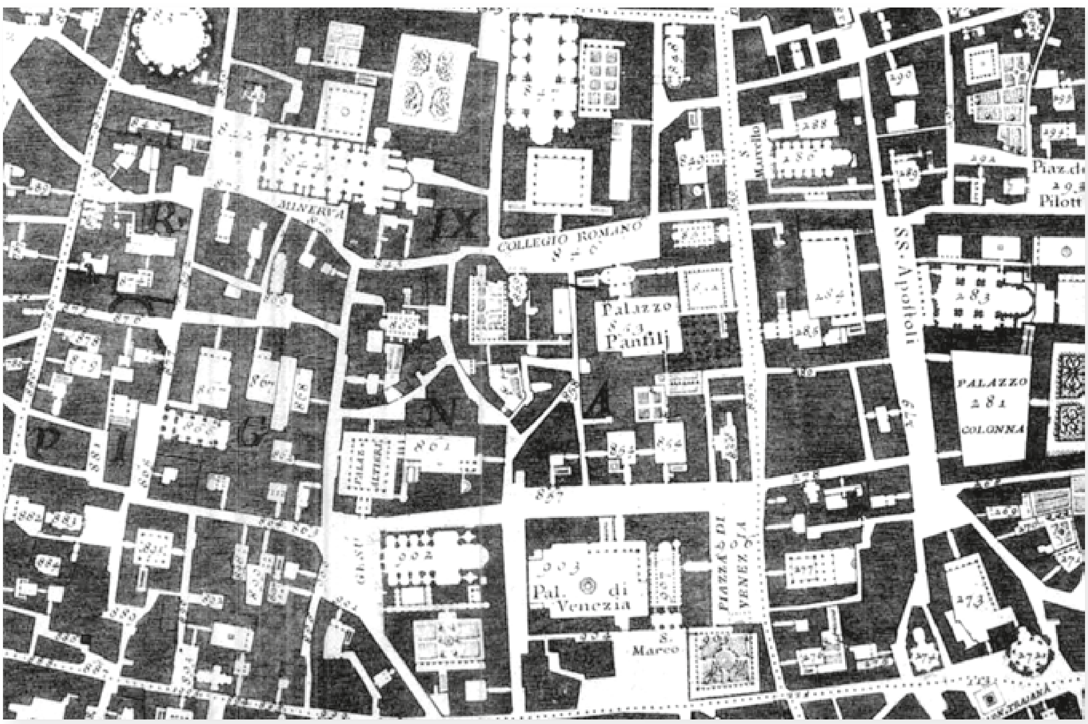
Paradoxically, increased resolution led to an entirely new socio-economic mindset, triggered by sheer quantity. It is no longer the performance or mode of an algorithm that drives change but its participatory capacities. Today's data-richness allows simultaneous comparison without condensing preferences into a third medium, like price or any other 'universal' language. As the economist Viktor Mayer-Schönberger shows, with big data direct exchange increases and the use of third-party means is dwindling.[7] This opens up a much more foundational turn: peer-to-peer paired with data richness fosters decentralised decision making. From distributive manufacturing to the internet of things, to blockchain, to sharing economies: distribution promises systematic shifts in the economy, industry and beyond. Noteworthy, in each case, is the distributive effect enabled by digital means.

Originating from code, digital assets design a statement from an observation. As the digital philosopher Aden Evens explains, 'digital bits select certain material properties and isolate them from other physical variable properties'.[8] Digital objects distance themselves from reality, and it is precisely in this gap that digital design gains new relevance. Incorporated into its partial materialities, a digital reality is distinct from other realities or, as Bruno Latour would put it, distinct from other modes of existence.[9] Instead of decreasing meaning to apprehend it, discretisation increases and produces realities.[10] Shifting the design intention from the transformative calculus towards discrete states inverts the role of abstraction. Far from being universal, suddenly it matters again which body computes, or in the words of the ecological thinker Donna Haraway: 'It matters what matters we use to think other stories with; it matters what knots knot knots, what thoughts think thoughts.'[11]

What Can Mereology Do For Architecture?

Here mereology begins as an attempt to describe a building through its parts using properties of transference, reflection and gluing: features of sharing. Mereology is a term derived from the Greek *meros*, meaning 'part', and refers to the study of a whole through the relationship between its parts. The word has appeared in various contexts over history, including philosophy, formal logic and mathematics, and it is a concept that already occurred in pre-Socratic philosophy.[12] Not to be confused with other part-to-whole theories such as set theory, which first defines a class and then subordinates its entities, mereologies begin with existing individuals or entities and describe their clusters, groupings and collectives. As a result of abandoning the whole, there is no uniform theory of 'mereology' in any discipline, but a plurality of concepts. There are two ways in which the term can be useful for architecture: first as a terminology, then as a project.[13] As a terminology, like a typology, morphology or topology, mereology can gather a specific body of knowledge. If the former are good at describing transformations from one analogy to the next, from one mass or one structure to another, the term 'mereology' can gather the techniques of bonding, joining, interlocking, entangling and overlapping of parts. Here, mereology contains strategies describing a building via the distributive relationships between its architectural parts. Mereological labels specify if there is an intended link or not, if the link is a proper relation or if the link is defined by a specific range of a condition. Mereological descriptions deal with access to parts, the integrity of parthoods and the weighting of their relevance and belonging.

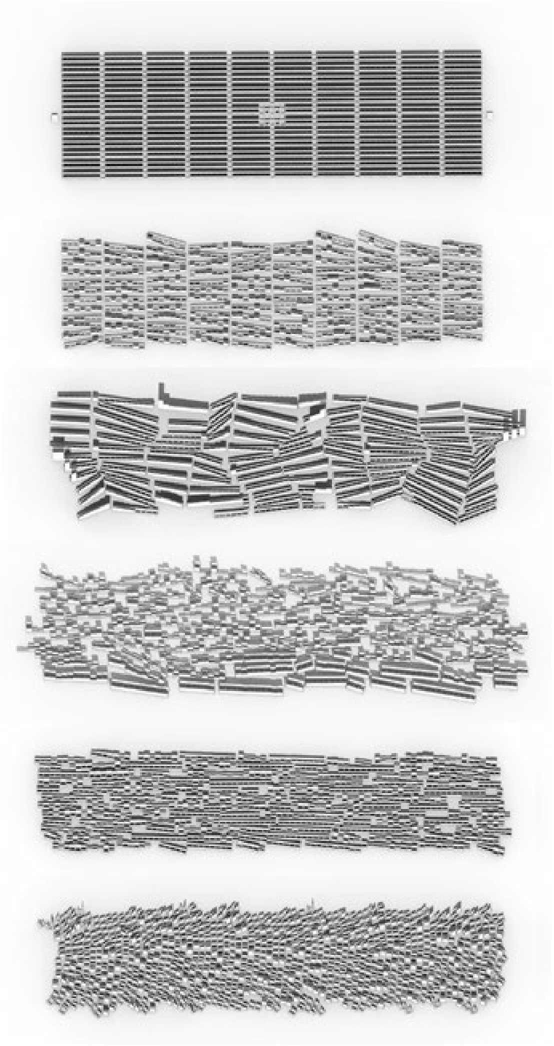
Precursors of mereological thinking, however, are not found in literally small parts, but at scales which exceed one building, one property or one perspective. Large quantities oblige partial design. So urban design begins by being partial, with a constructed reality in its narrated origin. Starting with the Map of Rome drawn up by Giovanni Battista Nolli in 1748, the first plan of modern urbanisation, the city has been rendered as an object, a constructed reality. Following the question of which property should be taxed and which not, Nolli's plan established a binary distinction between privately owned buildings and publicly accessible ones. Therefore, he drew the former as black masses and the latter as white, free spaces. Obviously, the black-rendered buildings are not solid in reality but contain liveable spaces, and most probably different modes of being public. If one pursues a universal language, with the attempt of comprehending a city in the plurality of its negotiations, it is only natural to limit the description to the lowest common denominator – in Nolli's case, a ratio between black and white bits. However, as the political philosopher Raymond Geuss has beautifully traced, the ideological rationale of being public comes in diverse modes across times and regions, extending from decency to rhetoric, spirituality and the limit of freedom.[14]



Giambattista Nolli, Extract from part 5/12 of *The New Plan of Rome*, 1748

The plan is also an early example of computing the city. The numbers are used to index each property, which made it possible to transfer mass and empty spaces into land registers.

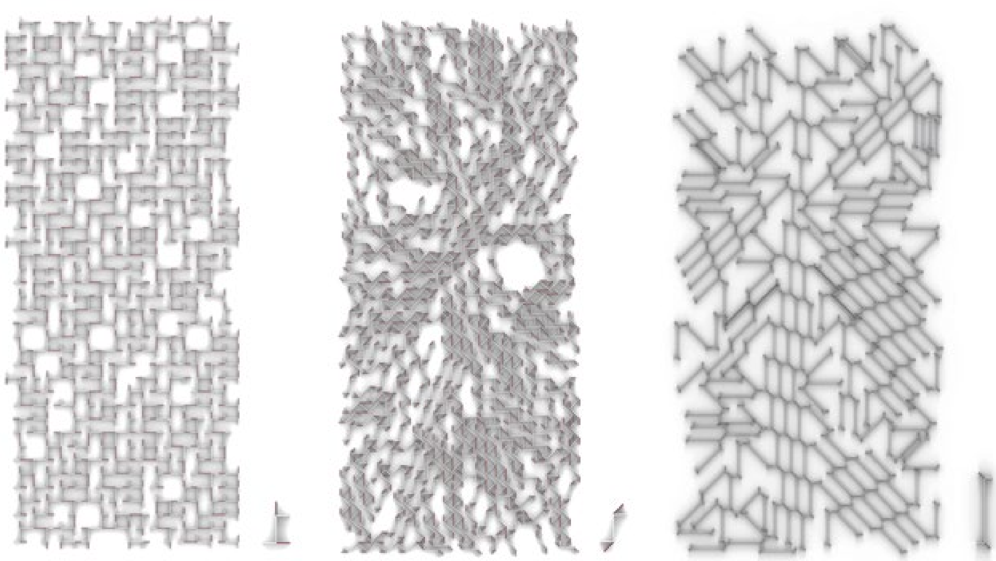
As an architect, one is faced with the incomprehensible challenge of constructing a city through its buildings alone. By designing a building, the city is also a part of its architecture; it comes into being with a building and is negotiated as a building. Starting with individuals means beginning with a stock-take of existing figurations of what a city is. It makes sense, as Haraway would put it, to look for the bodies with which bodies are embodied; the parts with which cities are partitioned; the buildings with which cities are built; the cities with which cities are urbanised. Transferring the digital culture of quantitative processes of grouping, comparing, nesting, sampling and filtering re-renders the city and opens up opportunities of its reconfiguration with particular parts of architecture. The city comes in a diverse range of textures – from that of a gathering of accommodated situations, as in Herman Hertzberger's Apollo Schools (1980–83) in Amsterdam; to the sequence of boulevards and plazas in OMA's Seattle Central Library (2004); to the diagonal light-cones in Ricardo Bofill's Xanadú project (1971) in Alicante, Spain; to the stitching of stairs in Piet Blom's Kasbah settlement (1973) in Hengelo, The Netherlands; to the knotted corridors in Kiyonori Kikutake's Pasadena Heights (1974) in Mishima, Japan: the city manifests with parts of buildings.



Daniel Koehler,
Variations on
Ludwig Hilberseimer's
Vertical City,
2014

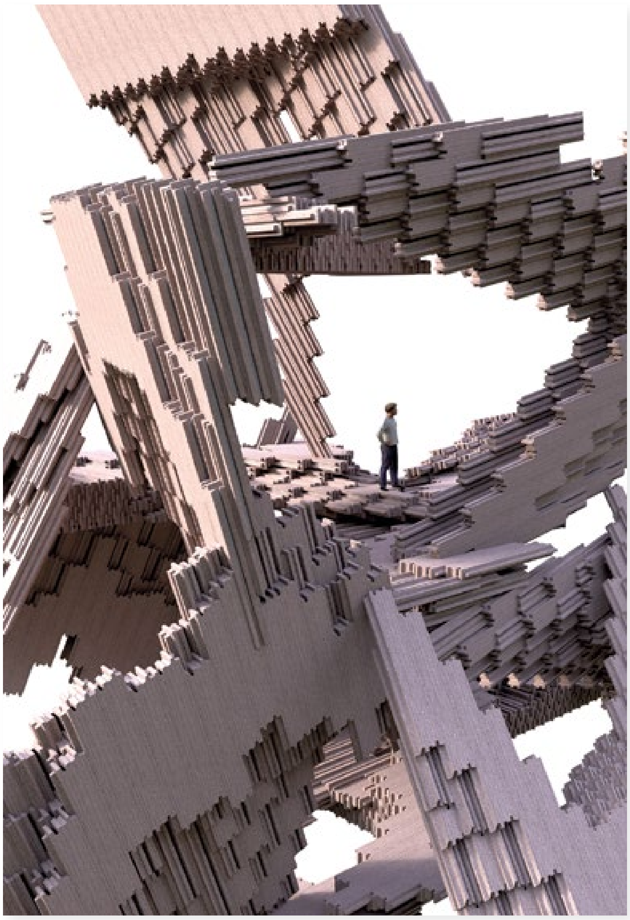
Inspired by the Vertical City (Hochhausstadt) drawn up by Hilberseimer from 1924, each city-element is based on the same number of conditions, but in varying density of its part-relations. For example: does sun insolation overlap with the arrangement of the house, the line, the block or the city-element itself?

The city comes in a diverse range of textures ...



Sheghaf Abo Saleh, Hua Li,
Chuwei Ye and Yaonaijia Zhou,
IIOOOI,
B-Pro Research Cluster 17,
Bartlett School of Architecture,
University College London (UCL),
London,
2018

Figure–figuration: plan studies based on the simultaneous design of a repetitive wall-figure and its plan-figuration.



Lab for Environmental Design Strategies (lab-eds),
House of Frames,
space sample,
2016

The fragment is based on the effect of a linear part relation. The wooden ledges share a line and are stacked into sheaves. The sheaves overlap in point connections between ledges of different sheaves.

Silu Meng, Ruohan Xu and Qianying Zhou,
NPoche, B-Pro Research Cluster 17,
Bartlett School of Architecture,
University College London (UCL),
London,
2018

Whole-to-whole-to-whole arrangement: nesting wholes as parts in a spatial sequence, with two hours' insolation on each shared area and no relationship between parts.

Parts Without Wholes

Mereology becomes its own project, taking participatory relations seriously. How can 'wholeness' be described without presuming a whole in the first place, and instead solely through distributive participation? Unlike in bottom-up discourses, from a distributive perspective an overall overview or whole does not exist; the joint arrangement can never be described in its full extent. Here, parts are understood not as components – ie, parts that are composed from a whole and to a whole. Parts are discrete, but also participating entities. In contrast to a whole, the autonomy of a body is not defined as a self-contained object, but around a ratio of a reality, a point of view, a filter or a perspective. Parts obtain their individuality not through their self-determination, but through a specific projection enabling participation.

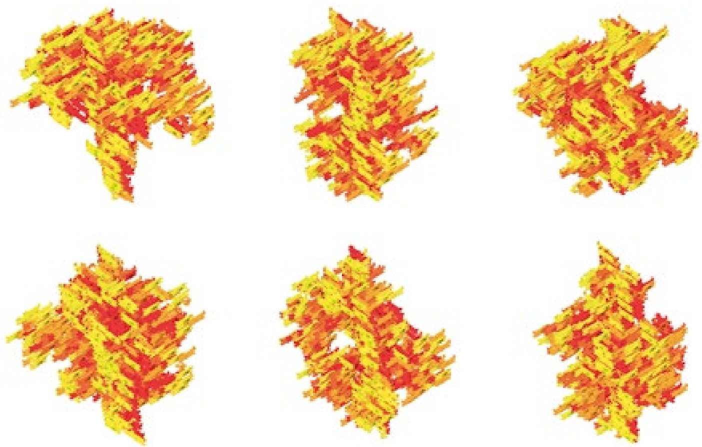
In architecture, the history of buildings designed as parts goes back a long way. One example is in the works of the classicist architect Karl Friedrich Schinkel, whose Charlottenhof Palace (1829), near Potsdam in Germany, follows the typological axiom of a villa, linking to the landscape with both of its entrances. One detail is essential: the entrance, not the villa, is linked to the landscape. Like in a chain of 'landscape, entrance, hall, entrance, landscape', the landscape ripples through the parts of the house. Schinkel's only intervention is the shift in the landscape. So the artificial slope reconfigures the internal plan-organisation of the palace for which it is known. Such an approach differs from collage, because it does not dissolve the parts in a third object but produces additional parts. Schinkel explains in his theoretical writings that the work of architecture is not intended to stand as a 'completed object', but rather is 'to show out into infinity the outspoken idea placed within'.[15] From a mereological point of view, the external condition overlaps with an internal part also in its absence, like an outward-looking projection. In opposition to the description of a whole as an autonomous entity, here it is described as a part between inside and outside, as 'that which is in' and 'that in which it is'.[16] Starting with parts, a whole can just be projected into partial aspects of a part.

Part to Part

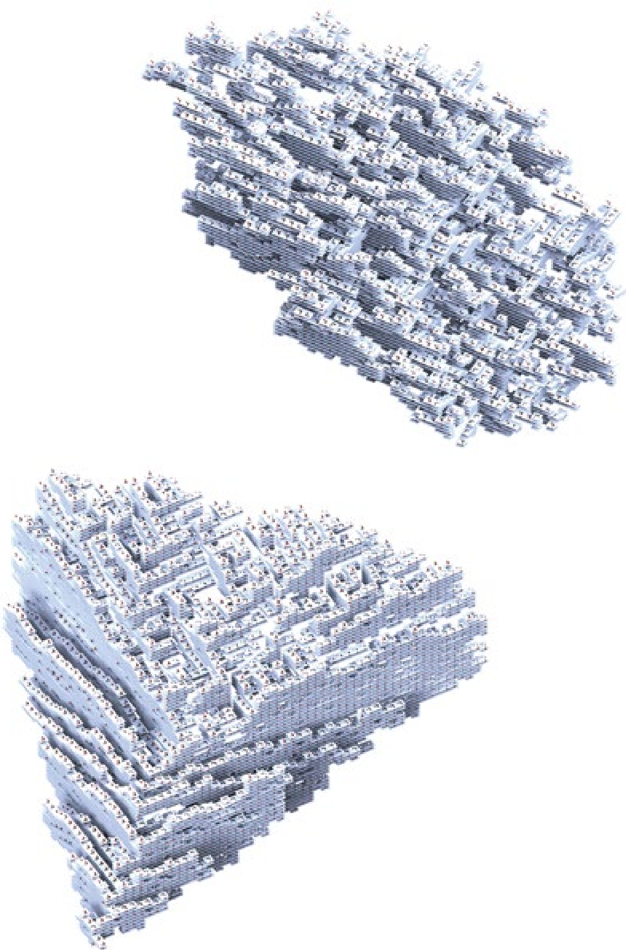
With such inferences, it is possible to form figurations which are already explicit with the attributes of their parts. The whole is projected as a specific part for the part as a whole. When wholes and parts are nested into each other, orders are turned upside down. This allows the short-cutting of hierarchies through design and makes unintelligible institutions – which is what cities are – explicit. In this way, a part-to-part relationship juxtaposes the single individual to the individuals of the institutions: to the organs of social, political and cultural negotiations.

How can intangible, non-material influences, such as insolation, become part of a settlement? Usually, such aspects are external criteria to a building. As a normative value to be complied with, the amount of insolation is the result of a legislative discussion. Thus, such influences remain transcendent and are interchangeable by another measure. However, the architectural arrangement does not change, it is only considered to be good or poor in non-discursive terms. Thereby, ultimately, the architectural typology withdraws

Genmao Li, Chen Chen and Zixuan Wang,
WanderYards, B-Pro Research Cluster 8,
Bartlett School of Architecture,
University College London (UCL),
London, 2017

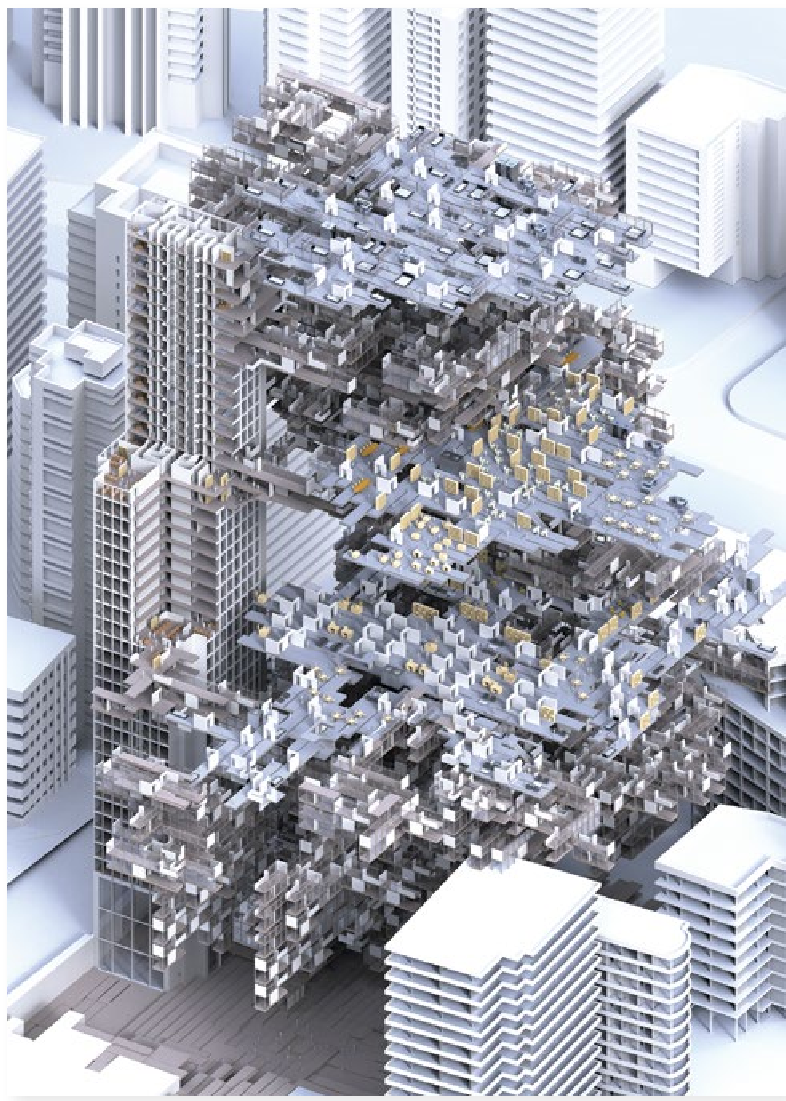


Figurations with coloured sun exposure time. Machine learning enabled the clustering, filtering and selection of figurations from the combinatorial space of the part-relation.



Genmao Li, Sun Studies,
B-Pro Research Cluster 17,
Bartlett School of Architecture,
University College London (UCL),
London,
2017

Whole-to-part arrangements of 3,500 rooms assembled to an overlap between the room and insolation; point relationship between parts.



Focusing on occupational restrictions, WanderYards shows how shifts of combinatorial granularity enable diversity through the repetition of space samples.

its form from the legislative process. Finally, it denies its participation and thus also relevance. But for a room, insolation turns easily into its own entity. Seen throughout the times of day and the seasons, with a set of light prisms the intangible sun can be scattered and accumulated across a room. Do the prisms interlock with the house or the room? Which relationship is more decisive – that of the rooms with the apartment, with the house, or with the prisms? Altering the linking, density or nesting of this bond will also change the overall figuration. Without predetermining the figuration itself, the whole is articulated as the overlap between parts. One could also say that the whole is distributed all over the parts.

Thinking Parts

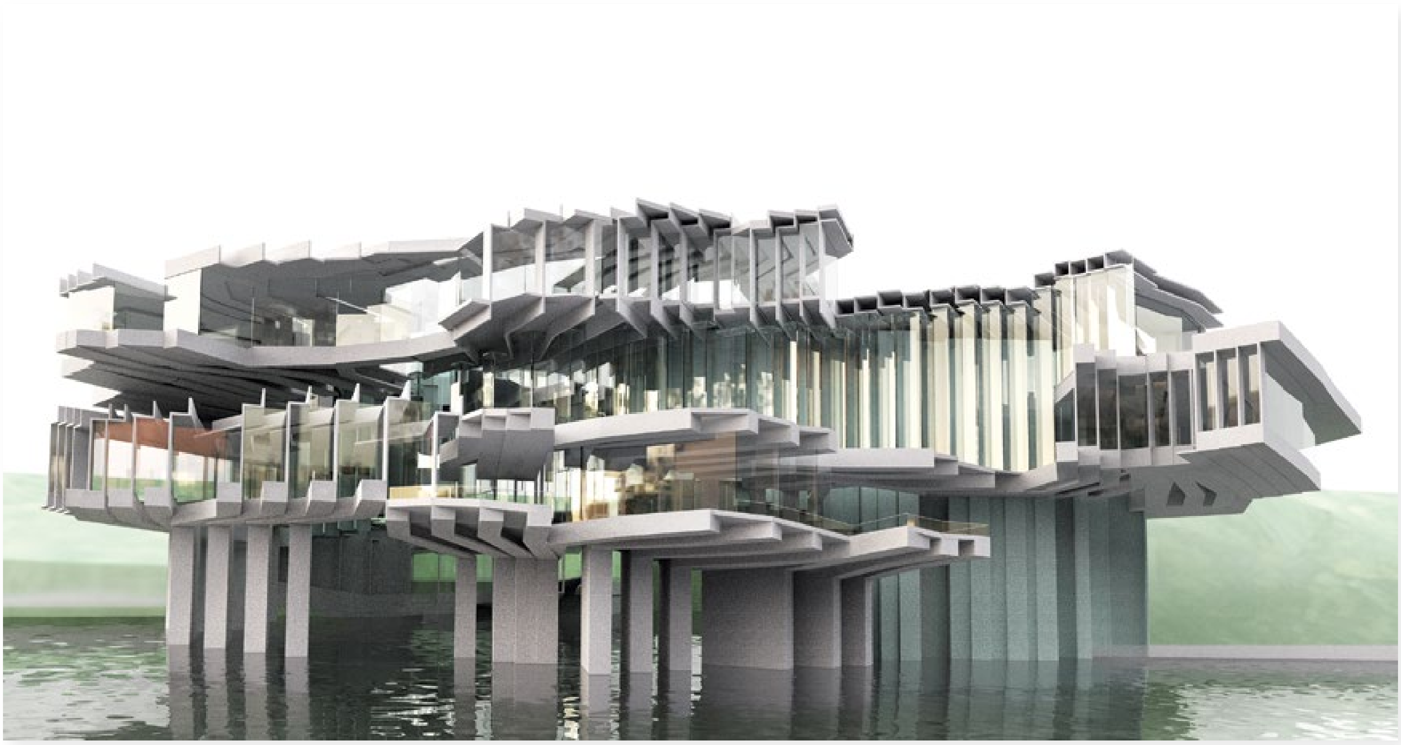
Parts and wholes-as-parts exist in the same way. As the ecological philosopher Timothy Morton summarises, such inferences turn classical notions of emergence upside down: 'The whole is always less than the sum of its parts.'[17] We are accustomed to entrusting ourselves to digital performance, and hope that by magic an extra value will emerge through the sheer quantity of data, and even that of a city. Digital architecture computed transformations to overcome Platonic bodies. Rightly so, because Platonic bodies are rigid vessels that cannot hold any extra value. But it is also rigidity which enables Platonic thinking. Rather than a process for evaluating or transforming information, Platonic thinking is, as revealed by Hannah Arendt, the ability to have an inner conversation, and is thus the gift of opening-up and exploring.[18] Perhaps it is exactly the Platonic part-being of digital objects and the more and more distinct realities that become impossible bodies *to think with*. It might be those unthinkable parts that overcome practice, habit and trade, and that ultimately enable thinking. ᗡ

Notes

1. Peter Eisenman, *The Formal Basis of Modern Architecture*, Lars Müller Publishers (Baden), 2006, p 25 – facsimile from Eisenman's PhD dissertation, University of Cambridge, 1963.
2. Christopher Alexander, 'From a Set of Forces to a Form', in Gyorges Kepes (ed), *The Man-made Object*, George Braziller (New York), 1966, pp 96–107.
3. Greg Lynn, 'Multiplicitous and Inorganic Bodies', *Assemblage* 19, 1992, pp 32–49.
4. Mario Carpo, *The Second Digital Turn*, MIT Press (Cambridge, MA), 2017, pp 18–19.
5. Max Tegmark, *Life 3.0*, Allen Lane (London), 2017, pp 61–7.
6. Klaus Schwab and David Nicholas, *Shaping the Fourth Industrial Revolution*, Crown Business (Geneva), 2018, p 20.
7. Viktor Mayer-Schönberger, *Reinventing Capitalism in the Age of Big Data*, Basic Books (New York City), 2017, p 7.
8. Aden Evens, *Logic of the Digital*, Bloomsbury Academic (London and New York), 2015, p 6.
9. Bruno Latour, *An Inquiry into Modes of Existence*, Harvard University Press (Boston, MA), 2013.
10. Shoshana Zuboff, 'Big Other: Surveillance Capitalism and the Prospects of an Information Civilization', *Journal of Information Technology* 30, 2015, pp 75–89.
11. Donna Haraway, *Staying with the Trouble*, Duke University Press (Durham), 2016, p 12.
12. Achille Varzi and Rafał Gruszczyński, 'Mereology Then and Now', *Logic and Logical Philosophy* 24, 2015, pp 409–27.
13. Giorgio Lando, *Mereology, A Philosophical Introduction*, Bloomsbury Academic (London and New York), 2017, pp 1–14. Lando proposes a parallel differentiation in Philosophy between Mereology as a discipline and as a theory.
14. Raymond Geuss, *Public Goods, Private Goods*, Princeton University Press (Princeton, NJ), 2003.
15. FA Herbig (ed), *Karl Friedrich Schinkel: Aus Tagebüchern und Briefen*, Henschelverlag (Munich), 1967, p 146.
16. Tristan Garcia, *Form and Object*, Edinburgh University Press (Edinburgh), 2014, p 119.
17. Timothy Morton, *Being Ecological*, Pelican (London), 2018, pp 92–3.
18. Hannah Arendt, *The Life of the Mind*, Harvest / HBJ Book (New York), 1981 (posthumous publication), p 14.

lab-eds (Rasa Navasaityte), Competition entry for the MK Ciurlionis Concert Centre, Kaunas, Lithuania, 2017

The tectonics of the concert hall follow a linear part-relation between space-enclosing frames made of prefabricated concrete elements.



Gilles Retsin

Bits and Pieces

Gilles Retsin Architecture,
Diamonds House,
Wemmel, Belgium,
2016

The Diamonds House consists of volumetric aggregations of serialised timber elements that are hollow on the inside. The project is no longer geometrical, nor does it have any fixed types. There is only one kind of element that bundles together and defines both functions and spaces.

Digital Assemblies: From Craft to Automation

Could automation turn architecture into a more accessible, mass-produceable cultural project? Guest-Editor **Gilles Retsin** recounts some experiments in this direction from the B-Pro Research Cluster 4 that he co-directs at the Bartlett School of Architecture, University College London, as well as from his private practice. Customisation here occurs in the assembly rather than in the building blocks themselves, with building syntax reduced to a small number of distinct elements, and resolution varying widely between projects. Design, rather than robotics, remains key.

We have probably all seen the images of Amazon's vast warehouses at some point. Thousands of cardboard boxes, arranged in no apparent order, where only on close inspection a few humans can be seen. The Amazon warehouse is the physical manifestation of our digital economy – the automated system of production that has come to define the 21st century. Driven by computational power, the digital economy as a system of production is fundamentally different from what we knew before. In the Amazon warehouse, machine-learning algorithms collide with banal cardboard boxes and the consequences of automation clash with workers' rights. In the 1990s, architects often used another system of production to debate changes in architectural paradigms – in this case, it was Henry Ford's Highland Park Plant in Michigan. The Fordist assembly line was used by architects newly interested in the digital to critique the old paradigm of serialised mass-production and assembly. This was soon to be replaced with mass customisation: the idea that digital machines could produce every object differently, at no additional cost. This new industrial model was exemplified by the Nike iD shoe that consumers could customise on a website (although later it turned out this only concerned the colours of the shoelaces and a limited choice of soles). Robots and other computer-controlled machines alike could be used to differentiate form and craft unique objects that no longer relied on the notion of assembly and parts.

Fast forward two decades: when we now compare Henry Ford's assembly line with the Amazon warehouse, we discover that there is at least a certain ambiguity in the difference between the two systems. They are both different and remarkably similar. Both are defined by seriality, repetition and discreteness. However, the big difference is not in the formal appearance of the Amazon warehouse, but in the logics behind this strange assembly of piles of cardboard boxes. The Amazon warehouse is about the mass customisation of logistics, not of form. What we see in the warehouse is a global, automated system of distribution based on just-in-time delivery, flexible, efficient and adaptive. It tells us what digital production really is: merely a capitalist technique for ultimate efficiency, a fully automated system of production. While this may sound gloomy, theorists such as Nick Srnick point out that ultimately this striving for efficiency could also lead to a democratisation of production.[1] In making production chains shorter and shorter, the means of production become more and more accessible as they require less and less capital.

From this brief discussion and given the pressure of the current global housing crisis and the accelerated automation of millions of jobs, it is clear that today the question of architecture is not first and foremost one of formal differentiation or a return to craft – digital or not. Rather, it concerns the potential of automation to lift architecture out of its niche into a qualitative cultural project that is accessible and reproducible on a massive scale.

Automation as Design Project

It is crucial to realise that the question of automation in architecture is in the first place a question of design and not one of robots. Merely automating the existing, analogue syntax of buildings does not make much sense. As a building consists on average of more than 7,000 different parts, any attempt to automate these many different processes is futile. However, if the syntax of a building can be reduced to just a few elements, automating their assembly becomes more feasible. This approach to automation is also prevalent in the robotics research of leading institutes such as the Center for Bits and Atoms at the Massachusetts Institute of Technology (MIT) and the Harvard Wyss Institute for Biological Engineering. Here, robotic research is paired with the design of simple operations and building blocks and also suggests that the customisation is in the assembly rather than in the assembled element. Neil Gershenfeld, founder of the Center for Bits and Atoms, argues that to speak about digital fabrication, the fabrication process needs to operate on a material that in itself is digital. A so-called 'digital material' is an assembly of discrete elements that have a limited set of connection possibilities, as opposed to an analogue material, which has continuously differentiated connections.[2] Think Lego blocks versus toothpaste. Digital materials are efficient for robotic assembly and have structural properties that outclass normal, analogue materials.

In a similar way, attempts to automate architecture should start with the syntax of the building and its basic building blocks or elements. The challenge then becomes how to design this digital syntax? Discrete architecture develops design strategies for serially repeating, recombinable sets of generic discrete elements that can be assembled into fully functional and complex buildings. It is this abstract notion of 'discreteness' – the generic unit or bit that pre-exist design – that has become the most defining aspect for a new generation of emerging architects working with computation, robotics and digital design. This is the subject of a long-term research agenda undertaken as part of the Research Cluster 4 postgraduate B-Pro programme at the Bartlett School of Architecture, University College London (UCL). Here, projects such as the INT robotically assembled chair (2016) make use of industrial robots to assemble timber building blocks into a variety of functional objects.

On a larger scale, the Tallinn Architecture Biennale Pavilion (2017) is one of the first built prototypes for Discrete architecture. Similar to Le Corbusier's Maison Dom-ino (1914–15), it is an abstract fragment of a larger whole, a demonstration of a new system of production with radical architectural implications. It is effectively also a research project on automation, testing the design of discrete building blocks that act as large-scale digital materials. Off-the-shelf standardised plywood sheets are CNC-milled into a kit of parts that can be combined into a lightweight building block able to perform in a variety of loading conditions. Elements are not optimised to perform in a unique condition, but respond through their iterative accumulation and recombination to different conditions. The elements can be cheaply mass produced and enable an open system of design and production.

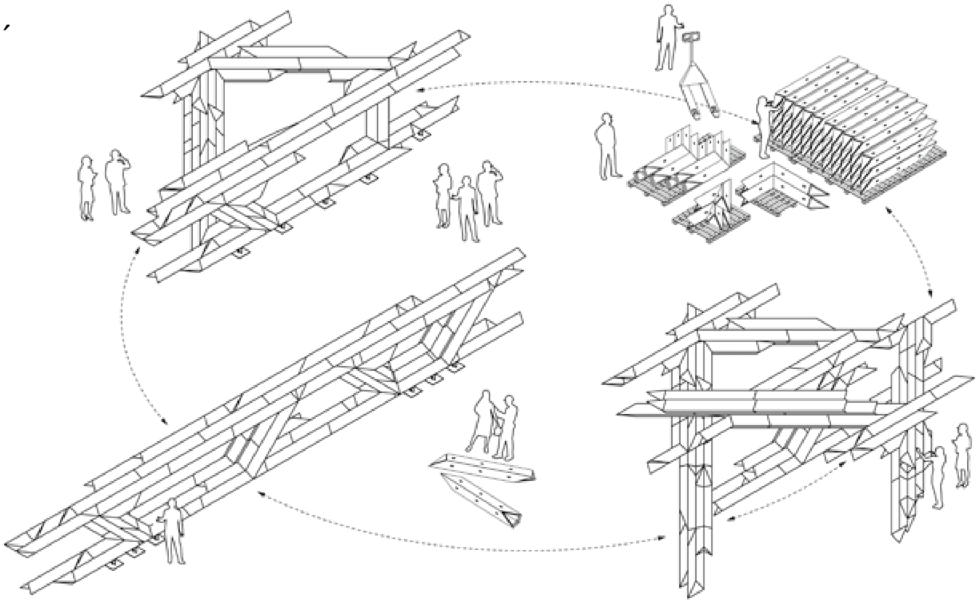
Zoey Tan, Claudia Tanskanen,
Qianyi Li and Xiaolin Yin,
INT robotically assembled chair,
B-Pro Research Cluster 4,
Bartlett School of Architecture,
University College London (UCL),
London,
2016

The INT chair uses an industrial robot to assemble serialised timber building blocks into a variety of structures. Rather than first computing an overall form, in this case every design and fabrication decision is computed only at the moment the robot picks up an element.

Discrete architecture develops design strategies for serially repeating, recombinable sets of generic discrete elements that can be assembled into fully functional and complex buildings.

Gilles Retsin Architecture,
Tallinn Architecture Biennale Pavilion,
Tallinn, Estonia,
2017

Testing the feasibility of discrete assembly strategies at the 1:1 scale, the pavilion makes use of plywood building blocks that exist independent of the whole and can be used to assemble a variety of small structures.



Generic timber building blocks are clustered together to form a loadbearing column, while the same element is used as a beam in the floor and ceiling planes. The assembly of the elements does not follow rigid geometrical notions and remains open so that it can be further adapted at any moment.

The pavilion articulates a horizontal, slab-like unit derived from a design for a large housing block. In this, the pavilion is more like an abstract prototype for a system of production.

This side of the pavilion is more informal and demonstrates the notions of an unfinished, open whole defined by jagged, open edges.

For the Biennale, 83 building blocks were assembled into a fragment of a large-scale housing project, articulating a horizontal direction that suggests an abstract housing unit. Unlike a Modernist assembly, the building blocks are not predefined, geometric types – like columns or slabs – that only operate for a specific function. And unlike a continuous, parametric design, these parts are not derived from a predefined whole, but pre-exist the design and are open ended. This approach has significant consequences for computation. Rather than computing an overall system from which the parts are derived, the parts themselves are the basis for the computational process. The underlying computational process is in this case not indexical to a natural process, but is based purely on the relations between parts, therefore bypassing the representational gap between the digital model and the physical reality as the parts that are computed are also the actual parts that construct the physical building. This is an important shift away from earlier generations of computational design that were all too often referential to natural processes, linearly derived from external environmental inputs or top-down optimisation criteria.

Digital Syntax

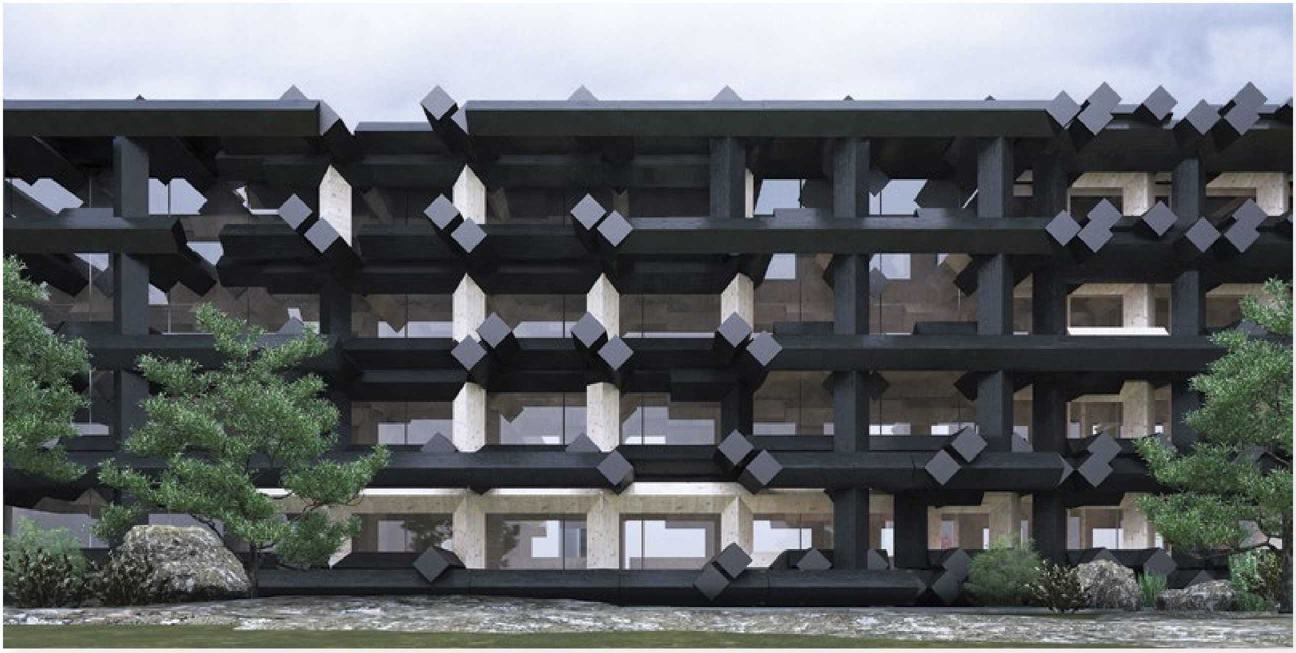
While the before dwelled on arguments of automation and its political and social implications, it is important to point out that there are radically new architectural opportunities to be explored in the shift to the Discrete, beyond mere logistics or efficiencies. Building elements understood as hierarchically equal, generic units have no function or meaning prior to assembly. Meaning and function become an emergent property of the interaction between parts. Unlike Modernism or the early digital work, Discrete architecture is therefore no longer defined by strict hierarchies between predefined parts, but becomes free, open and adaptable.

In the Diamonds House (2016), a multifamily residence in Belgium, for example, a wholly new, ironically almost 'organic' tectonic appears, where there is no more distinction between structure and cladding, column or floor. A complex, functional whole is achieved as an emergent property of the interaction of simple, serialised elements that pre-exist the design. The Diamonds House can no longer be understood as a defined super-form, delimited by archetypical geometry such as the line, plane or surface. Instead of a clear distinction between solid and void, or figure and ground, we now have an abstract volumetric space, a point cloud, within which elements, bits and pieces take a position, and through their recombination enable functional conditions for inhabitation. This results in an open and blurry architecture that has a certain resistance to the 'image' that has haunted architecture over past decades, from the Postmodern to BIG's iconic diagrams or parametric sculptural super-forms.

Using similar elements to the Diamonds House, the 200-metre (650-foot) long Project for a Housing Block (London, 2018), although based on serialised, repeating elements, demonstrates how each of the apartments is fundamentally different and unique as a result of the recombination of generic building blocks. It shows that unlike Modernist housing projects, a Discrete design agenda can achieve differentiation at no extra cost. Moreover, this differentiation is not superficial or restricted to the cladding as is often the case in a housing block based on an overall super-form. This is a deep differentiation, where every apartment has a unique spatial layout defined by the recombination of generic elements. Just as in the Tallinn Architecture Biennale Pavilion, this differentiation is not inaccessible or expensive. The serialised elements are prefabricated, and it is only their placement that is differentiated, which in an automated and digital workflow is not more expensive.

Gilles Retsin Architecture, Project for a Housing Block, London, 2018

This project for a 200-metre (650-foot) long housing block makes an argument for the shift from mass customisation of parts to mass customisation of assemblies. A repeating, serialised element is positioned in a voxel grid and combines with neighbouring parts to produce a functional structure. The organisation of the building is therefore continuously differentiated in every instance while only making use of repeating elements.



Low Resolution

Once it is established that architecture is no longer about defining an overall super-form, but about the relations between the parts, the resolution or quantity of these parts does not necessarily matter. The same approach could run on a resolution of thousands of elements or just five; fundamentally, the relations between the parts are not different. The proposal for the Suncheon Art Platform (2016), a museum in South Korea, further explores a lower resolution, working with just a few extra-large elements ranging from 10 to 15 metres (30 to 50 feet) long. The extreme large scale of the elements here assigns an even stronger importance to the parts than in the more high-resolution Diamonds House. Increasing the size of the parts results in an architecture that is less blurry and cloud-like, reintroducing a strong and clear figure while remaining diffused and open at the same time. The Nuremberg Concert Hall (2018), a competition proposal in collaboration with architect Stephan Albrecht, provocatively explores this tension of resolution and abstraction. The project consists of a greatly reduced number of extra-large, prefabricated cross-laminated timber elements that are populated in a voxel space. Despite the lower resolution, the syntax of this building remains equally radical: there are no columns or slabs, just one repeating element that defines an almost organic, monolithic structure. The assembly of these elements results in what seems like a perfect box. However, ontologically speaking there is no super-form box, only an assembly of hierarchically equal parts. The Nuremberg Concert Hall project explores the limits of resolution and differentiation and is most critical of the expectations that have driven the last two decades of digital research. Using Rem Koolhaas's words in this context, it has 'a high tolerance for repetition and an even higher tolerance for excitement'.[3]

Gilles Retsin Architecture and Studio Stephan Markus Albrecht, Nuremberg Concert Hall, Nuremberg, Germany, 2018

This proposal for the new Nuremberg Concert Hall is based on a voxel space where every voxel contains a notional V-shaped element. These are then digitally assembled into larger, repeating L-shaped sections and physically translated into cross-laminated timber sections. The entire building is defined by one material process, therefore shortcutting the production chain.

Gilles Retsin Architecture, Suncheon Art Platform, Suncheon, South Korea, 2018

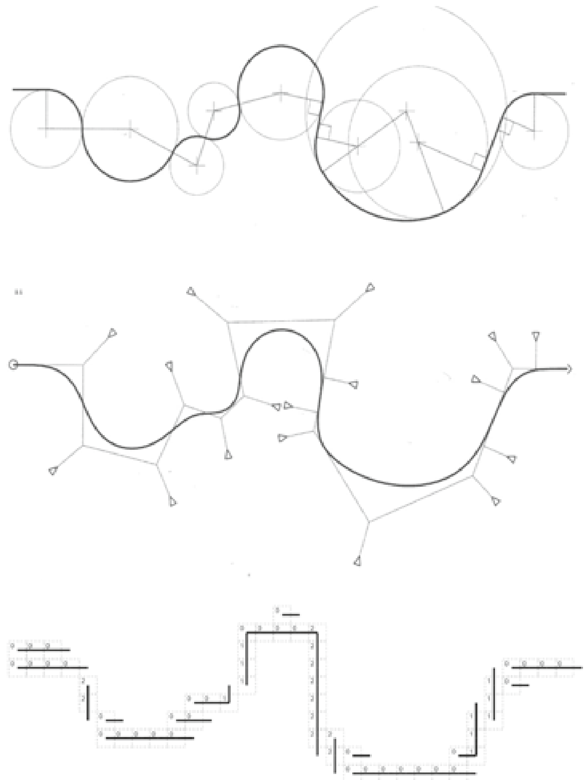
This competition entry for a new museum makes use of extra-large timber elements of up to 15 metres (50 feet) long. The elements contain pre-installed building services and can be combined into a variety of functional structures. Here they form a series of pavilion-like structures around a network of courtyards.

To summarise the shift from continuity to discreteness, it is useful to refer to Greg Lynn's spline diagram, first published in his seminal *Animate Form* in 1999. The diagram compares a Modernist assembly to the continuous differentiation of the NURBS curve, without parts.[4] In his book *The Mereological City* (2016),[5] Daniel Koehler describes a discretised 'broken curve' as per Mario Carpo's earlier, seminal text.[6] In the same spirit, as a comparison, a voxel-based discretisation of a curve can be added to Lynn's original diagrams. Made of discrete building blocks, this digital 'curve' shares the notion of assembly with the Modernist curve Lynn originally referred to. However, this form of assembly is no longer based on geometry and fixed types, but on a digital logic of generic units. The initially Modernist understanding of architecture as an assemblage of prefabricated, discrete elements here enters the new domain of the digital, resulting in an automated architecture that is both efficient and mass produced, but also excessive and unique. Shifting from 'digital design' to automation, this is the context for a Discrete architecture. To form the basis for a complex and qualitative automated architecture, we need first to redefine its fundamental elements. ⅅ

Notes

1. Nick Srnicek and Alex Williams, *Inventing the Future: Postcapitalism and a World Without Work*, Verso (London), 2015.
2. Neil Gershenfeld *et al*, 'Macrofabrication with Digital Materials: Robotic Assembly', in Achim Menges (ed), ⅅ *Material Synthesis: Fusing the Physical and Computational*, September/October (no 5), 2015, p 123.
3. Rem Koolhaas in conversation with Vladimir Pozner at the Moscow Urban Forum, 17 July 2018.
4. Greg Lynn, *Animate Form*, Princeton Architectural Press (New York), 1999.
5. Daniel Koehler, *The Mereological City: A Reading of the Works of Ludwig Hilberseimer*, Transcript Verlag (Bielefeld), 2016.
6. See Mario Carpo, 'Breaking the Curve: Big Data and Design', *Artforum*, February 2014; www.artforum.com/print/201402/breaking-the-curve-big-data-and-design-45013, and Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*, MIT Press (Cambridge, MA), 2017.

The initially Modernist understanding of architecture as an assemblage of prefabricated, discrete elements here enters the new domain of the digital, resulting in an automated architecture that is both efficient and mass produced



Gilles Retsin, Digital curves (after Greg Lynn), 2016

Greg Lynn's 1999 diagram (top) compares a Modernist assembly of circle fragments to a curvilinear NURBS curve (centre). The NURBS diagram rejects the notion of parts and argues for a complete continuity. Here, a new diagram is added below, based on a discrete, computational notion of assembly, suggesting a parallel with the Modernist notion of assembly, but with parts that have a digital logic – generic units detached from type, geometry or predefined meaning.

Mollie Claypool

OUR
AUTOMA
FUTURE

A Discrete Framework for the Production of Housing

TED

Ossama Elkholy,
Cooperative Casting,
Unit 19,
Design Computation Lab (DCL),
Bartlett School of Architecture,
University College London (UCL), London,
2018

In Cooperative Casting, a discrete kit of ½ EPS moulds that can attach to one another are used to assist in a quick initial deployment and occupation of the sites, enabling users to negotiate living space with their neighbour by rotating the combined uncast pieces. Casting the moulds adds permanence to the user's dwellings, but more importantly becomes used as a negotiation tool for further adaptation, expansion or evolution of the building as a whole.

What are the social, economic and political consequences of a shift towards full automation for the production of architecture – and, specifically, housing? It is a question that an experimental studio within the Design Computation Lab at the Bartlett School of Architecture, University College London has been exploring for several years. The lab's co-director **Mollie Claypool** discusses the philosophical, theoretical and design background against which their investigations have been carried out, and presents some of the housing fabrication projects that they have produced.

In a world plagued by a housing crisis where millions live without adequate shelter, how can a fully automated production chain for architecture enable us to produce more quickly, more efficiently and with highly reduced costs, housing that can respond to changes in family structures, in the way we organise our communities, and in how we relate to our physical and virtual environments? How can the automation of the built environment enable us to rethink the way in which we incorporate these technologies and new social and economic frameworks into architectural design and construction practices that engage with wider communities that include architects and contractors, but also users/inhabitants, policymakers and/or other stakeholders? How does this social awareness affect historical and cultural understandings of the meaning and value of what the Discrete holds for architecture? These are some of the questions which have been the catalyst for a body of work produced over the last four years in Unit 19, an experimental architectural design studio that is part of the Design Computation Lab (DCL) at the Bartlett School of Architecture, University College London that develops Discrete, automated frameworks for the production of housing.

There are several paradigms that Unit 19's work has contextualised itself against, within and/or in reaction to, as a means of projecting potential possibilities for the future of architectural design and construction. The work draws on the writings of contemporary philosophers and theorists, and notably on technological left-accelerationism as expounded by Nick Srnicek, Alex Williams, Benjamin Bratton and the collective Laboria Cuboniks. Contextualising the work alongside manifestos such as Laboria Cuboniks' 'Xenofeminism: A Politics for Alienation' (2015), Unit 19 believes in the need to 'strategically deploy existing technologies to re-engineer the world'.[1] This is not an impossible challenge, nor is it 'a free-floating project, since [the] frameworks […] already exist and have traction in the world'.[2] It requires an assessment of, engagement with, and disruption of the economic, social and political issues that currently restrain societal shifts towards Discrete design and full automation, whether these are political, economic or cultural, or are stereotypes or discriminatory practices.

Finally, We Are Digital

Architecture is a profoundly material discipline that must acknowledge whom it is supposed to serve in more meaningful and valuable ways. To work with a Discrete model is therefore to be against neoliberalism, monopolisation, centralisation, customisation, localism, consumerism, the analogue, non-scalability, and highly Discrete and laborious design production (some being qualities of 'folk politics').[3] By promoting systemic thinking, universal and flexible frameworks, economies of scale, platforms, open-source, decentralisation, the prototypical, mobility, prosumerism, the digital, scalability, and continuity in design production, we can propose an 'all digital' or 'wholly digital' Discrete approach to the automation of housing production.

As Srnicek explains further in *Platform Capitalism* (2016), 'in order to understand our contemporary situation, it is necessary to see how it links with what preceded it. Phenomena that appear to be radical novelties may, in historical light, reveal themselves to be simple continuities.'[4] A new generation of designers are now questioning the lack of social value and impact of the work of previous generations of the digital which was ultimately unable to translate into architecture and which holds real positive value for, and of, the wider public. That work, using Srnicek's terms, therefore constitutes 'simple continuities'. This is aligned with the argument towards the discretisation of the spline that the architectural historian Mario Carpo argued for in his essay 'Breaking the Curve' in *Artforum* in 2014.[5] It draws on work on digital materials by Neil Gershenfeld at Massachusetts Institute of Technology (MIT) Center for Bits and Atoms who defined a digital material as being 'assembled from a discrete set of parts, reversibly joined in a discrete set of relative positions and orientations'.[6] Digital materials by their very nature are able to transcend scales and platforms due to their (geometric, structural, material) abstraction and therefore can be more inclusive and equitable as a framework for design.

An all-digital Discrete approach has roots in 20th-century architecture, particularly in the work of Jean Prouvé (Maison Tropicale, 1949–52), Buckminster Fuller (exemplified by his book *Nine Chains to the Moon*, 1938) and Frei Otto (notably the Munich Olympic Stadium, 1972) who developed entire production chains for their projects (amongst others surely also recognised elsewhere in this issue of AD). However, these architects were still limited by the modernist paradigm for architectural syntax – ie column, beam, floor slab, stair etc (although Fuller made some progress in disrupting this with the Dymaxion House (1930), as did Otto). When we move away from building elements being specific to their architectural function and towards an architecture made of a discrete set of parts, then we begin to move into the wholly digital paradigm, thinking of building blocks as open-ended, scalable, universal and versatile. Contemporary projects such as WikiHouse (2011–) or the work by Ensamble Studio such as Cyclopean House (2014–16) are attempts to pursue aspects of a wholly digital project. WikiHouse still exists within earlier digital paradigms because it is a highly bespoke and customised model for the production of housing. Similarly, the Cyclopean House has a high degree of fixity even though it utilises distributed manufacturing and is made of a discrete kit of parts.

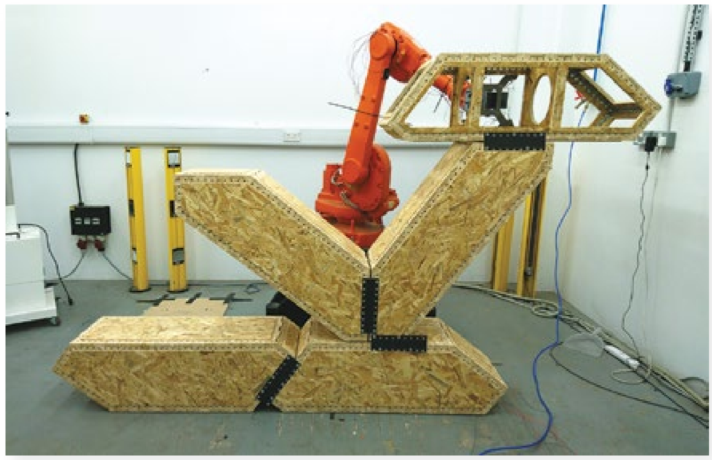
Prosumerist Co-production

Today's smart gadgets and devices that emphasise an individualised and real-time fully customisable experience of the built environment are ubiquitous. This paradigm of the individual is ignorant of the meaning and value that that individual could add to the process of producing their physical environment: it is merely the customisation of a standard. The 'end-user' has a limited amount of perceived value in this kind of economic model. Unit 19/DCL is against privileging the notion of the 'end-user' as well as customisation for the sake of a 'personalised' architecture, and is for the integration of the 'user' at all stages of design, fabrication, assembly and inhabitation of architecture. Unit 19 projects recognise that the way in which many digital technologies have been used succumb to the constraints and protocols determined by systems of power and centralised networks of capital and capitalist production.

By advocating a participatory, co-produced framework for housing, the concept of 'prosumption' or the 'prosumer' rather than consumption and the consumer can be engaged with. This enables prosumer(s) – embedded at each stage of the design, fabrication and assembly process, and over the course of the period of ownership of the house – to increase the value of their own impact into the architectural system by embedding their knowledge into our systems of production. The work of Ivo Tedbury (2017), notably his Unit 19 project semblr, explored developing open-source software such as web- or desktop-based apps that enable non-specialised users (the 'layman') to access design tools in order to use them to specify their needs and test different outcomes, using economic, physical (eg site-based) and/or social constraints to do so. Users can specify how many parts they need according to their current needs, taking into account any possible predictions for required adaptations over time to changing financial or social circumstances.

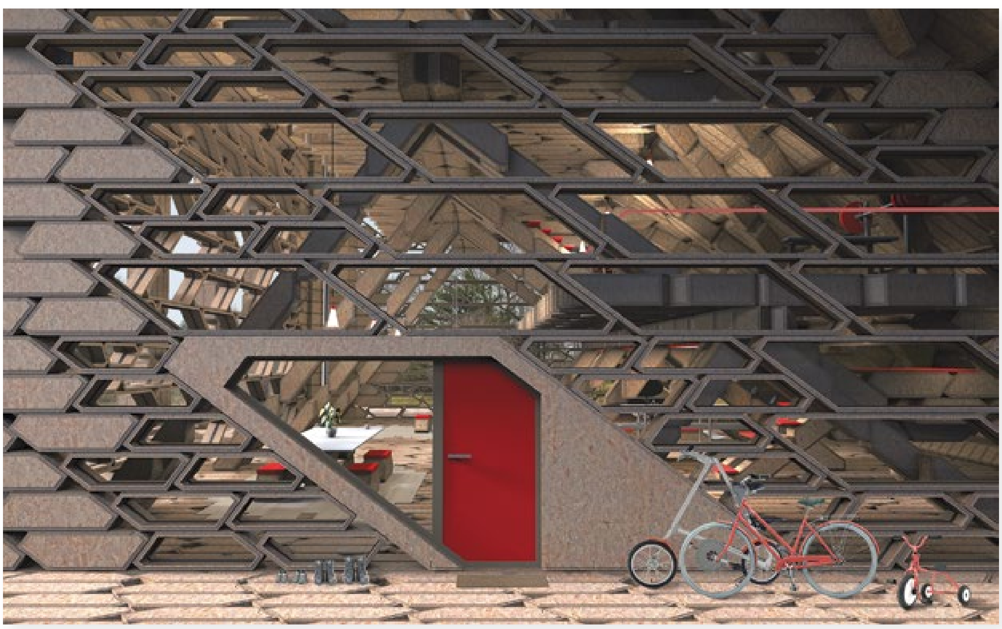
As in many Unit 19 projects, semblr proposes an online platform where users can test potential building outcomes utilising specific constraints such as financial, familial, contextual or other requirements which are constrained against structural, material and geometric possibilities of the kit of parts.

Ivo Tedbury,
semblr,
Unit 19,
Design Computation Lab (DCL),
Bartlett School of Architecture,
University College London (UCL),
London,
2017



The system's technical foundation is a single syntax for cross-disciplinary coordination between the building elements (and their geometry), and the robot's end effector (tested here with an industrial robot).

In semblr, discrete timber building blocks and distributed robots that move relative to the structure that they assemble make up the building assembly process.



This platform enables outcomes to be tested for changes that may be required over time, allowing users to expand or contract their home as required, making it more or less permanent depending on lifestyle or other constraints.

Automated Redistribution

Fully automated technologies can also aid in the predicting of how the system may cope with or anticipate changes in the future, as well as reducing the amount of human labour (and therefore a degree of overall cost of design and construction). Autonomous robots can be used to assemble, disassemble and reassemble houses entirely, picking up parts and distributing them where required, as in Ivo Tedbury's project semblr (2017). These techniques require substantially less human labour than is typical of traditional construction or assembly of housing, enabling a redistribution of resources across society.

On a larger scale, by designing into the framework a chance for wider community-led engagement with the geometric (structural, spatial, material), economic and social rules of the part-to-whole relationships that are built into discrete kits of parts, communities at whatever scale can inform the way that the social, political or economic models of the whole (eg the architectural outcomes) are realised. More traditional construction materials such as precast concrete can be utilised alongside discrete kits of vacuum-formed moulds that allow for relatively quick, repetitive fabrication of parts, such as in Oscar Walheim's project Avila Automatic (2017). Lightweight materials such as foam (sprayed with fibre-reinforced concrete), as in Julia Baltsavia's project i-Architecture (2017), or oriented strand board (OSB) as in Alessandro Conning-Rowland's project Chamfer: A Cooperative Housing Platform (2018), can be used and designed to be fabricated for the least amount of waste possible and forego the use of heavy machinery in assembly.

If parts individually act as one half of a mould for in-situ concrete casting, a community can uses the set of expanded-polystyrene (EPS) moulds to design and negotiate spatial configurations over time with varying degrees of privacy and temporality, making areas of the housing permanent by casting when required and negotiated by the community, as in Ossama Elkholy's project Cooperative Casting (2018).

The redistribution of resources through a Discrete model enables inclusivity, distributing knowledge (both specialist and non-specialist) throughout the project, providing for more equitable and democratic production of housing. The design question for architects therefore shifts from how buildings respond to a social or physical context through their appearance or presence, to how they are produced, and thus embody particular cultural conditions, including economic, political or social values. In this, the role of the architect shifts towards that of a designer of a system, where the architect manages a conceptual and methodological framework for architectural production. Importantly, it also enables users to be not passive receivers of knowledge via specialists, but active participants in informing how automated technologies are used and the shifts in conceptions of value and social practices that they might produce. Otherwise, what are we (you, architect) doing this for?

Julia Baltsavia,
i-Architecture,
Unit 19,
Design Computation Lab (DCL),
Bartlett School of Architecture,
University College London (UCL),
London,
2017

i-Architecture proposes an open-source system based on a kit of parts that can be fabricated using robotic hot-wire cutting, allowing for rapid and efficient deployment of an open-ended and adaptive housing project. The discreteness of the parts allows for scalability from the minute stair detail to overall structural organisation.

The redistribution of resources through a Discrete model enables inclusivity, distributing knowledge (both specialist and non-specialist) throughout the project, providing for more equitable and democratic production of housing.

Alessandro Conning-Rowland,
Chamfer: A Cooperative Housing Platform,
Unit 19,
Design Computation Lab (DCL),
Bartlett School of Architecture,
University College London (UCL),
London,
2018

Chamfer enables resident-initiated, funded, democratically designed and self-constructed housing, made possible through shared living, shared knowledge and the combinatorial possibilities of building element chunks. The geometry of these chunks promotes desired spatial and social outcomes, whilst physically they embrace low-cost materials such as OSB and cardboard and highly accessible fabrication technologies such as CNC milling.

Oscar Walheim,
Avila Automatic,
Unit 19,
Design Computation Lab (DCL),
Bartlett School of Architecture,
University College London (UCL),
London,
2017

opposite: Avila Automatic explores a self-replicating, recombinant architecture through the deployment of vacuum forming on computer-numerically controlled (CNC) moulds that generate precast concrete building elements. The discrete and digital formwork facilitates the exploration of a new kind of construction framework that has scalability engrained into the system from the outset.

Towards Discrete Continuity

Advanced digital fabrication and manufacturing technologies such as industrial robots and 3D printers are commonly used in construction either as replacements for human labour (mimicking actions of the human body) or on the other end of the spectrum, as representational devices: to make copies/replicas of existing building elements. Recent examples include SAM the robotic bricklayer by Construction Robotics, and Winsun's 3D-printed houses or 3D-printed wall panels. Buildings realised by the architects of the first digital turn were/are often hugely over-budget and inefficient, as the basic building blocks for architecture are still planned and put together through processes that are very much reliant on techniques developed in the 19th century with the advent of the Industrial Revolution – for example, a very slow, laborious and highly Discrete production framework. In addition, the legal system has only now just begun to catch up with a system where parties are simultaneously an author and owner of a design.

Utilising smart contracts and blockchain, we can speculate on a near-now in housing production that disrupts this dichotomy where design and construction are held in opposition (whether due to financial, political, legal or socio-cultural issues). Ownership can be incremental and capital transparent. Overly specific building elements, as in conventional design where every piece is designed and fabricated with high degrees of specificity and low tolerance, have no place in this kind of model. Instead, through the Discrete, building blocks are part of a feedback loop between design and fabrication. Building blocks can be distributed with an exactness to the virtual model, with high tolerances due to use of robotics to programme both fabrication and assembly behaviours. This is closely aligned to Gershenfeld's recognition that while fabrication technologies are embedded with digital logics, materials were analogue.[7] In a wholly digital model for the production of housing, there is almost no difference in architectural syntax between design, fabrication or assembly. Furthermore, this kind of platform can be coordinated to cross-scale in terms of systems of material to labour, from material manufacturing to post-occupation and from analogue labour to automated labour. A model for Discrete continuity facilitates our inevitable future of full automation. ᗡ

Notes

1. Laboria Cuboniks, 'Xenofeminsm: A Politics for Alienation', 2015, www.laboriacuboniks.net/#zero/3.
2. Nick Srnicek and Alex Williams, *Inventing the Future: Postcapitalism and a World Without Work*, Verso (London), 2015, p 107.
3. *Ibid*, pp 9–13.
4. Nick Srnicek, *Platform Capitalism*, Polity Press (London), 2016, p 9.
5. Mario Carpo, 'Breaking the Curve: Big Data and Design', *Artforum*, February 2014, www.artforum.com/print/201402/breaking-the-curve-big-data-and-design-45013.
6. Neil Gershenfeld, Matthew Carney, Benjamin Jenett, Sam Calisch and Spencer Wilson, 'Macrofabrication with Digital Materials: Robotic Assembly', in Achim Menges (ed), ᗡ *Material Synthesis: Fusing the Physical and Computational*, September/October (no 5), 2015, p 123.
7. *Ibid*, pp 122–7.

Manja van de Worp

Rubens Structures

Traditional built structures are based around fixed load paths, meaning a largely fixed programme. But what possibilities are opened up if load paths can be made flexible? **Manja van de Worp** – who directs YIP Structural Engineering London, teaches at the Royal College of Art in London and leads the Data Informed Structures course at the Institute for Advanced Architecture of Catalonia in Barcelona – introduces the concept of 'Rubens structures'. Engineered with adjustable components, they can cater for a building's evolving usage. Although more resource-hungry in the first instance than their traditional counterparts, they could offer economic and material advantages over time.

A Different Lightness Through Performance Adaptability

Maryan Ewais, Jessica Dias, Lina Salamanca and Luisandres Bonillamillan,
The Continuous Line,
Data Informed Structures course,
Institute for Advanced Architecture of Catalonia,
Barcelona,
2014

The Continuous Line is a so-called Rubens structure: a design type that aggregates structural performance, here allowing for different seating positions through overlaying different load paths.

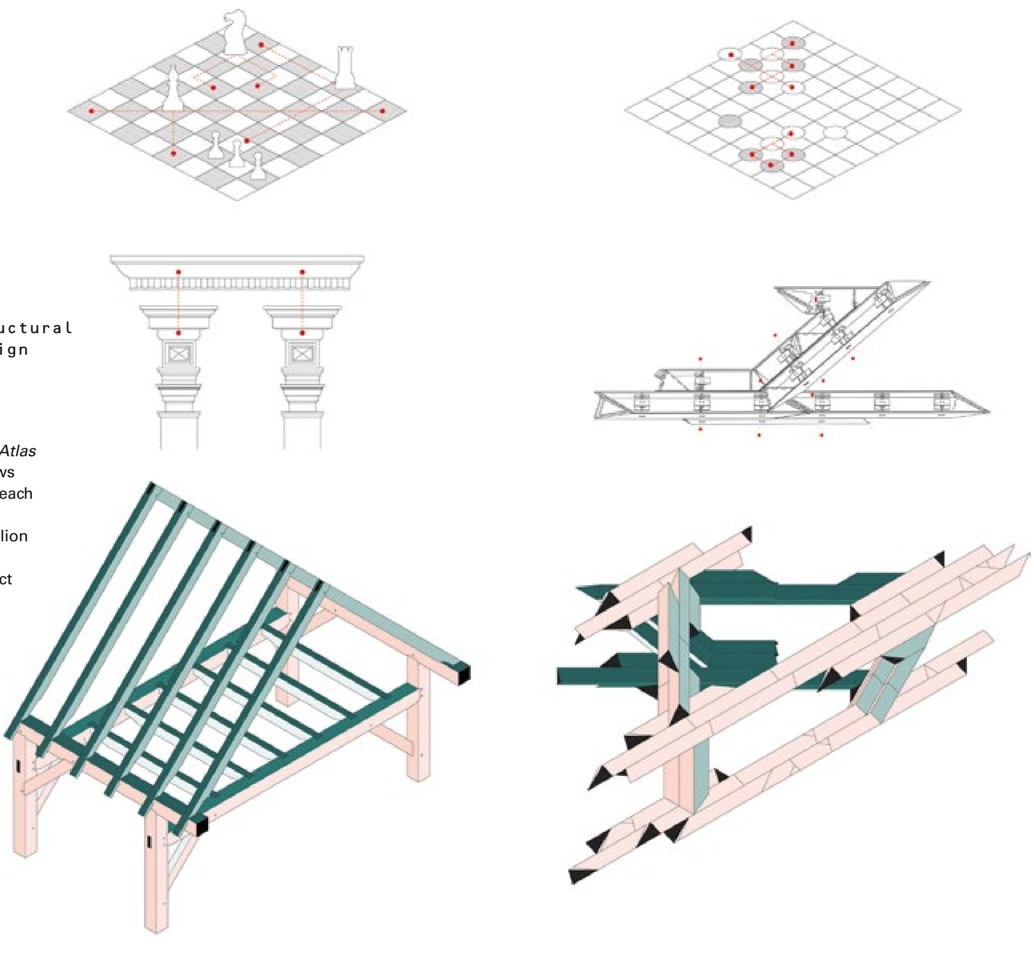
Rubens structures challenge the traditional philosophy of structural design. Their name stems from the figures of women in the paintings of the Flemish artist Peter Paul Rubens (1577–1640): famously ample rather than skinny. Traditional optimal structural design is concerned only with using the least amount of material to solve a single purpose. Rubens structures however propose a heavier lightness – one that has redundancy yet is still efficient. Structures are therefore seen as discrete elements which are organised differently over time. While the traditional fixed structural design approach limits flexibility of use, Rubens structures embrace the multiple future uses/performances that a structure can provide.

Reshaping the static nature of buildings, Rubens structures have the ability to change over time without any additional change in elements. They are designed to adapt their performance by triggering different load paths to reorganise their structural response based on external inputs. A continuous dynamic equilibrium is created with a Rubens structure's 'surroundings' and system change is made possible within one entity. An example of this is The Continuous Line (2014), a chair designed by four students on the Data Informed Structures course at the Institute for Advanced Architecture of Catalonia (IAAC), which overlays a variety of load paths. It combines the structural performances for different inputs of seating position and orientation and creates a single structure to embody them all. The Continuous Line forms a relationship between location of load, support and geometry with a structural response triggered by each orientation of the chair.

Difference in Degree

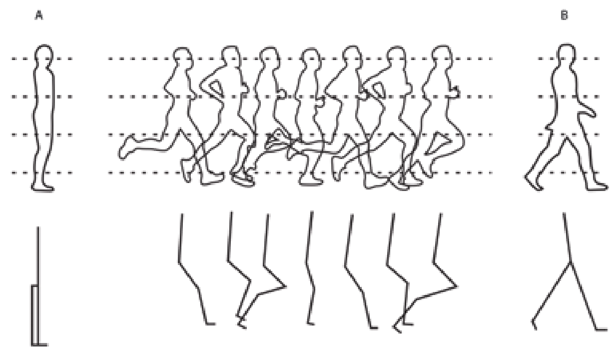
When designing Rubens structures, structural elements must not have a single defined performance but instead offer multiple possibilities. Gilles Deleuze uses the analogy of the games of Chess and Go. In Chess, each piece is defined by its performance – that is, by its ability to perform in a specific way on the chessboard. Each chess piece is 'different in kind'. In the game Go, every piece has the same capacity, yet its contribution to the overall performance is not fixed, as it depends on its position – that is, on its association to its neighbours. Each Go piece is 'different in degree'.[1]

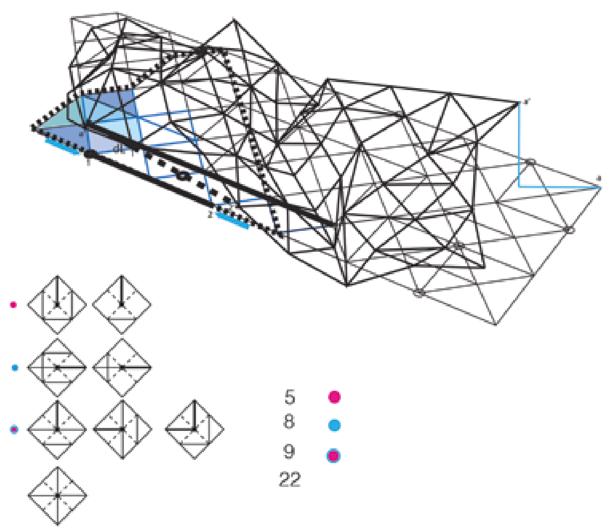
Structurally an element with a single use can be seen as different in kind – such as where a beam behaves differently from a column both in terms of load transfer as well as design methodology (a beam being designed for bending, while a column is designed for compression which may cause bending). The Tallinn Architecture Biennale (TAB) Pavilion (2018), designed by Gilles Retsin and engineered by YIP Structural Engineering London, is a structure made up of discrete and block-like elements that utilise a Rubens design strategy. The elements find their function through specific clustering, and therefore allow the possibility of change and performance over time. The design does not consist of elements with a specific structural typology. Rather, different element properties are defined through connections and relationships to neighbouring elements adopting a notion of Go; of difference in degree. By reorganising the same elements, multiple different equilibriums can be achieved, and thus multiple designs.

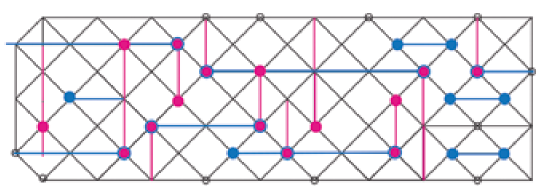


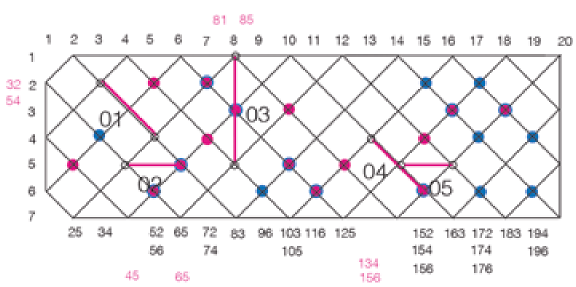
YIP Structural Engineering London, Comparison of traditional 'skinny' structural design and the 'Rubens' structural design principles of the Tallinn Architecture Biennale (TAB) Pavilion, 2018

Inspired by Reiser + Umemoto's comparison in their book *Atlas of Novel Tectonics* (2006), the left side of the diagram shows 'difference in kind', represented as a timber system where each element has a specific role and performs only the function it is designed for, like in Chess. On the right is the TAB Pavilion structure, which is based on 'difference in degree', where an element's performance is generated by the impact of neighbouring elements, like in Go.









Continuous Equilibrium

Exploring a similar design methodology, our bodies are likewise not designed to stay still and remain stable. When we walk, we use temporary instability in order to transition from one stable state to another in a continuous equilibrium. To allow this transition, neighbouring elements must change their role within the whole (load transferring from left to right leg and so on). The exploration of a continuous equilibrium between stable states was the focus of my personal research on the Emergent Technologies and Design (EmTech) postgraduate course at the Architectural Association, London (2006–7), which started with applying structural redundancy methodology in a folded plate system solely constructed of hinges and cables. By strategically locating 'mountain' and 'valley' folds, the system transforms between three different states. The difference in degree is based on the geometric configuration it is in, its components' (local) fold direction and their global relationship to the cables. In the dynamics of the structural system, material performance, as well as geometry and fabrication, do become a composite – and cannot be seen as independent in driving structural behaviour. A dynamic continuous equilibrium is formed within one system housing multiple designs.

Manja van de Worp,
Continuous Equilibrium,
Emergent Technologies and Design,
Architectural Association (AA),
London,
2007

The project explored principles of walking, where movement creates a stable transition between states, to allow for a multiplicity of forms to be captured within one system.

A dynamic continuous equilibrium is formed within one system housing multiple designs

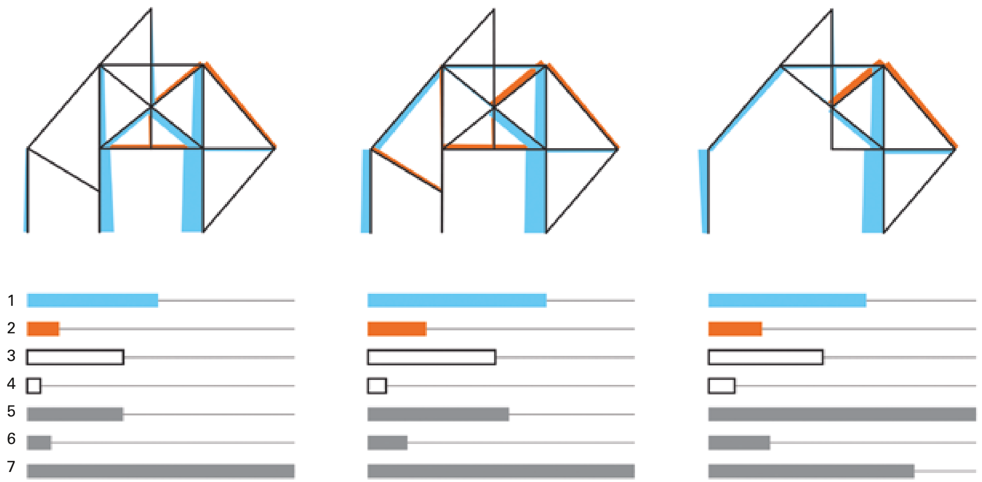
Efficiency Through Redundancy

Structural optimisation reaches beyond the action of making the most effective use of a singular situation, or optimisation for a few specific cases. In redundant structures, not all elements work to their full capacity or equally hard, as evident in any structural analysis. If we take this into the case of extreme redundancy – where elements are capable of taking on many roles – parts can be mobilised differently over time. By directing loads in a specific way, different geometries allow structures to be expanded or altered in such a way that the architectural impact of design can be rethought.

Change over a lifetime no longer means the addition of material, but rather the mobilisation of less-used paths within the designed structures. Through the addition or removal of specific elements, as well as the addition of new supports and strategic loading of the structures, these changes all enable different performances to allow different design responses by using their redundant yet efficient properties.

YIP Structural Engineering London, Spatial and growth adaptation by triggering different load paths, 2018

below: The ability to transform in function because of redundancy is a trait of Rubens structures. This analysis series showcases the use of lower-stressed elements to increase a structure's height during the course of its life, as well as changing its function by removing elements and thereby utilising the existing structure more. Series 1: Manipulation of load-path through support conditions. Series 2: Manipulation of load-path utilising redundancy in element performance.



1 Maximum compression

2 Maximum tension

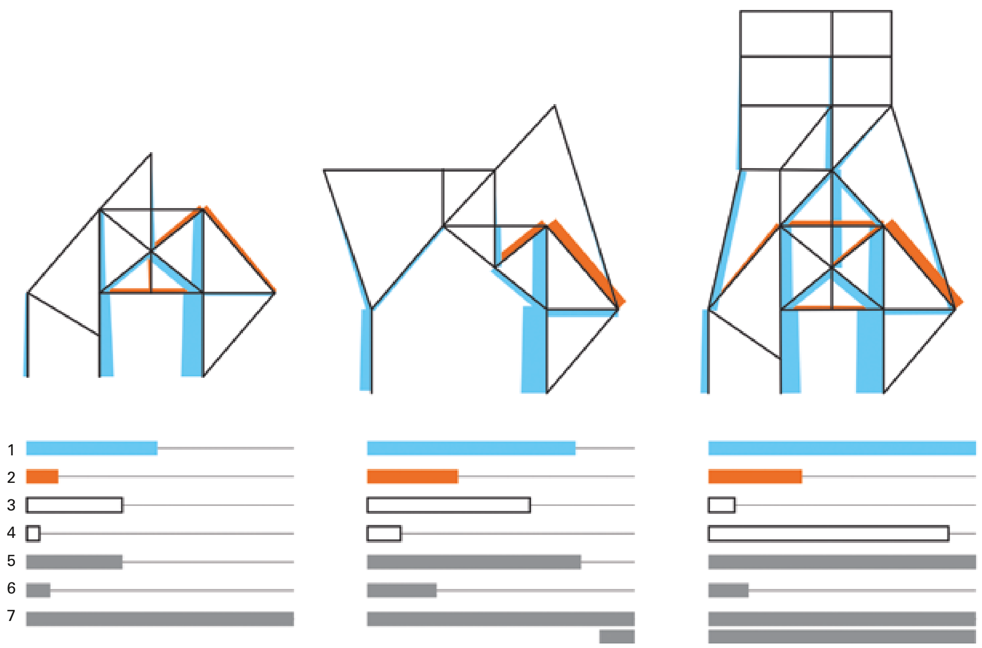
3 Maximum utilisation – axial force

4 Mean utilisation – axial force

5 Maximum utilisation – combined force

6 Mean utilisation – combined force

7 Mass increase

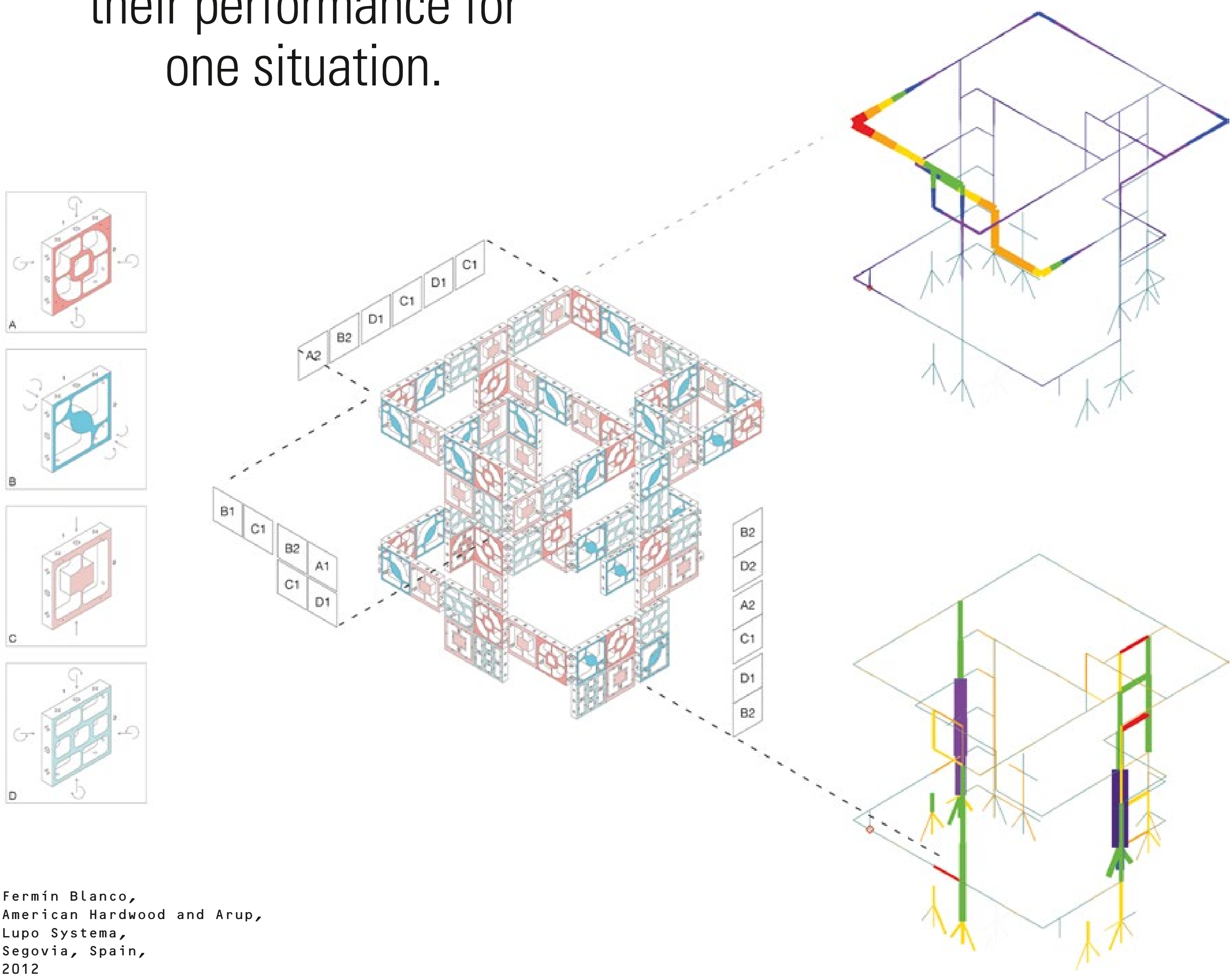


We can now understand and predict how certain assemblies change their behaviour by triggering load paths, and thus alter the structural typology. This is very different from solely checking their performance for one situation.

New Models of Structural Analysis

In structurally analysing Rubens structures, it is necessary to challenge the fixed state and, together with that, the performance of a single element. For example, in Lupo (2012), a timber-element-based system in tulipwood designed by Fermín Blanco and engineered by Arup for Segovia, Spain, the role of each element can constantly be redefined by the whole, throughout its lifespan. Elements are flexible in the way they connect to each other in order to form larger assemblies that change performance based on an anisotropic nature of the pieces and their connectivity.

Traditionally, the absolute most conservative design combination drives the design. But if we are in control of multiple outcomes – for example, by setting a range of possibilities and rules – then we are able to redefine the structural design possibilities. We can now understand and predict how certain assemblies change their behaviour by triggering load paths, and thus alter the structural typology. This is very different from solely checking their performance for one situation.



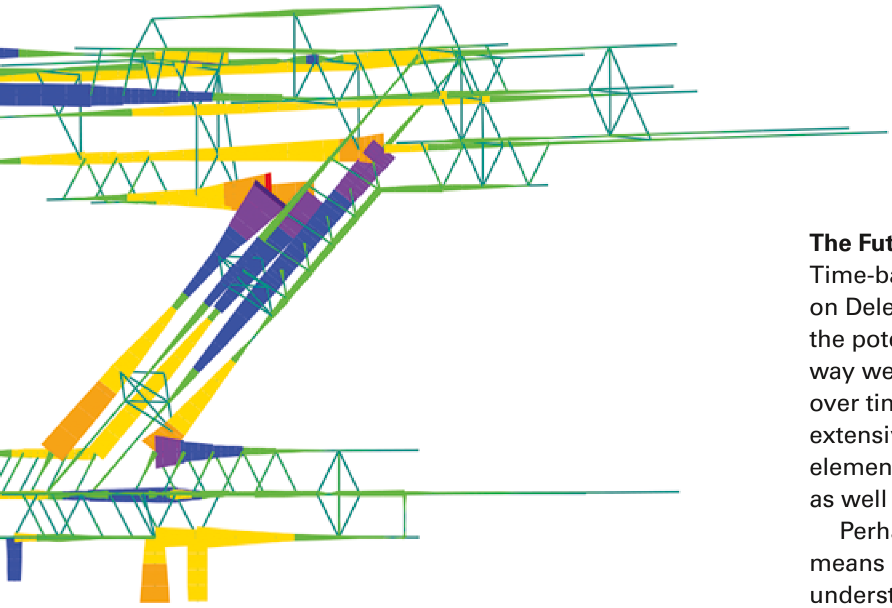
Fermín Blanco,
American Hardwood and Arup,
Lupo Systema,
Segovia, Spain,
2012

above: The behaviour of the structure is dependent on the type of connections and on the position and type of tulipwood Lupo block. In the case of Segovia 2012, a finite set of elements is strategically placed and oriented to respond to overlaying structural needs within the design.

Manja van de Worp,
1 of N: A Rubens Structure for TAB Pavilion,
Tallinn,
2018

The competition winner for the TAB Pavilion uses the ability to re-cluster elements in a different way to enable different structural performance. It is no longer a single analysis or a single design, but one of many.

A multitude of possibilities suggested by a changeable and reusable structure allows for architecture to grow, unfold, transform and form a dynamic continuous equilibrium with its surroundings over its lifetime.



The Future of Structural Time-Based Variation

Time-based variation manifested in Rubens designs builds on Deleuze's 'difference in degree'. They shed new light on the potential of architectural design, enabling a change in the way we conceive structures to allow for function to change over time. Yet these means of time-based variation through extensive redundancy have rarely been implemented. Here elements are being freed from conventional classification as well as conventional structural verification procedures.

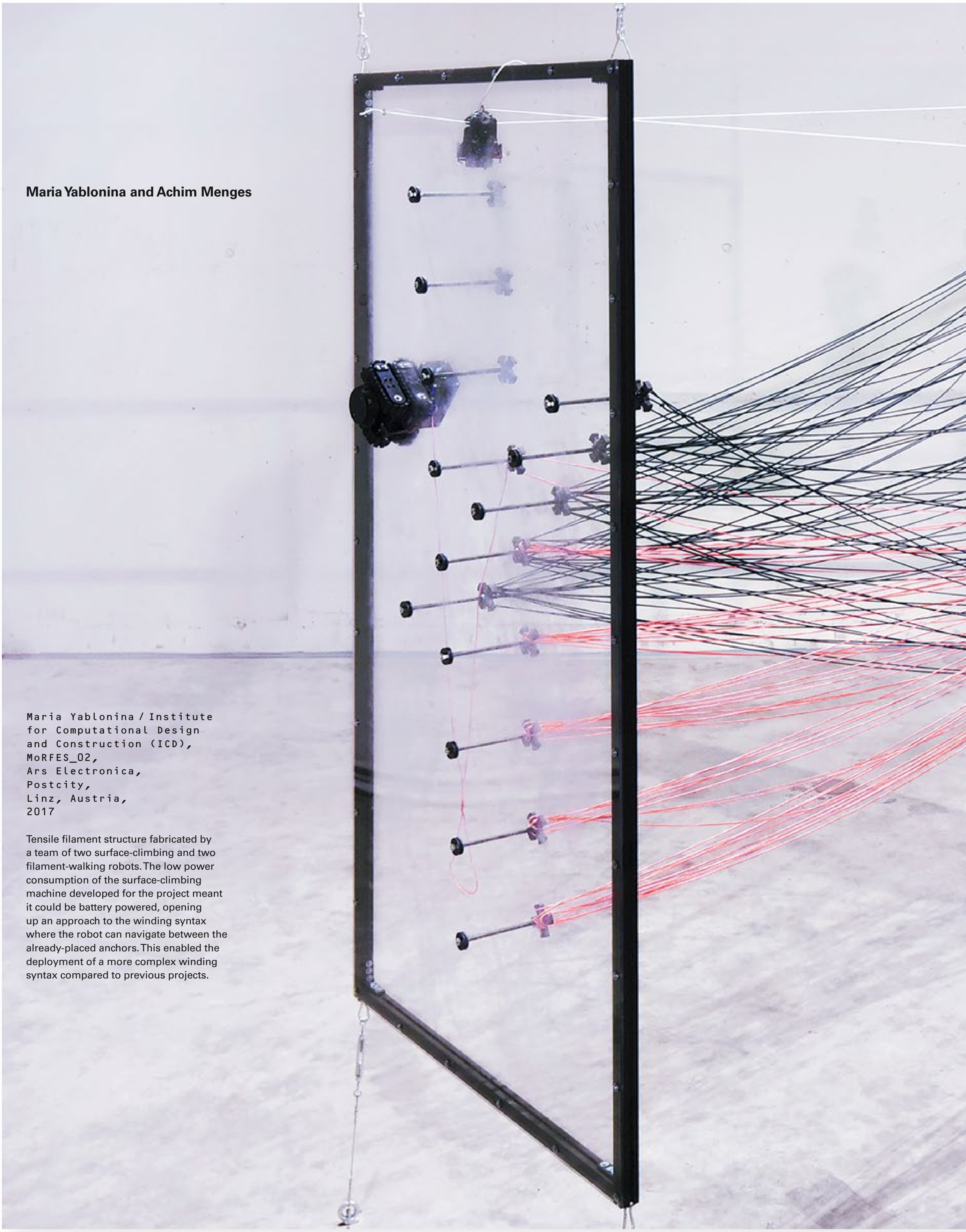
Perhaps structures do not need to be classified by their means of transferring load. When multiple load paths are understood and controlled, structures can allow for multiple means of transferring loads and cannot simply be classified in terms of a single typology. When this system of classification ends, a more closely linked architectural and structural design realm arises. It therefore allows a different scope of structural design for buildings – one that is tuned to what will be needed in the future, designed through changes in structural performance as well as structural behaviour.

A multitude of possibilities suggested by a changeable and reusable structure allows for architecture to grow, unfold, transform and form a dynamic continuous equilibrium with its surroundings over its lifetime. ⅅ

Notes

1. Gilles Deleuze and Félix Guattari, *A Thousand Plateaus* (1980), Athlone Press (London), 1988, Chapter 12: '1227: Treatise on Nomadology:–The War Machine', referred to in Jesse Reiser and Nanako Umemoto, *Atlas of Novel Tectonics*, Princeton Architectural Press (New York), 2006, p 40.

Maria Yablonina and Achim Menges



Maria Yablonina / Institute for Computational Design and Construction (ICD), MoRFES_02, Ars Electronica, Postcity, Linz, Austria, 2017

Tensile filament structure fabricated by a team of two surface-climbing and two filament-walking robots. The low power consumption of the surface-climbing machine developed for the project meant it could be battery powered, opening up an approach to the winding syntax where the robot can navigate between the already-placed anchors. This enabled the deployment of a more complex winding syntax compared to previous projects.

Distributed Fabrication

Cooperative Making with Larger Groups of Smaller Machines

The University of Stuttgart's Institute for Computational Design and Construction is pioneering research into fabrication systems that involve multiple mobile robots performing discrete tasks in tandem. PhD candidate **Maria Yablonina** and founding director **Achim Menges** set out the benefits of their co-design strategy where machine, process and object are considered codependently – as demonstrated by their experiments with thread-like materials.

Over the past few decades, digital fabrication processes have been gaining momentum in the field of architecture and design; some would say gradually becoming the new mainstream.[1] While the construction industry is racing to increase the efficiency of existing processes through automation of work in a conventional construction environment,[2] the field of architectural research is implementing robotic technology towards discovering new materials, fabrication methods and ultimately a new design space. An industrial robot arm has become a somewhat iconic symbol of this undertaking. Research labs and institutions across the world push the boundaries of what is possible in architecture by augmenting robots with custom end-effectors and software, reappropriating them for architectural tasks in all possible materials from brick and wood to 3D-printed concrete and carbon fibre. However, could it be that today, when we are arriving at the point where processes no longer need to be designed specific to their human agent, the metaphor of the arm extension that the industrial robot suggests is not enough?

The Robot Arm is Not (Always) the Solution

Along with high precision and manipulation complexity of the industrial machines, researchers have to accept their vestigial physical properties inherited from the manufacturing assembly-line logic the robots were initially intended for. Robot arms are designed to perform repetitive tasks in controlled factory environments, which is often contradictory to an architectural task of creating unique elements on site. To break out of the lab and production-hall spaces, we need to rethink the relationship between the machine and the object it is producing beyond the assembly-line logic towards a system where the product that is the structure remains static, and machines have to move around it.[3] Examples of such systems, like the Minibuilders project at the Institute for Advanced Architecture of Catalonia (IAAC)[4] and Force-aware Robot Collectives for On-Site Construction at the Wyss Institute for Biologically Inspired Engineering at Harvard University and the Institute for Computational Design and Construction (ICD) at the University of Stuttgart,[5] have demonstrated that designing a smaller bespoke mobile robot specific to the task at hand can be more promising than using available machines.

This is not to say that the next step in advancing digital fabrication is to get rid of the robot arm and start from scratch. A robot arm and a single-task mobile machine are not two opposing models, but rather equal parts of a more extensive library of methods that can be combined into heterogeneous multi-robot systems. An example of such a system is the Institute for Computational Design and Construction and Institute of Building Structures and Structural Design ICD/ITKE Research Pavilion 2016–17 at the University of Stuttgart, where two industrial robots performed high-precision and high-payload tasks while an unmanned aerial vehicle (UAV) transported the material, thus increasing the work envelope of the overall system.[6]

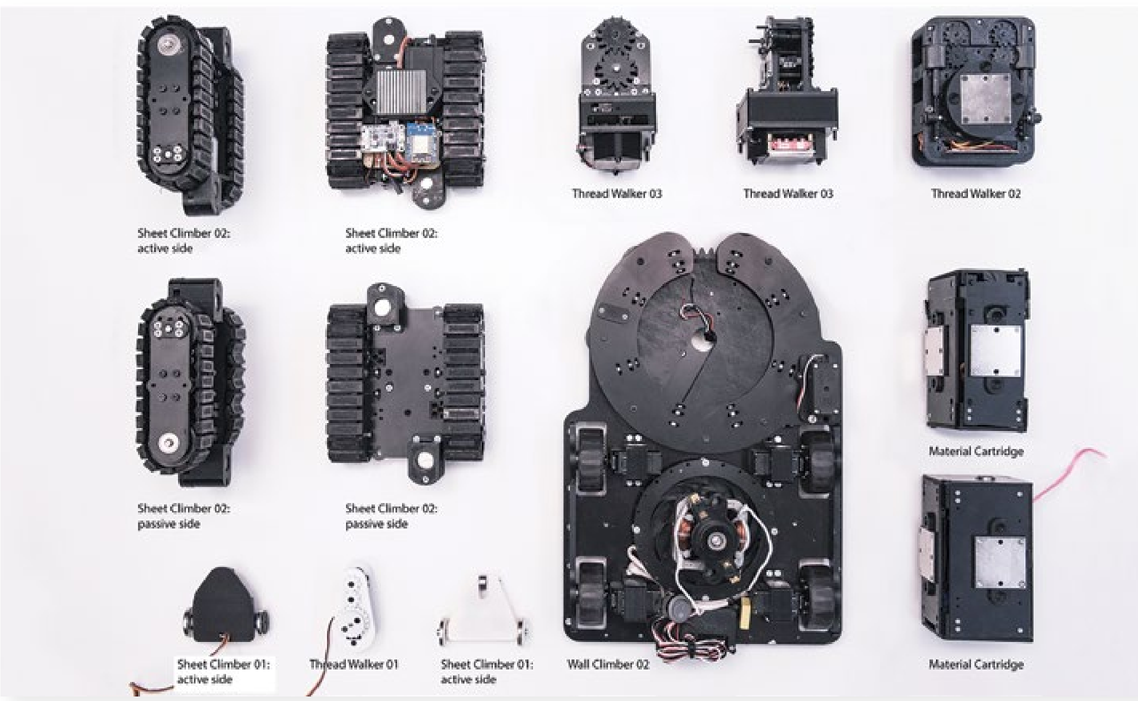
Further development of a broader library of robotic methods implies advancements in hardware tools as well as software and design solutions for heterogeneous multi-machine collaboration platforms where each hardware part is performing precisely the tasks it is best at, contributing its affordances to the overall fabrication goal.

Co-designing the Process, the Machine and the Artefact
Ongoing research at the Institute for Computational Design and Construction (ICD) since 2015 suggests an approach to robotic fabrication where unique tasks are discretised into their essential components: one- and two-dimensional movements that are then distributed across multiple bespoke mobile machines. Thus, the embodied intelligence of the fabrication process is not centralised in one complex robot, but is becoming discrete, allowing for a level of modularity, flexibility and scalability of the process through changing the types and the number of operating units. This approach implies a shift from robot-oriented design,[7] where fabrication processes are derived from the capacity of a given machine, towards a co-design strategy in which the process, object and the machine producing it are developed codependently, the limitations and parameters of one continuously informing others.

Experimenting with Heterogeneous Robot Teams for Filament Materials
The series of experiments and projects undertaken at the ICD demonstrate the potential of the co-design and machinic task distribution strategies applied to fabrication processes of tensile filament structures. Unique scalability and low weight properties of the filament and thread-like materials suggest low-payload mobile machines capable of operating at a variety of scales depending on the desired span of the structure.

The process of building with thread-like material consists of iteratively anchoring it onto the supporting structure in a specific sequence. Performing this robotically requires two machinic routines: anchoring, and transportation of the material between the anchor points. These two routines have become the foundational input for a kit of bespoke locomotion systems and anchoring mechanisms developed as part of the ICD's research. This catalogue of robotic devices is continuously expanding from project to project, the limitations discovered in every experiment becoming parameters for following additions, iteratively augmenting the kit with new machines and operations.

The Mobile Robotic Fabrication System for Filament Structures (2015–18)[8] proposes a collaborative team of two wall-climbing robots that can anchor the material onto preinstalled hooks and pass the material bobbin from one robot to the other. Positioned on two adjacent walls in an interior space, these robots produced a three-dimensional architecture-scale artefact following a precalculated winding syntax and using a real-time path correction algorithm relying on a camera-based tracking system. For the *MoRFES_01* project (Milan, 2017), the robotic system was expanded towards a larger work envelope through the addition of a single filament-walking robot, resulting in a 7-metre (23-foot) long robotically wound structure fabricated in a gallery space. Further increasing the number of units in this system granted an opportunity to use multiple material sources and to complete more complex winding sequences, allowing for broader geometric freedom of the object produced, as demonstrated in the *MoRFES_02* project (Linz, 2017).

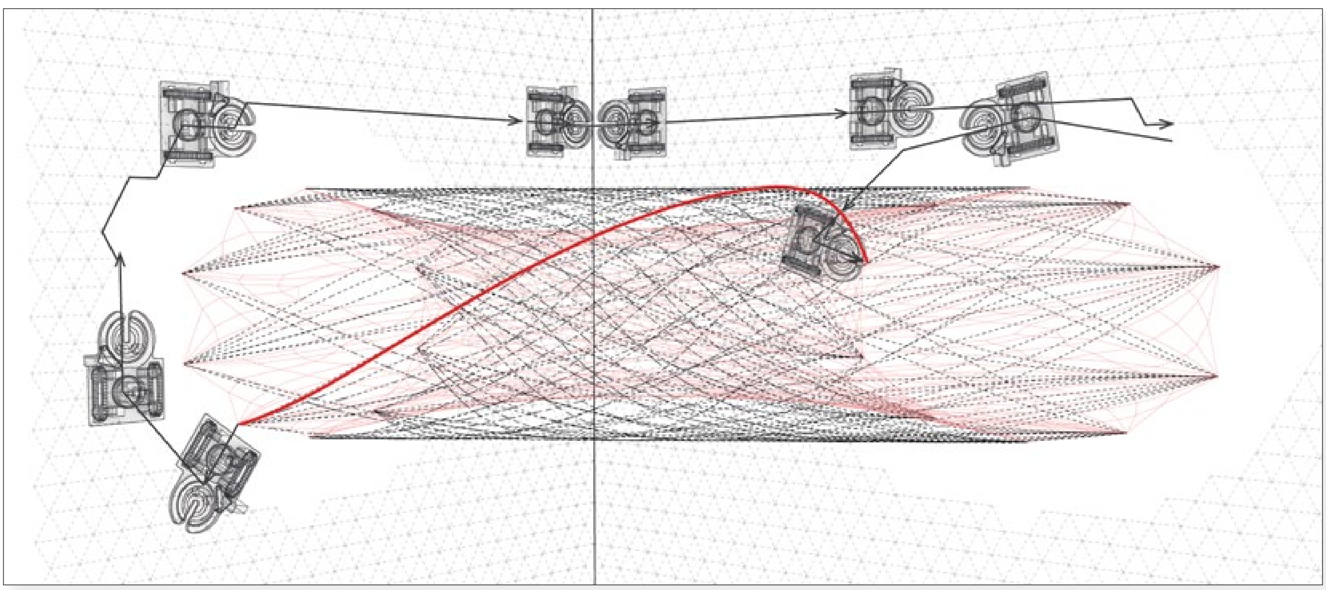


Maria Yablonina / Institute for Computational Design and Construction (ICD), Mobile robotic fabrication systems research, Stuttgart, 2015-18

The current kit of bespoke mobile machines for fabrication with filament materials developed at the ICD. The catalogue is an ongoing project where new devices are iteratively added based on the changing requirements of the fabrication processes.

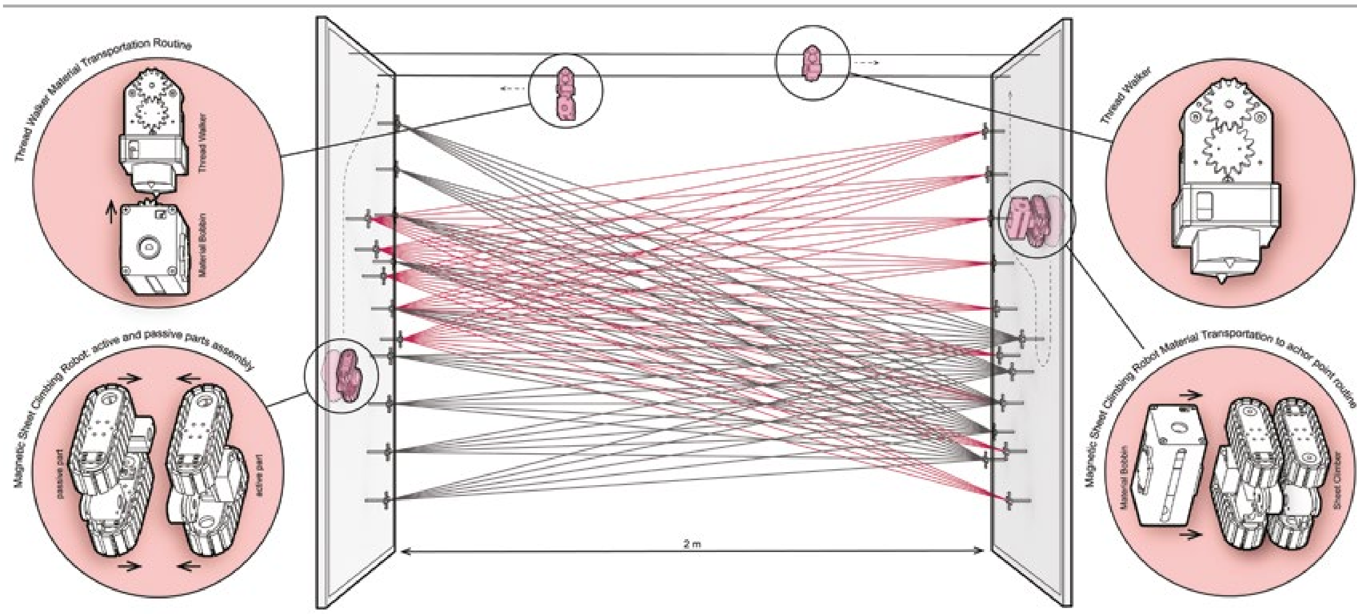
Maria Yablonina / Institute for Computational Design and Construction (ICD),
Mobile Robotic Fabrication System for Filament Structures,
Stuttgart,
2015

Tensile filament structure fabricated by two collaborating wall-climbing robots. By iteratively anchoring and passing the material from one robot to another, a robotic team produces a wound three-dimensional structure anchored to the interior walls. Throughout the fabrication process, the robots rely on an external camera-based perception system for navigation and real-time path correction.



Maria Yablonina / Institute for Computational Design and Construction (ICD),
MoRFES_01,
Milan Design Week,
Logotel,
Milan,
2017

Tensile filament structure fabricated in an exhibition space by a team of two wall-climbing robots and a filament-walking machine. The thread walking machine is transporting the material between two vertical surfaces, while the wall-climbing robots perform the anchoring routines. The robotic winding process was demonstrated live in a series of events open to the public.

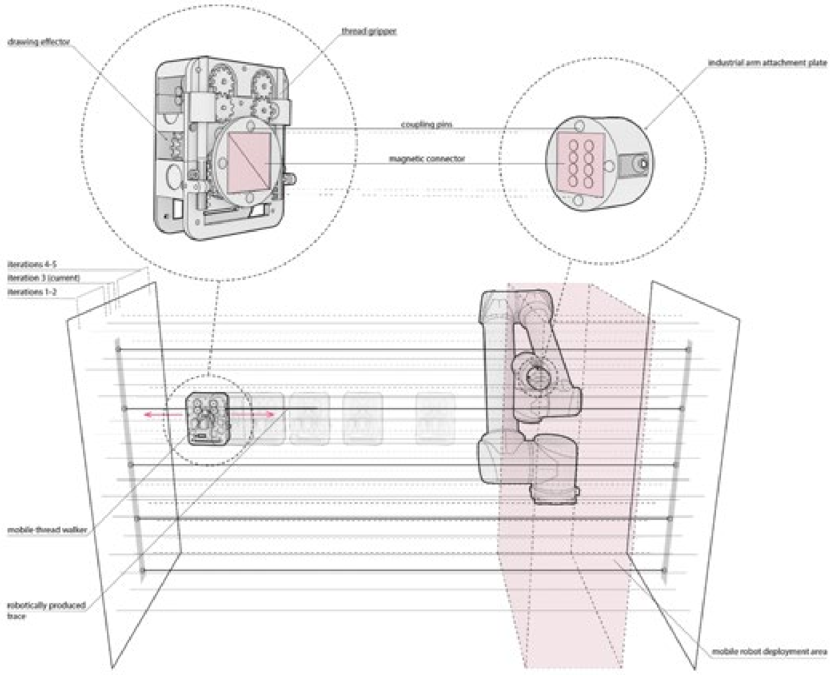


Maria Yablonina / Institute for Computational Design and Construction (ICD),
MoRFES_02,
Ars Electronica, Postcity,
Linz, Austria,
2017

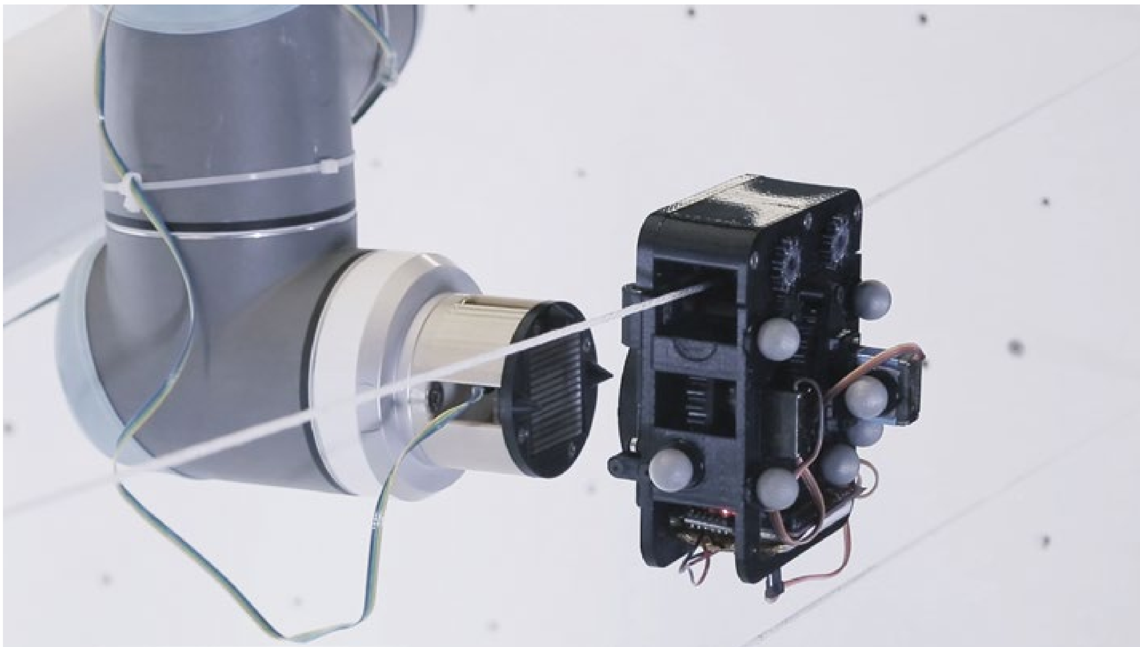
Fabrication logic diagram for the winding process of a tensile filament structure between two surfaces. Increasing the number of filament-walking robots meant two filament bobbins could be used simultaneously, thus increasing the speed and the winding-sequence complexity of the produced structure.

Maria Yablonina / Institute for Computational Design and Construction (ICD),
Spatial Drawing,
Autodesk Pier 9,
San Francisco,
2016

Diagram outlining the hardware setup for the Spatial Drawing project. The robot arm is used to position the filament-walking drawing robot on the preinstalled threads. The filament walker iteratively colours specific areas of each thread to create a drawing that reveals itself when observed from a particular vantage point. The project was conducted as part of the Autodesk Pier 9 Artist-in-Residence programme.



A heterogeneous team of two robots performing collaborative fabrication tasks towards a common outcome. Using a robot arm and a bespoke mobile machine within a single fabrication setup leveraged the affordances of both machines while counteracting their limitations.



Maria Yablonina / Institute for Computational Design and Construction (ICD), Spatial drawing with a heterogeneous two-robot team, Autodesk Pier 9, San Francisco, 2016

Detail of the filament-walking robot positioning routine performed by the robot arm. An electromagnetic effector was designed to allow the arm to pick up and transport the mobile robot between threads.

The ongoing development of the library of methods in this research does not exclude the addition of robot arms and other off-the-shelf tools as long as the required operation justifies its application. In a series of experiments that were part of the Spatial Drawing project conducted at the Autodesk Pier 9 technology hub, San Francisco, in 2016, a robot arm was used to position and deploy a mobile unit that leverages the accuracy and complexity of industrial robot movement while expanding the work envelope through the locomotion capability of the mobile machine. The project demonstrates the benefits of a heterogeneous robot team where one machine's unique properties counteract others' limitations, moving beyond increasing speed or scale and enabling new tasks to be performed, pushing the boundaries of the existing design space.

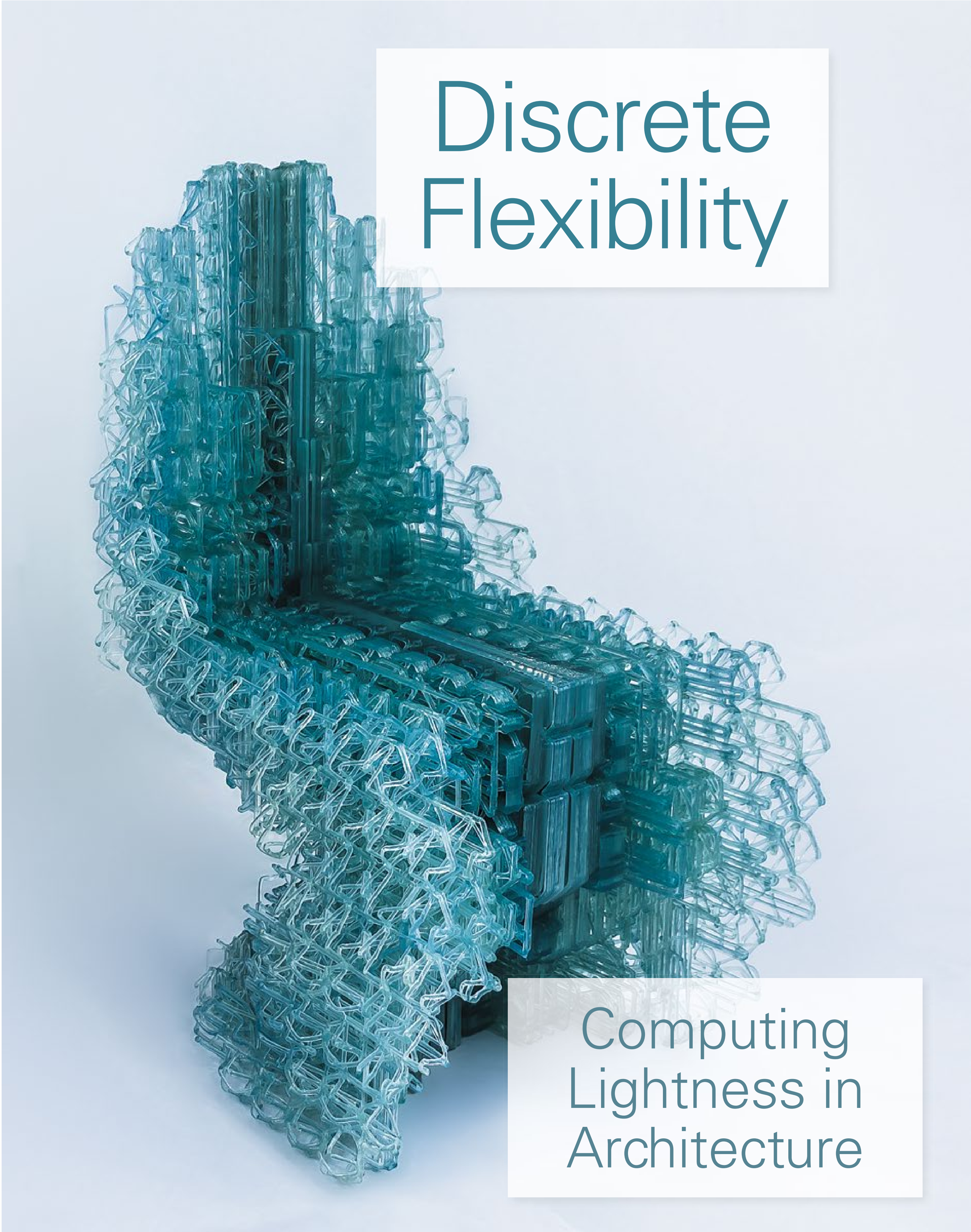
A Larger Library of Robotic Tools and Processes

This body of work serves as an early start for a more extensive library of hardware and software methods that could grow beyond material-specific applications. Treating existing machines as part of a continuously expanding toolkit that can be added to provides not merely a post-processing solution for materialising complex geometries, but an approach where hardware limitations are becoming soft boundaries to be pushed against. In the future, bespoke architectural robot teams can become permanent residents of inhabited space, continuously constructing, deconstructing and reshaping it, venturing into the field of robotic architecture where an adaptive structure becomes the machine.[9] ⅅ

Notes

1. Greg Lynn, 'Giant Robots', *Log* 36, Winter 2016, pp 13–16.
2. Thomas Bock and Thomas Linner, *Construction Robots: Elementary Technologies and Single-Task Construction Robots*, Cambridge University Press (New York), 2016.
3. Leslie Cousineau, *Construction Robots: The Search for New Building Technology in Japan*, American Society of Civil Engineers (Reston, VA), 1998.
4. Sasa Jokic *et al*, 'Robotic Positioning Device for Three-Dimensional Printing', Institute for Advanced Architecture of Catalonia, Open Thesis Fabrication, Barcelona, Spain, 12 June 2014; https://arxiv.org/ftp/arxiv/papers/1406/1406.3400.pdf.
5. Nathan Melenbrink *et al*, 'Towards Force-Aware Robot Collectives for On-Site Construction', in *ACADIA – Disciplines and Disruption (Proceedings of the 37th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, Cambridge, MA, 2017, pp 382–91.
6. Benjamin Felbrich *et al*, 'Multi-Machine Fabrication: An Integrative Design Process Utilising an Autonomous UAV and Industrial Robots for the Fabrication of Long-Span Composite Structures', in *ACADIA – Disciplines and Disruption (Proceedings of the 37th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, Cambridge, MA, 2017, pp 248–59.
7. Thomas Bock and Thomas Linner, *Robot-Oriented Design: Design and Management Tools for the Deployment of Automation and Robotics in Construction*, Cambridge University Press (New York), 2015.
8. Maria Yablonina *et al*, 'Mobile Robotic Fabrication System For Filament Structures', in *Fabricate – Rethinking Design and Construction (Proceedings of the Fabricate Conference 2017)*, Stuttgart, 2017, pp 202–09.
9. All projects and experiments conducted with the support of the GETTYLAB.

Discrete Flexibility



Computing Lightness in Architecture

Design Computation Lab (Manuel Jimenez García and Gilles Retsin) with Nagami and Vicente Soler, VoxelChair v1.0, Centre Pompidou, Paris, 2017

VoxelChair v1.0 is based on a Discrete approach whereby objects can be defined as volumetric aggregations, bypassing the use of any surface topology. The complex formal articulation emerges from the combinatorial algorithm, which allows for a differentiated material distribution.

If composed of rigid voxels, Discrete structures can only approximate at curves. But what if the building blocks are made of flexible materials? As co-founder of the Design Computation Lab at the Bartlett School of Architecture, University College London and co-founding principal of MadMDesign, **Manuel Jimenez García** has been leading parallel initiatives to develop and test structure-generating software that explores this proposition. Here he outlines its potential by showcasing some of the prototypes and installations that the new software has produced.

The premise of the continuous space, based mainly on the new morphologies conceived by Greg Lynn as blobs and hyposurfaces in the late 1990s,[1] has more recently been materialised by architects such as UNStudio in their Mercedes-Benz Museum in Stuttgart (2006) and Zaha Hadid with the Heydar Aliyev Center in Baku, Azerbaijan (2007). These complex structures generated in a digital environment are often brought to life following a post-rationalisation process in which continuous surfaces are broken down into highly differentiated panels supported by custom-made structural elements. The viability of such levels of customisation relies on the use of digital fabrication tools. However, these processes are still slower than traditional manufacturing methods when applied to large volumes and, more importantly, the excessive variability often leads to an exponential decrease of efficiency in their assembly.

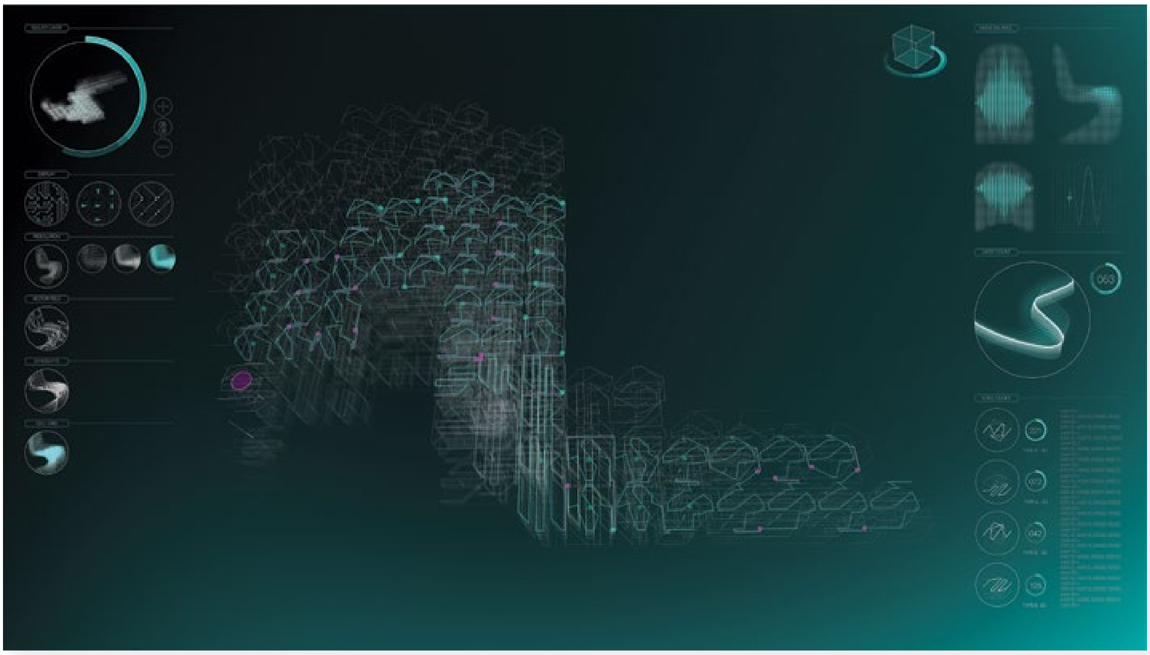
Discrete design methods aim to turn the continuous paradigm upside down, shifting formal complexity from the design of the whole to the assembly logic of the parts. Fabrication constraints can thus be introduced in the early stages of the design process, resulting in a faster and more efficient design-to-fabrication workflow. Discrete methods commonly make use of Cartesian geometries, whereby surfaces are described as a combination of orthogonal blocks. The approximation to a curvilinear space is then purely driven by the resolution of the used voxels.

MadMDesign's research on flexible structures makes use of a Discrete method to create a curvilinear space through physical deformation rather than increased resolution. The intention is to develop a computational workflow focusing primarily on the use of linear elements, which inherit a larger number of degrees of freedom than two-dimensional surfaces or three-dimensional blocks. This makes possible a closer approximation to a curvilinear topology while maintaining the logic of connectivity of a combinatorial method.

Computing Lines

With the aim of establishing a universal approach for Discrete design methods, the Design Computation Lab at the Bartlett School of Architecture, University College London (UCL) is developing a software that can generate complex, non-repetitive structures from the aggregation of linear elements. Although at its core is the aggregation of elements of different natures, initial development has focused on the creation of continuous toolpaths for robotic plastic extrusion. This method enables local optimisation of the structure, avoiding the use of global, computationally expensive problem-solving algorithms. After prototyping the printing process in a limited number of discrete units, the units are instantiated and connected to generate a ready-to-print continuous line. The combinatorial algorithm allows for differentiated material distribution. Material density and direction can be locally controlled by changing the scale and orientation of the fragments, producing a gradual differentiation of the strength of the object across its volume.

The software was first tested for the creation of VoxelChair v1.0 (2017), which makes use of four different fragment types that were assembled into a 2.36-kilometre (1.5-mile) continuous toolpath. Developed in collaboration with Vicente Soler, creator of the Grasshopper plugin 'robots', and fabricated by Nagami, a design brand and robotic manufacturing startup based in Avila, Spain, the prototype established the computational principles necessary to aggregate linear elements in response to structural parameters. However, this initial version of the software still operates within a Cartesian grid, approximating the curvilinear morphology of the volume to be filled – in this case, a Panton chair – in an orthogonal manner.



Design Computation Lab (Manuel Jimenez García and Gilles Retsin), Discrete Design Software, Bartlett School of Architecture, University College London (UCL), London, 2017

The software establishes a new design method that can generate 3D objects from the combination of discrete toolpath fragments. This allows local optimisation of the structure, avoiding the use of global, computationally expensive problem-solving algorithms.

Softmodelling

In parallel to the research work being undertaken at UCL, MadMDesign is currently developing a software that allows application of the previously mentioned combinatorial methods in larger-scale structures. Softmodelling (2012) focuses on the control of flexible materials, aiming to automate the creation of a discrete line-based structural frame from a membrane. It establishes a new workflow where polygonal modelling and physics simulations are run simultaneously. What is modelled becomes automatically 'physically active', allowing topological modifications to the object at every step of the design process.

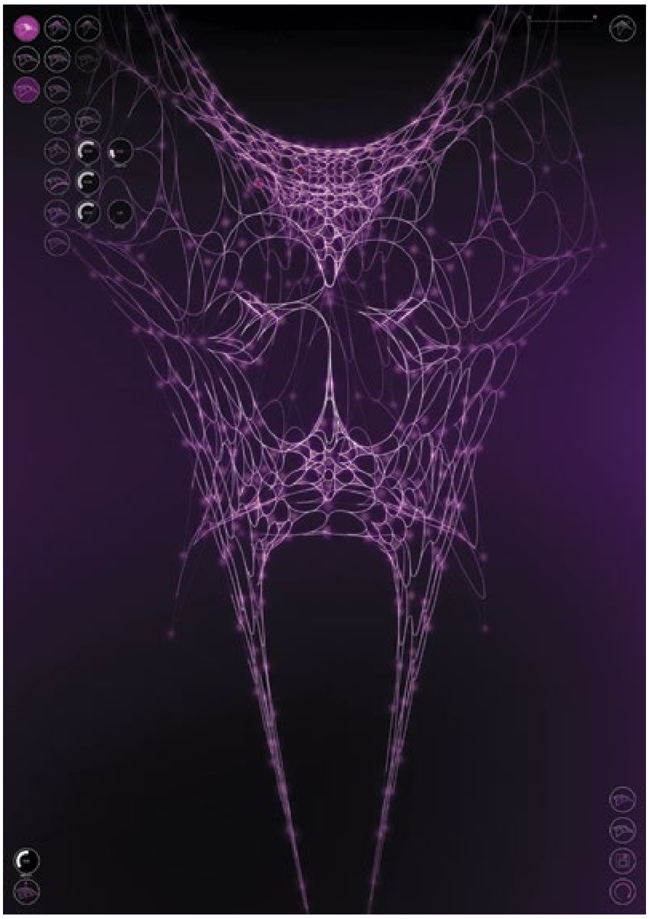
The emergence of a discrete-based structural frame is embedded in the surface manipulation. Flexible lines are adapted in the most suitable combination to establish a symbiotic relationship with the membrane, resulting in a reciprocal structure in which both frame and membrane work in conjunction to create structural stability.

Softmodelling has been tested in a series of installations, including the trans-computational pavilions created as part of the Architecture Association Visiting School Madrid programme and exhibited at the Colegio Oficial de Arquitectos de Madrid (COAM) in 2013 and 2015, at Roca Madrid Gallery (2014) and at Clerkenwell Design Week, London (2015). The installations make use of bending-active materials such as PVC pipes and fibreglass rods to investigate the stability of a structure through the different geometrical combinations of its elements, focusing therefore on the combinatorial process of discrete flexible linear elements to achieve a force balance within the overall frame.

Digital Bamboo

Further development of Softmodelling included the testing of materials with different degrees of flexibility. Prototypes such as Offshore Bezier (Taipei, 2015) explored the possibilities of bent bamboo in large-scale assemblies, analysing the performance of this material in active bending structures to feed the software with data that would improve its versatility as a design tool.

Bamboo is a natural material with a high breaking strain.[2] Regardless of the material's high strength, the geometrical constraints to locally control stiffness in the assembled structure are of the same nature as those present in the PVC and fibreglass installations previously explored. The Woven Memory by MadMDesign and Chieh Shih makes use of a robotic bending method to create a variety of 3D curves from bamboo rods of almost identical length and thickness. This modular structure was first exhibited as part of the Space Media Festival in Taipei in 2016, and was later disassembled into a collection of five different discrete bamboo elements to be reassembled into a wall-ceiling installation at the Modern Body Festival in The Hague, Netherlands, in 2016. The project demonstrates the versatility of a discrete system based on bending active elements, the flexibility of which allows for more freedom when reconfiguring the structure.



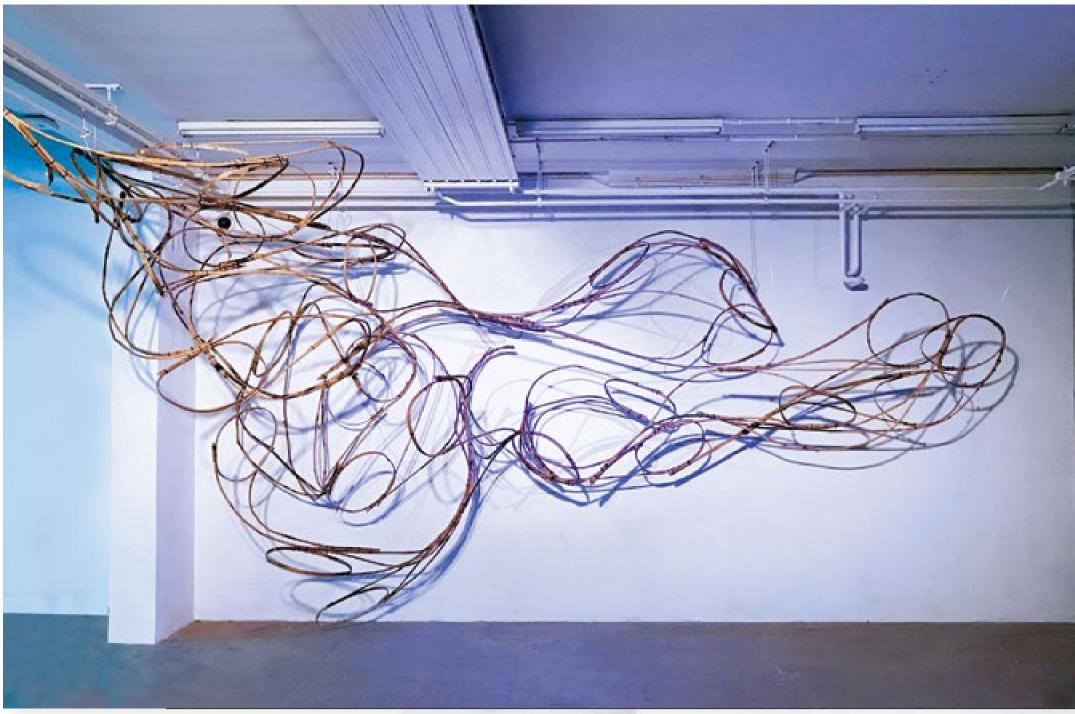
Manuel Jimenez Garcia / MadMDesign, Softmodelling 3.0, 2012

Softmodelling is a polygonal modelling/simulation software developed in Java. This version allows for the configuration and connection of multiple bent elements to create a structure in equilibrium. The connectivity is controlled through simple modelling operations of the mesh, which acts as a flexible membrane.

Softmodelling focuses on the control of flexible materials, aiming to automate the creation of a discrete line-based structural frame from a membrane.

MadMDesign (Manuel Jimenez García and Christina Dahdaleh) with Chieh Shih, The Woven Memory v2.0, Modern Body Festival, The Hague, Netherlands, 2017

The installation is a collection of six modules that connect to create a lightweight framework. The arrangement retains the bending forces in the structure, hence maximising its strength.



The Woven Memory makes use of Softmodelling not only for computing flexible materials, but also to output fabrication instructions. This modular structure is composed of robotically bent bamboo strands that bundle together into larger structural configurations.

Discrete Lightness

A similar strategy was followed for the PANDA (Pipe Assembly Networked Discrete Architecture) collaborative research project by MadMDesign and the Architectural Association Visiting School Madrid (2017). Here, a wireframe modular element was built at two different scales, using fibreglass rods of identical length. The modular elements were designed for their interconnectivity, allowing the shift from small-scale elements to larger ones and vice versa. The active bending properties of this material allowed for the controlled distribution of tension along the structure, erected as a vault that expands in volume as it reaches the supports.

Air D-Cell prototype (2018) expands this system with the addition of pneumatic structures within the discrete elements, aiming to improve the structural performance as well as to offer a partial enclosure. The tension of the connected linear elements is dynamically controlled through the introduction of an inflatable system within the cells, establishing a reciprocal force between the pneumatic volume and the wireframe structure that constrains it. Similar to the Tensairity structural concept created by Mauro Pedretti and registered by Airlight Ltd,[3] the linear elements that use this lightweight structure increase their strength due to their interaction with the pressure of the inflatable elements.

Manuel Jimenez García / MadMDesign
with the Architectural Association
Visiting School Madrid,
PANDA (Pipe Assembly Networked
Discrete Architecture),
Colegio Oficial de Arquitectos
de Madrid (COAM),
2017

The PANDA construction system is based on fibreglass discrete elements. Structural equilibrium is achieved through combinatorial methods that keep the rods in tension when connecting into bending-active structures.

Manuel Jimenez García / MadMDesign,
Air D-Cell,
2018

Air D-Cell is the evolution of PANDA into a volumetric lightweight construction system. The insertion of pneumatic elements into the fibreglass bending-active frame multiplies structure strength and allows for the creation of enclosed spaces.

Computational simulation and combinatorial methods such as those discussed here could favour the emergence of universal flexible building blocks, which could bring the 1960s' dream of a soft, portable, unwasteful architecture closer to becoming a reality.

Towards Universal Flexibility

The inherent portability of flexible structures has historically led not only to a plethora of temporary installations, but also to lightweight dynamic architectures with the potential to respond better to our increasingly nomadic lifestyle. Pneumatic structures were widely adopted at Expo '70 in Osaka, Japan. However, in the late 1960s architects including David Greene, Paul Jungmann, the Haus-Rucker-Co group in Vienna and José Miguel de Prada Poole had already explored the potential of these kinds of structures. An example is Casa Jonás (Madrid, 1968), in which Prada Poole introduced an architecture aware of its own entropy,[4] a housing system able to dynamically respond to spatial needs.

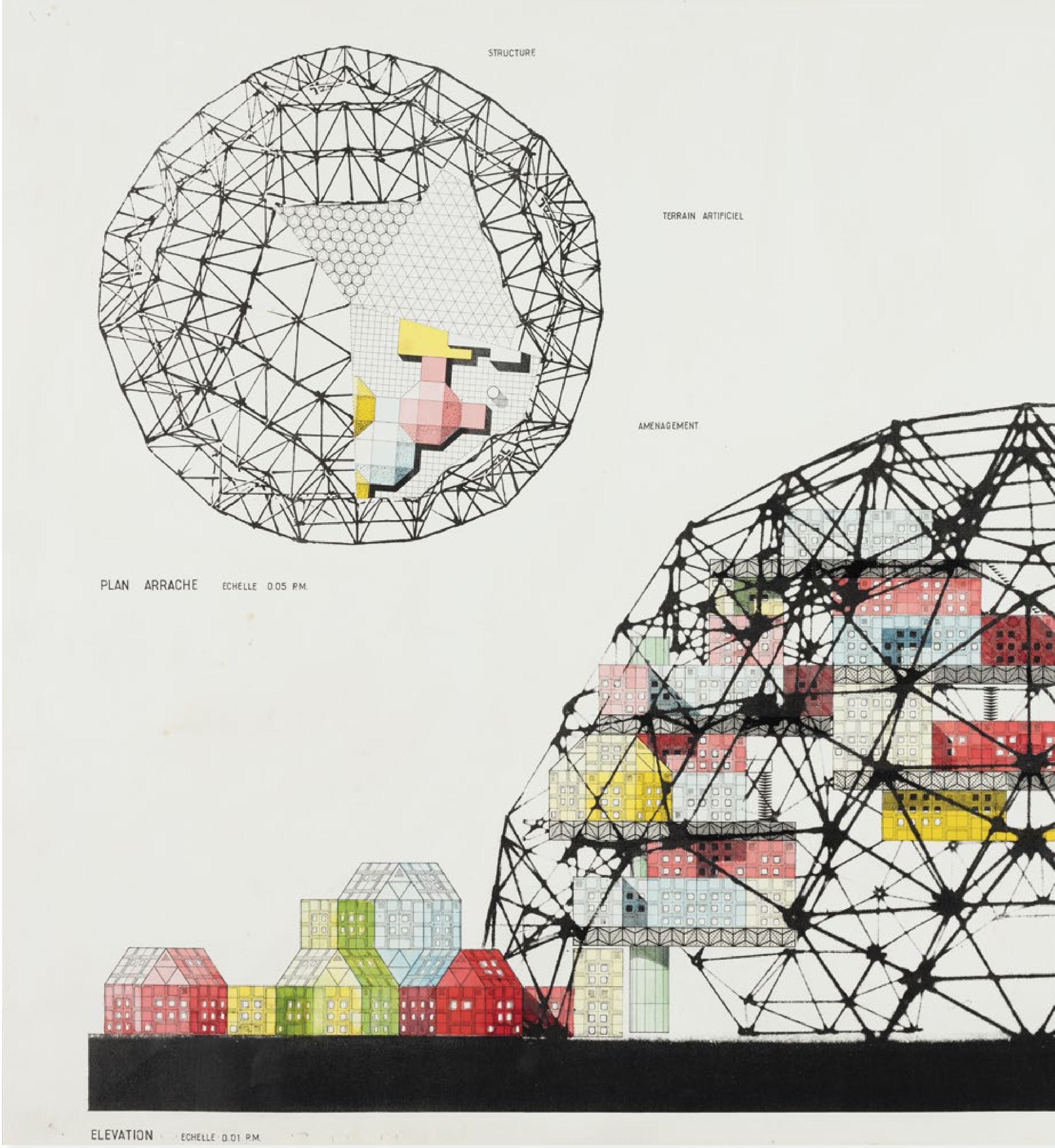
The introduction of a Discrete approach could expand the potential of these structures to be infinitely reconfigurable. Computational simulation and combinatorial methods such as those discussed here could favour the emergence of universal flexible building blocks, which could bring the 1960s' dream of a soft, portable, unwasteful architecture closer to becoming a reality. ⌀

Notes

1. Greg Lynn, *Animate Form*, Princeton Architectural Press (New York), 1999.
2. Julian Lienhard *et al*, 'Active Bending, A Review on Structures Where Bending is Used as a Self-Formation Process', *International Journal of Space Structures*, 28 (3&4), 2013, p 188.
3. Rolf H Luchsinger, Mauro Pedretti and Andreas Reinhard, 'Pressure Induced Stability: From Pneumatic Structures to Tensairity', *Journal of Bionic Engineering*, 1 (4), December 2004, pp 141–8.
4. Antonio Cobo, 'Smart Structures', *Pasajes Arquitectura*, 134, 2014, pp 16–18.

José Miguel de Prada Poole, Casa Jonás, Superior Technical School of Architecture of Madrid (ETSAM), 1968

Prototype of the architect's dynamic housing system that responds to spatial needs. The pneumatic cellular structures formed by flexible elements could be elongated or reduced according to the air pressure in bellows attached to each side of the cell or segment.


STRUCTURE
TERRAIN ARTIFICIEL
AMENAGEMENT
PLAN ARRACHE ECHELLE 0.05 P.M.
ELEVATION ECHELLE 0.01 P.M.

Et Alia

A Projective History of the Architectural Discrete

David Georges Emmerich, Agglomération (sous une coupole stéréométrique), 1958–60

This agglomeration of housing units under a stereotomic cupola exemplifies Emmerich's exploration of crystalline aggregates: the complex spatial order was endowed with a political operability through auto-construction.

The Discrete did not arise out of nowhere. Curator and author **Emmanuelle Chiappone-Piriou**, who lectures at TU Wien (the Technical University of Vienna) and the École Nationale Supérieure d'Architecture Paris-Malaquais, tracks its antecedents since the early 20th century: from the Bauhaus to Ulm School of Design, from Team 10 to the Metabolists, and from cybernetics to evolutionary architecture.

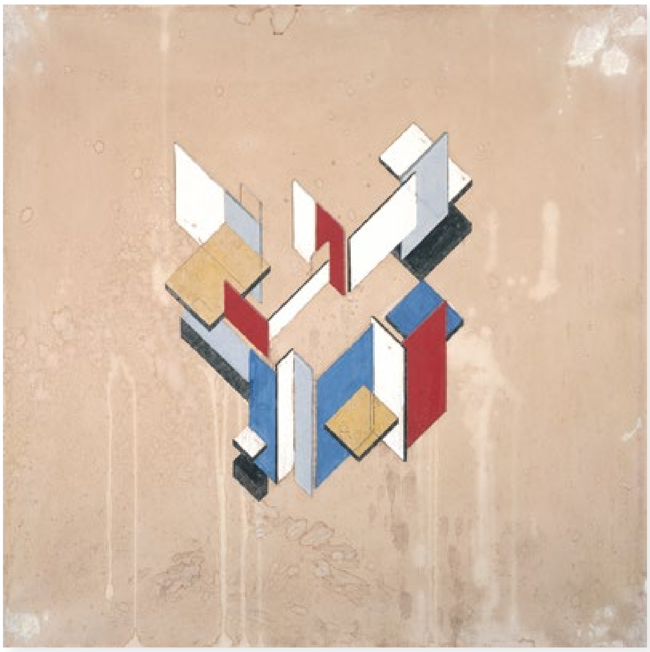
'There are some who think that the number of the sand is infinite in multitude' and others who, without regarding it as infinite, think that 'no number … is great enough to exceed its multitude', writes Archimedes (287–212 BC) in his *Sand Reckoner*, a demonstration of the measurability of the Universe. A unit 'relating to which all numbers are continuously proportional', the sand grain allows evaluation of the previously ungraspable – the cosmos – just like 'bits' were to be considered, centuries later, as the essential measure of information theory, capable of measuring the complexity of the biggest form. From sand to bit, from material to digital, the Discrete changes state; that may well be its nature, simultaneously evident and hardly graspable, evading definition by remaining highly mutable. As Archimedes's sand grain, the digital Discrete is that with which to operate abstractly, conceptually and quantitatively in a world forged by multidimensional computational processes and datascapes that have long evaded known magnitudes.

In their search for the Discrete, as the *one*, the minimum atom of communication that might suffice 'to draw the universe out of nothingness',[1] architects making use of code today appear to conflate data with structure, form and materiality. Embracing this conflation, a projective history of the architectural Discrete can be found in 20th-century architectural snapshots that can be seen as sharing a common ambition to objectify discreteness.

These precedents punctuated the modern quest for rationalisation, the search for a numerical objectification of design processes and the resulting move away from the tradition of subjectivity. Beyond Modernism, these architectures exploited the ultimate rational tool that is the (conceptual) grid, thus shifting towards standardised systems as logically and formally determined assemblies of combinatorial and autonomous elements. Projects such as Jose Sanchez's Block'hood video game (pp 28–9), Daniel Koelher's investigations into the mereological city (pp 30–37) or Guest-Editor Gilles Retsin's structural research for the 2017 Tallinn Architecture Biennale Pavilion (p 56), reclaim that history, combining an 'accelerated structuralism' with the autopoeitic conception of the generic computational simulation. Yet, if examples of rule-based methods of aggregation and combinations of (similar or variable) elements from closed ensembles are recalled in these works, it is not solely in terms of design strategies. The interweaving of techno-scientific exploration with the search for a universalist condition carries lessons for today; from the early 20th-century quest for an abstract harmony, to socially driven, structuralist attempts to 'humanize quantity',[2] to the universality of coded morphogenetic processes, these evocations can help frame how a non-deterministic architectonic synthesis for our computational world can be conceived. Searching for historical traces of the Discrete and of what it has come to encompass ideologically and conceptually, at least in projective and imaginary modes, thus initiates discussion of the nature of this synthesis, on the conflation of matter, structure and code.

Elements

The Bauhaus, De Stijl and Constructivist movements radically redefined architecture over the first three decades of the 20th century. All reworked its fundamental concepts in search of a universal dimension of art and architecture that would correspond to the normativity and perceptions proper to the industrial world. Parallel to Dutch artist and theoretician Piet Mondrian's spiritual explorations in abstract painting, the Dutch polymath and De Stijl founder Theo van Doesburg called for an exclusively universal method of representation and production that would contain all possible elementary expressions;[3] as in his unbuilt *Monument for Leeuwarden* (1916), an autonomous, neutral architecture would emerge from the coordination and measured relations of parts, anticipating Kasimir Malevich's similar quest in the early 1920s for the cube-based, zero-degree architecture of his white, abstract, volumetric-spatial *Architectones* models. From the canvas to the city, De Stijl broke with the traditionally homogeneous understanding of space in favour of a diffracted, *n*-dimensional definition. Their extreme, complete abstraction aimed at establishing a harmony between the subject and the universe by expressing 'precisely what is human'.[4]



Theo van Doesburg,
Contra-constructie,
1923

Van Doesburg's Elementarist architecture was to be built from a series of components articulated and integrated within an *n*-dimensional, relative and nonhierarchical whole.

Standard Types

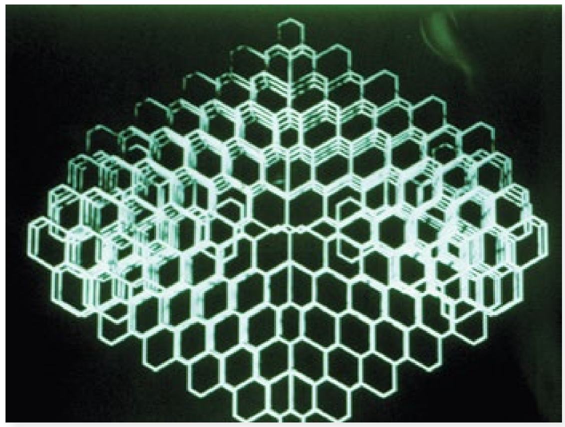
Although inspired by the Bauhaus, the Ulm School of Design (1953–68) adopted a rational, scientific and industrial approach that revived the positivist tradition of the 1920s Sachlichkeit figurative artistic movement. The Bauhaus's spirituality, embedded in the geometrical grid, was replaced with 'the search for a grammar, a syntax of creation',[5] as graphic designer Otl Aicher wrote, that would encompass economical and functional notions with aesthetic categories, proportions and series. Ulm designers revived Walter Gropius's definition of the standard as a 'formal common denominator,'[6] the generic nature of which crystallised its democratic value. In 1925, the early Modernist architect and Bauhaus founder had advocated for the standardisation of dwelling and reiteration of a 'basic cellular unit' in order to form larger urban groups. Fundamental was the variation in size; the diversity it created gave 'civic dignity and coherence' to urbanity.[7] In the Ulm design approach, developed by Hans Gugelot, elements were conceived in such a way as to assemble into groups of products, allowing for the development of rationalised architectural modular systems based on 'functional types'[8] corresponding to specific constructive and functional criteria and working with dimensions and systems of dimensions.

Units and Cells

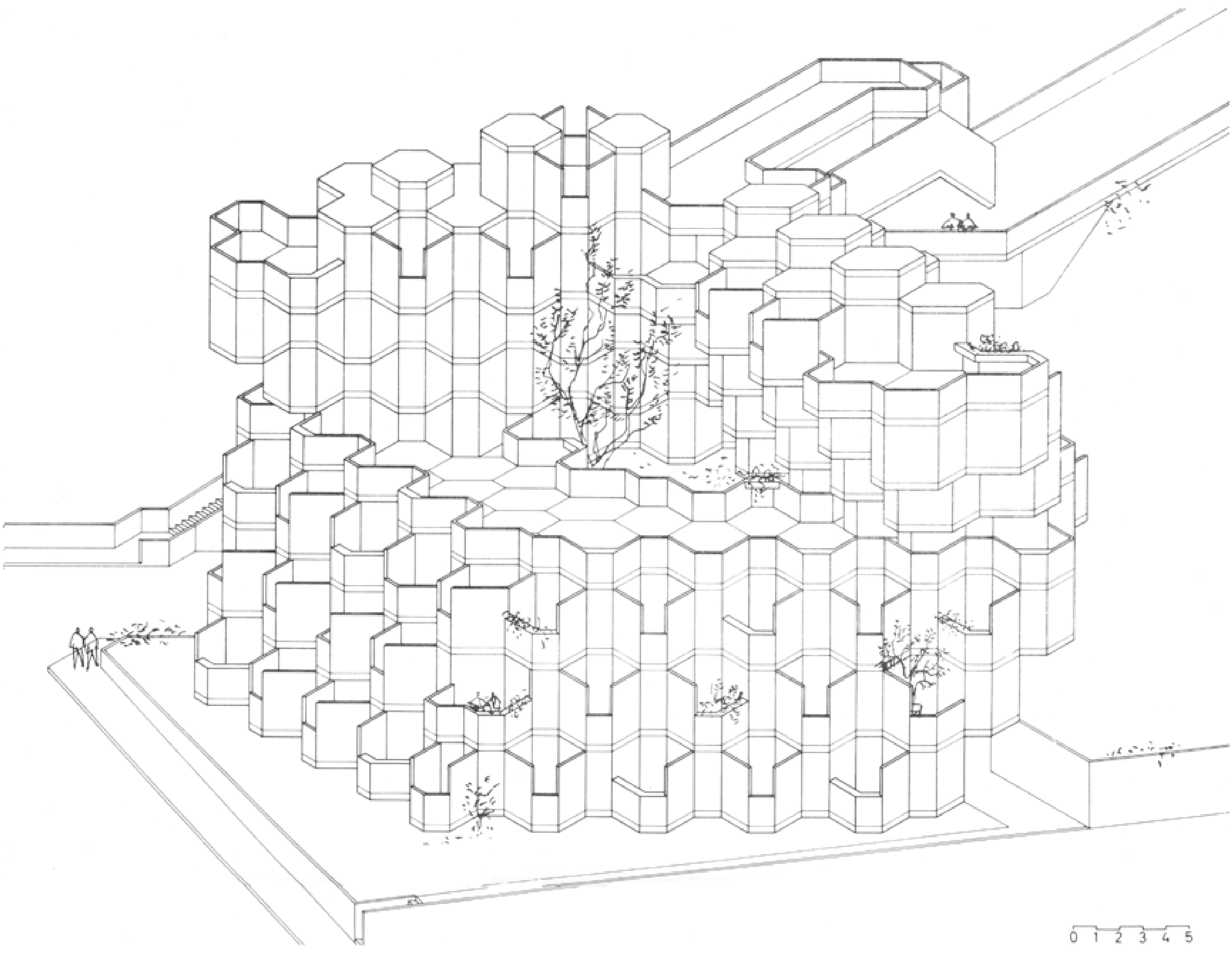
Units and cells surfaced within the Modernist hegemonic functionalism of the 1950s as a way of adapting urban structures to the changing form of society by articulating social subdivision through architecturally distributive functions. At the 1953 Congrès Internationaux d'Architecture Moderne (CIAM), Alison and Peter Smithson proposed redefining the principles of human association by incorporating ideas of continuous change and individual desire. They were joined by architects including Giancarlo de Carlo, Jaap Bakema, Georges Candilis and Aldo van Eyck, forming the Team 10 group to explore planning as 'the built counter form of a more complete and complex human reality',[9] and accommodate freedom of choice within quantitative strategies that dealt with the greatest number. As in the Smithsons' competition entry for the Golden Lane housing estate in the context of London's postwar rebuilding (1952), communities needed to be 'built up from a hierarchy of associational elements' (the house, the street, the district, the city) or 'appreciated units',[10] as community-based subdivisional structures. Although understood as 'finite plastic realities', unit groupings remained 'woven into a modulated continuum';[11] indeed, for the Smithsons, infrastructure served to re-establish the capacity of disappeared 'unchanging large-scale things' (man-made or natural) to render the 'whole community structure comprehensible' and assure 'the identity of the parts within the whole'.[12] This strong correlation between density and distribution allowed for 'differentiation and unity through rhythm and sub-rhythm',[13] as seen in the structuralist projects such as Zvi Hecker's packing of prismatic hexagons in his Dubiner Apartment House in Raman Gan, Israel (1963) and Jean Renaudie's non-normative volumetrics.

Zvi Hecker,
Dubiner Apartment House,
Ramat Gan, Israel,
1963

Designed with Eldar Sharon and Alfred Neumann, the Dubiner House is composed of a series of prismatic hexagonal prisms, designed as spatial blocks, integrated within an elongated hexagonal prism. The modular composition created a visually and spatially diverse environment, fit to the local climate and topography.



This strong correlation between density and distribution allowed for 'differentiation and unity through rhythm and sub-rhythm'



The techno-oriented visionary projects of the same period further challenged traditional urban continuity in attempting to conjugate functional pluralism with growth and variability. Regardless of the name, capsules, pods and cells were still generic, industrialised solutions to homogeneity and lack of flexibility, the difference residing in how they hierarchically related to the whole, be they isolated units, plugged to a structure or agglomerated with one another. From Metabolist investigations to British pop rationalism, from Yona Friedman's Spatial City (1959–60) to Eilfried Huth and Günther Domenig's Stadt Ragnitz (1965–9), the megastructural approach posited the primacy of an integral, equipped structure within which a secondary system composed of 'discrete, rapidly changeable functional units' would fit.[14] These differed from the 'cellular agglomerations'[15] that eliminated the separation of primary and secondary structures via the adjunction of structurally and functionally autonomous cells. Alongside Moshe Safdie's model residential complex Habitat 67, built for the 1967 International and Universal Exposition in Montreal, many projects exploring the possibility of simultaneously generating the supporting structure and spatial definition remained purely experimental, among them Safdie's speculative Habitat Puerto Rico (San Juan, 1968) scheme for 800 low-cost homes, only 30 of which were constructed.

Connected Objects

Standardisation and repetition also fuelled research on structural morphologies, which, following Konrad Wachsmann, Richard Buckminster Fuller and Robert Le Ricolais, opened architecture to a topological spatial order. In the 1960s, Fritz Haller developed a functionalist polyscalar system (mini, midi, maxi) using a universal spherical connector, which he further exploited to develop the iconic USM Haller modular furniture system, while members of the Groupe d'Etude d'Architecture Mobile (GEAM) explored the mathematical modelling of morphogenetic processes, in particular crystalline structures.

Moshe Safdie,
Habitat Puerto Rico,
San Juan, Puerto Rico,
1968

The prefabricated hexagonal housing units of this unfinished project could have been transported by trucks, as in Safdie's earlier Habitat 67 realisation in Montreal. Only 30 modules were constructed in San Juan's Carolina district, as well as on remote sites, as funding was pulled in 1973, putting a stop to the project.

In this non-syntactic, non-representational spatial order, 'the nature of the elements … has no importance', wrote David Georges Emmerich, 'only the situation between the elements does, that is to say the topological structure of their group'.[16] The French architect produced tensegrity structures through articulation of invariable finite elements – nodes, segments, complex polyhedral modules – within a connective space. Applied to multifunctional housing (for example in his Agglomération, 1958–60), Emmerich's 'crystalline aggregates' and 'pilings' were endowed with a democratic value: open to potentially infinite spatial extension, the auto-constitution of the form incarnated the possibility of a direct social and political operability, through auto-construction.

Bits and Voxels

This search for complexity led architects to embrace information theory and cybernetics, not only to elaborate interdisciplinary models describing complex phenomena, but also to generate equally complex computed syntheses of data, abstract concepts and symbols. Constantinos Doxiadis's hypothetical Ecumenopolis (1967), a 'city of the whole inhabited earth'[17] within which localities and individualities would interact in an orderly manner, is paramount in the context of the universal dimension that nascent computation came to represent.

As the world started to be measured, evaluated and computed in binary code, a non-figurative architecture emerged based on the analogical relationship between form and computational processes, in which the grid opened to the systematic incorporation of quantitative parameters in multiple dimensions. Andrea Branzi's typewritten *Computer Drawings* (1967) depict localised accumulations of discrete symbols within an isotropic grid as vibrancies of the informational matrix. Considered simultaneously as 'atoms of knowledge',[18] extracted from a finite symbolic repertoire, and as agglomerated, almost crystal-like, industrial goods, these symbols reveal how the avant-garde Archizoom group he founded in 1966 critically reduced reality, conflating architecture with global communicational, productive and distributive systems.[19] These symbolic aggregations were intended as qualitative variations; that is, structured quantities reminiscent of the opposite poles that once forged the metropolis, now reduced to intensities within the controlled continuum and weak urbanism of Branzi's *No-Stop City* (1969) global urbanisation project.

This weak, diffuse urbanism was to be based on programming, an idea Leonardo and Laura Mosso contemporarily explored from a humanist perspective in their work during the 1960s on one of Europe's three Universal Automatic Computers (UNIVAC). A 'service of language', understood semantically and freed from any formal preconception, programmed architecture could be 'talked by the users themselves' to auto-program their personal status within their community; this continuous, dynamic control thus brought 'qualitative human capital gain'.[20] This interaction of human and artificial intelligences was translated into a speculative voxel-based modelling of the territory (*Città programmata*, 1968–9), similarly to *Seek* (1970), a computer-controlled environment designed by Nicholas Negroponte with the MIT Architecture Machine Group. An investigation

John and Julia Frazer's Universal Constructor (1990) topped a decades-long exploration into evolutionary architecture that aimed at achieving 'in the built environment the symbiotic behaviour and metabolic balance that are characteristic of the natural environment'.

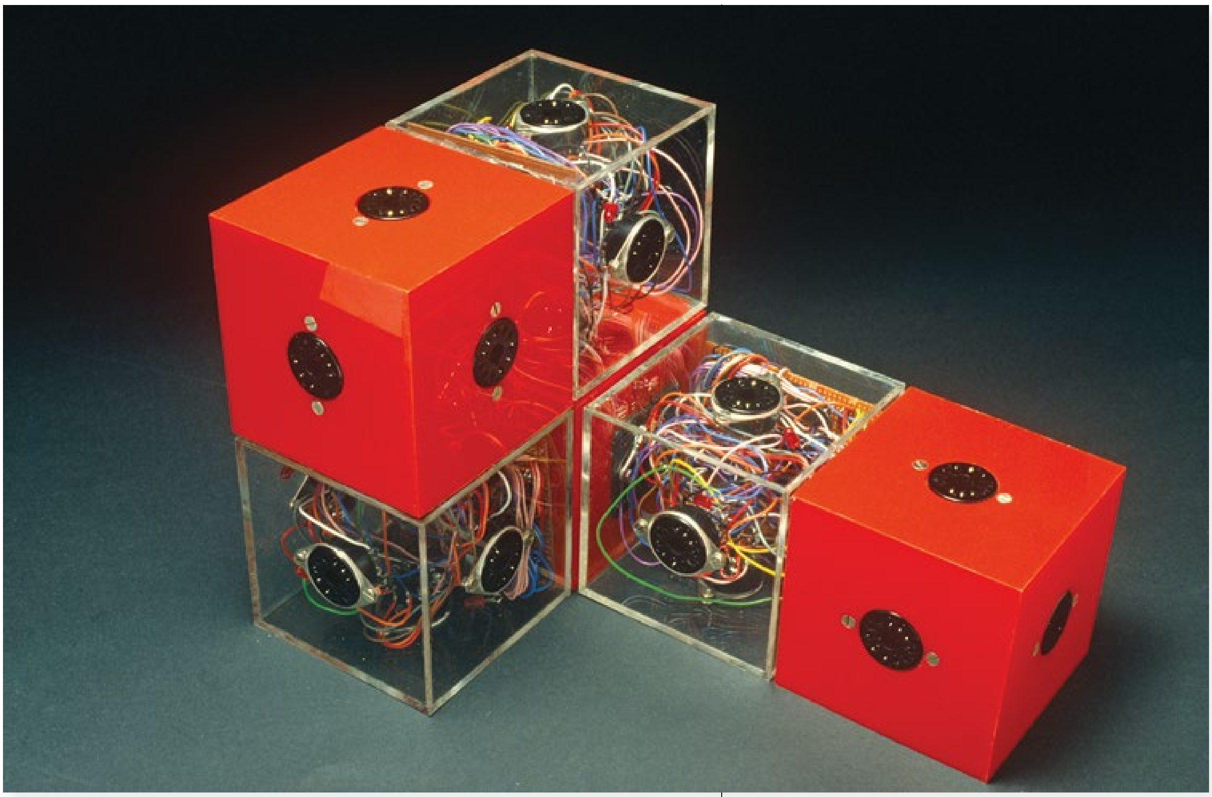
John, Julia and Peter Frazer, Evolutionary Architecture: Three-dimensional intelligent modelling system, 1980

These working prototypes were among the first in a series of experiments using physical models as input devices. Each cube was assembled from kits of parts with embedded electronics and was capable of self-inspection and communication with a controlling processor. The experiments led to the architects' Universal Constructor (1990), a self-organising interactive environment, also composed of cubes.

into the potential of an automated architecture, stemming from the interaction with complex nonlinear behaviours, this 2,000-block landscape underwent constant re-elaboration; as captive gerbils would randomly modify the original configuration, a robotic arm would attempt to rearrange it in a rationalised spatial approximation of the animals' production.

Particles and Agents

John and Julia Frazer's Universal Constructor (1990) topped a decades-long exploration into evolutionary architecture that aimed at achieving 'in the built environment the symbiotic behaviour and metabolic balance that are characteristic of the natural environment'.[21] Polyautomata and neural networks fully decorrelated design from objects, moving beyond the industrial understanding of architecture as a modular assembly of kits of parts and reframing it as dynamic processes of emergence, both physical and *in silico*. The universal self-organizing machine was composed of 286 cubes that communicated with a virtual model through embedded electronics, their automated permutation generating rationalised spatial arrangements. 'Some day, we shall get a morphology of the art by some architectural Linnaeus or Darwin, who will start from the simple cell and relate to it the most complex structures'.[22] In quoting William Lethaby (1911), John Frazer anticipated current research into emergent properties and behaviours, in which, as Luciana Parisi puts it, the entry point into the digital material of design is lowered.[23] Through simulation, architecture hence dynamically emerges from the micro-transactions among discrete agents, while the cellular automata used by many of the architects exploring computational processes enable the generation of complex systems through the articulation of neighbouring conditions of discrete cells within a closed set of data.



The Unassigned

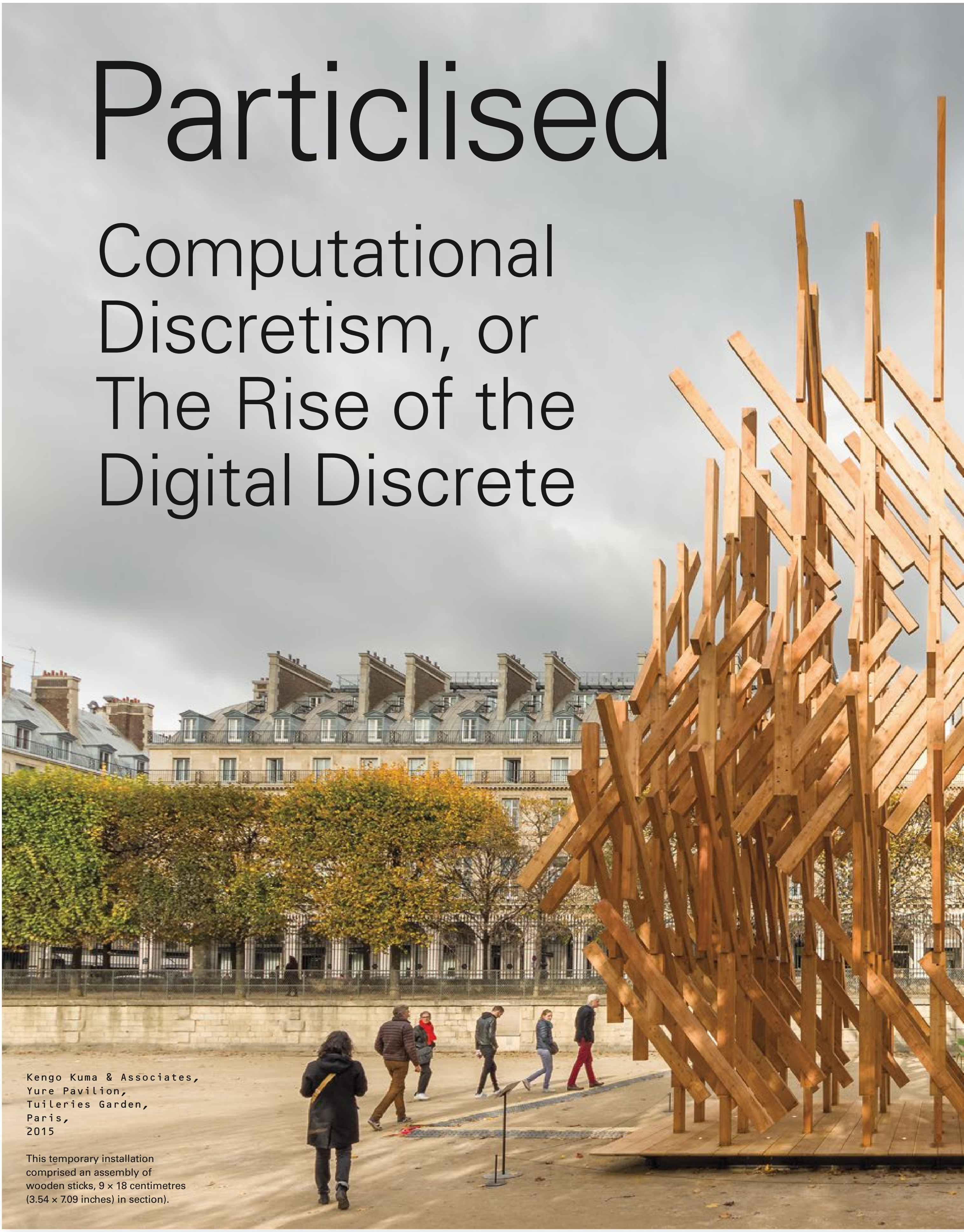
The vertical integration of these discrete computational models with digital fabrication techniques and robotics comes with the promise of unprecedented complexity, as much as with the threat of extreme normalisation. Reflecting on the different approaches of the Bauhaus and Ulm School of Design, Aicher identified two worldviews: the individual and the concrete, *contra* the general and the abstract.[24] It could be argued that this opposition is now obsolete, as the digital Discrete has the potential to escape empiricism, pure operationality and semantics, facilitating an objective, non-deterministic search for universality. The pre-eminence of the discrete element and its inherent compositional consistency indeed relieves the systemic view from the ontological precedence of the whole, keeping the architectural aggregative process open. Through the use of binary code, there now appears to be a revival of the 1960s belief that the 'sensitive articulation of number' enables an abstract environment to be forged in which one can feel at home no matter where one is.[25] However, Justus Dahinden's 1971 interrogation of whether 'the cellular division of the microstructure that aimed for the liberalisation of architecture would not, simultaneously, accelerate the disintegration of society'[26] still proves relevant today in a world largely conceptualised through emergent dynamics. How, thus, can architecture accommodate contingency and heterogeneous expressions of a non-anthropocentric multitude yet still provide the conditions for commonality? ⅅ

Notes

1. Matko Meštrović, 'L'observateur observé', *Bit International*, 1, 1968, p 13.
2. Aldo van Eyck, 'Nagele Schools', 1960, in Alison Smithson (ed), *Team 10 Primer*, Studio Vista (London), 1968, p 83.
3. Theo van Doesburg, 'Schliderkunster en Plastiek: over contra-compositie en contra-plastiek, Elementarisme (Manifest-fragment)', *De Stijl*, 7, 1926, pp 33–45.
4. Theo van Doesburg, *G*, 3, June 1924, p 48.
5. Otl Aicher, 'Bauhaus et Ulm', in François Burkhardt, Claude Eveno and Herbert Lindinger (eds), *L'Ecole d'Ulm: textes et manifestes*, Éditions du Centre Pompidou (Paris), 1988, pp 10–14.
6. Walter Gropius, *The New Architecture and the Bauhaus* [1925], MIT Press (Cambridge, MA), 1965, p 37.
7. *Ibid*.
8. Herbert Ohl, 'Construction industrielle à Ulm', in Aicher, Burkhardt and Eveno, *op cit*, pp 18–19.
9. Aldo van Eyck, *op cit*.
10. Alison and Peter Smithson, 'CIAM 9, Aix en Provence, 1953', in Alison Smithson, *op.cit*, p 48.
11. Alison and Peter Smithson, 'Uppercase', cited in Alison Smithson, *op cit*, p 48.
12. *Ibid*.
13. Aldo van Eyck, *op cit*.
14. Maki gave the first definition in his *Investigations in Collective Form*, *A Special Publication*, 2, Washington University (Saint Louis, MO), 1964.
15. Justus Dahinden, *Urban Structures for the Future*, Praeger (New York), 1972. Original German edition: 1971. Quote translated from the French version, 1972, p 20.
16. David Georges Emmerich, 'Réseaux', *Techniques et Architecture*, 1, 1965, pp 10–13.
17. Constantinos Doxiadis, 'Ecumenopolis: Tomorrow's City', *BRITANNICA Book of the Year*, Encyclopaedia Britannica (Chicago, IL), 1968, p 30.
18. Abraham Moles, 'Théorie de l'information', *Bit International, op cit*, p 20.
19. Archizoom, 'No-Stop City, Residential Car Park, Universal Climatic System', *Domus*, 496, March 1971, pp 49–54.
20. Leonardo and Laura Mosso, 'Architecture programmée et langage', *Architecture d'aujourd'hui*, February/March 1970, p 19.
21. John Frazer, *An Evolutionary Architecture*, Architectural Association (London), 1995, p 9.
22. John Frazer, *op cit*, p 21. Citation from William Lethaby, *Architecture : An Introduction to the History and Theory of the Art of Building*, 1911.
23. Luciana Parisi, *Contagious Architecture, Aesthetics and Space*, MIT Press (Cambridge, MA), 2013.
24. Otl Aicher, *op cit*.
25. Aldo van Eyck, *op cit*.
26. Justus Dahinden, *op cit*, p 19.

Particlised

Computational Discretism, or The Rise of the Digital Discrete



Kengo Kuma & Associates,
Yure Pavilion,
Tuileries Garden,
Paris,
2015

This temporary installation comprised an assembly of wooden sticks, 9 × 18 centimetres (3.54 × 7.09 inches) in section).

Has the dominant influence of classical science on architectural aesthetics had its day? **Mario Carpo**, Reyner Banham Professor of Architectural Theory and History at the Bartlett School of Architecture, University College London, comments on the evolution of a new science that has shifted away from continuous towards discrete models. As he observes, this is not limited to the most digitally minded: there are surprising parallels between the work of an architect such as Kengo Kuma, with all his anti-computational zeal, and the young protagonists of the second digital turn.

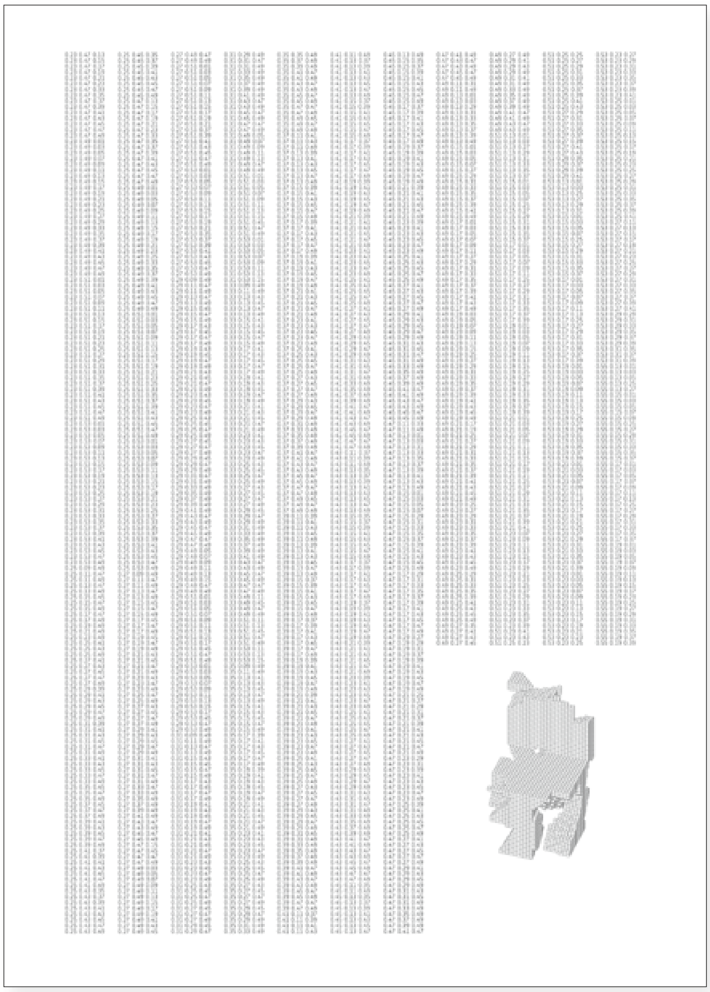
Digitally intelligent architecture no longer looks the way it did. While some in the profession, and many in the general public, still seem to assume that the use of computational tools inevitably results in the design and production of smooth and curvy lines and surfaces, most experiments in schools and in avant-garde practices for the last 10 years or so have been probing a very different visual environment: disjointed, disconnected and fragmentary – often voxellised, filamentous or chunky.

A New Visuality

I first became aware of the rise of a new visuality – indeed, of a new style – in digital design and fabrication around 10 years ago, and this led to an article and later a book mostly devoted to the same interpretive conundrum:[1] Why are computer-generated voxels (or other, similarly discrete parts) replacing computer-generated splines as the distinctive image of today's computational technology? After all, today's computers are not very different from those of 30 or 20 years ago.

For sure, fabrication hardware has changed, if silicon chips have not. The technical protagonist of digital fabrication in the 1990s was the CNC milling machine – a legacy, subtractive fabrication technology that, by the way it works, favours the milling of smooth, streamlined curves. To the contrary, today's industrial-grade 3D printers print out little cubes, or voxels, which designers often choose to leave in plain sight. Ditto for the robotic weaving of extruded filaments, or the robotic assembly of prefabricated components: based on the addition of discrete parts, these rapidly developing fabrication technologies favour an 'aggregational' way of building, at all scales and sizes. And of all the above this issue of AD offers memorable instances.

But this is only part of the story. The first epiphany of what I call the second digital style, or the style of computational discretisation – Philippe Morel's *Bolivar Chair* of 2004 – was not 3D printed. It was fabricated using traditional laser cutting and manual assembly. But its voxellised look was deliberately meant to reveal the computational method used to calculate it – finite element analysis (FEA), a mathematics of discrete parts that is at the core of today's design tools, and which is conceptually and technically remote from all traditional methods of structural design. And this is where today's computation is breaking new ground: today's computers are so fast and powerful that methods of calculations that would have been practically unusable only a few years ago are now perfectly functional – merely due to the brute force and speed of today's machines. Some like to think of these new computational tools as a new form of artificial intelligence (AI) – an expression that harks back to earlier (and failed) computational experiments. In fact, it is easier to admit that we are dealing here with the rise of a new scientific method, or indeed of an entirely new science, which is the reverse and nemesis of the old science we knew – the science of Galileo and Newton, aka modern science. This was until recently the only functioning science we had. No more.



EZCT Architecture & Design Research, Philippe Morel with Hatem Hamda and Marc Schoenauer, Studies on Optimization: Computational Chair Design Using Genetic Algorithms, 2004

Axonometric rendering of *TestBolivar-320 Chair*, with list of voxel coordinates. Each TestBolivar model is optimised by running 36,000 structural evaluations using finite element analysis (FEA).

Material (Dis)continuity

Modern science and technology – the science we studied at school, and the technology that propelled the industrial revolution – always aimed at making things simple. The world as we see it is a meaningless mess: in order to understand it, predict it and act on it, we must convert it into simpler formulas or laws we can more easily comprehend within our mind. But our mind is hard-wired for small data: there are limits to the amount of stuff we can remember and we are slow in processing quantitative information. This is why science favours short, user-friendly notations, mostly expressed through mathematical equations and functions, to determine relations of cause and effect among a very limited number of measurable factors.

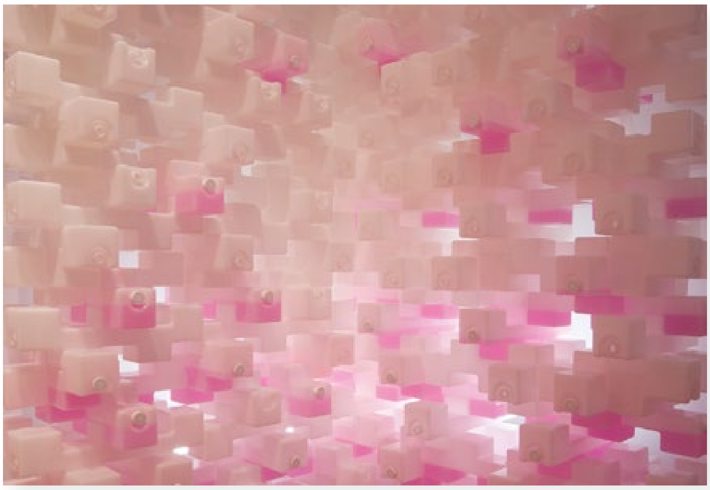
Built on similar premises, statics and mechanics of materials were among the most successful of modern sciences. In the 19th century the theory of elasticity adopted the most powerful mathematical tool then available –

differential calculus – to describe the deformations under stress of an ideal building material, perfectly isotropic, homogeneous, and continuous at every scale. Leibniz's and Newton's differential calculus was the culmination of classical mathematics, and it modelled nature using ideal notions – the infinite and the infinitesimal – that do not exist as such in reality; due to the way it notates infinitesimal increments, calculus best describes natural phenomena subject to smooth and continuous variations – the kind of variations that can be scripted as a mathematical function and graphed as a continuous curve. Not surprisingly, Leibniz also thought that continuity is a universal law of the physical world: in his classical worldview, which became a tenet of modern science, nature does not jump (*natura non facit saltum*).

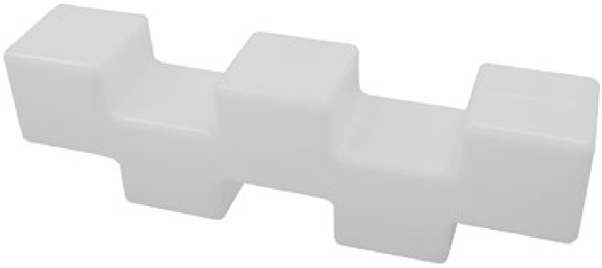
Natural building materials, however, did and do – as, far from being continuous, they tend to have all sorts of gaps and cracks and knots and slits and fissures all over. This is why in the course of the industrial revolution scientists had to invent new, artificial materials that could be as continuous and homogeneous as the mathematical functions then used to describe them: industrial-grade steel was the best match they could concoct, as steel is designed and made to have the same elastic properties everywhere and in every direction; a bit later, reinforced concrete came up as the second best. The theory of elasticity was the cornerstone of late 19th-century and of 20th-century civil engineering, but that theory has well-known limits, too: predicated as it is on a postulate of absolute continuity, both material and mathematical, it can calculate the deformations of the Eiffel Tower, which is made of iron, but it cannot calculate the resistance of a 3-metre- (10-foot-) tall brick-and-mortar garden wall, because each mortar joint in that wall represents one of those 'jumps' or gaps that Leibniz's nature is not supposed to make – and Leibniz's mathematics cannot describe.

Which is why FEA, an alternative mode of calculation based on three-dimensional grids of very small, discrete particles, started to be developed as of the mid-20th century; but finite element models generate such huge amounts of data that no one could make any use of them before the recent adoption of powerful electronic computing. Likewise, as of the 1970s several post-modern theories of science, known collectively today under the name of complexity theory, started to favour discontinuous scientific models for all kinds of purposes and tasks – from the theory of evolution to social sciences, from thermodynamics to the science of materials. Among the mathematical spinoffs of such theories one in particular, cellular automata (CA), posited that some natural phenomena can be best modelled by dividing continuous matter into rows of indivisible cells, then writing rules that describe simple interactions between each cell and those next to it. Once again, this particlised method was long seen as a mathematical curiosity of no practical use – until it became clear, not long ago, that today's electronic computers, unlike human computers, can work with CA just fine. Indeed, using CA computers can already outsmart us, in some cases solving problems long considered unsolvable. CA simulations are based on the endless

Kengo Kuma & Associates,
Water Block House,
New York City,
2008



Commissioned by the Museum of Modern Art, New York, for the exhibition 'Home Delivery: Fabricating the Modern Dwelling', the structure is made of prefabricated blocks, each formed of five undulating hollow cubes. This modular building system can produce dwellings in infinite configurations.



Water gives the blocks stability and provides natural insulation. The blocks are made primarily of polyethylene; when empty they are lightweight and easily transportable.

repetition of a limited number of very simple operations. Computers can work that way, and we cannot, because no human being could perform so many calculations in any practical amount of time.

Unlike humans, computers do not need science to compress and shorten their number-based operations. Think of the mathematical notation of a continuous function, in the usual format $y = f(x)$: a few letters and numbers suffice to notate an infinite number of points, which all satisfy the same stated conditions (ie, they all belong to the same curve when we graph it). Electronic computers, however, would typically translate that formula into a huge log of coordinates for a never-ending (literally) list of points – all individually designated, one by one. That list would not make any sense to us, and it would be very unpractical for us to use – because it would take forever to compile it, for a start. But computers are not in the business of making sense of the world. Besides, they can work out any never-ending log of discrete data faster and better than we would by dint of our shortest and most elegant mathematical formulas.

Excessive Resolution

More examples could follow, and the impact of such epistemic changes is already ubiquitous – including in many technologies of daily life. And sure enough, the design professions have already taken notice, as many among today's digital innovators are trying to compose with this unprecedented data-opulence – trying to make some design sense of the overwhelming levels of figural and structural granularity that big data, or AI – or whatever we choose to call this new scientific paradigm – already allows or abets. Sometimes the superhuman resolution of AI is patently, even ostentatiously displayed in the finished work: a surface where one could count 4 billion discrete voxels is the outward and visible sign of an inward but non-human logic at play, as no human could notate 4 billion voxels one by one, the way computers do. Ditto for a building made by the robotic assembly of 4 billion standard and non-standard parts – a problem of data management that would be all but unimaginable in the absence of advanced computational tools: no human could take in, and take on, that much information. In all these instances, the rising style of computational discretism, or particlisation, is giving visible form to a new, post-scientific method, which already reveals the inner workings of an artificial mind that no longer works the way ours always did – and still does.

Kengo Kuma & Associates, GC Prostho Museum Research Center, Kasugai-shi, Aichi Prefecture, Japan, 2010

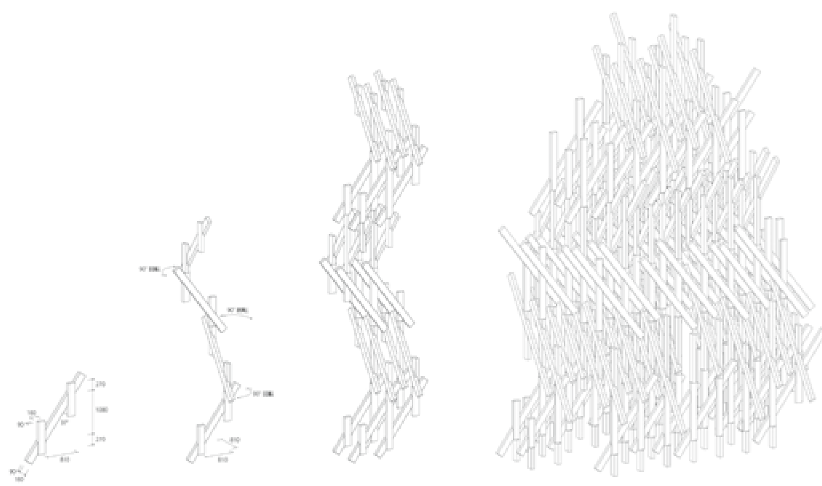
A medium-scale wood structure built by combining small-section wood members – 6 × 6 centimetres (2.36 × 2.36 inches) – based on a traditional wooden toy from the Hida Takayama region in Japan. No glue was used to build it; the wood grid supports the structure, and also serves as display space for the items exhibited in the museum.

Kengo Kuma & Associates, Yusuhara Wooden Bridge Museum, Takaoka-gun, Kochi Prefecture, Japan, 2010

A double-cantilever bridge whose structure is built with overlapping wood members, a construction method derived from the system called 'Tokiyo' used in traditional Japanese temple architecture.

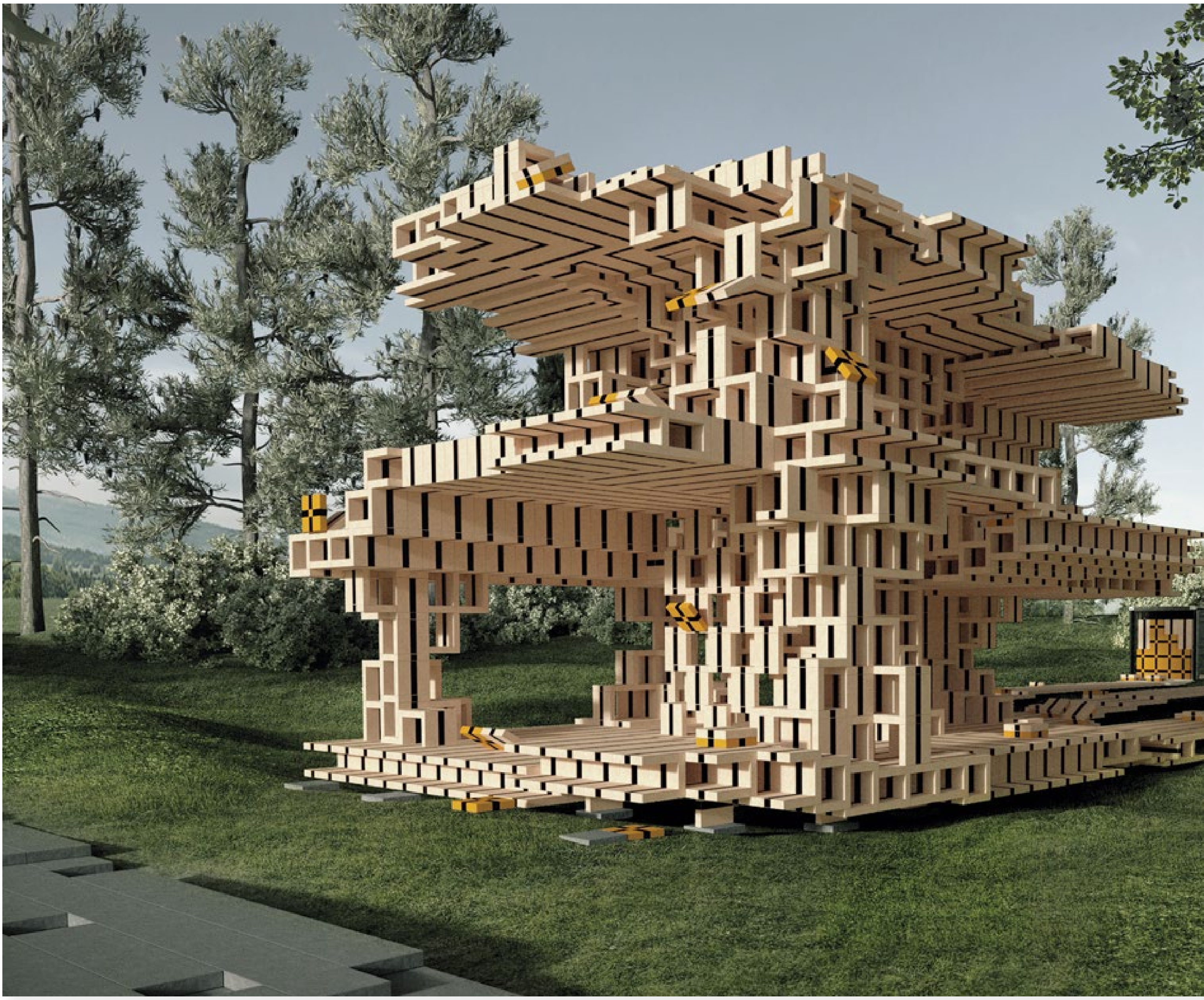
Not surprisingly, signs of this new scientific and technical paradigm, and of the way of building derived from it, are increasingly visible even outside the rarefied and often self-referential precincts of the digital avant-garde. Kengo Kuma is one of the protagonists of today's global architectural scene. He is not known for having ever nurtured any interest in computational experiments. In fact, quite the opposite: after first gaining international acclaim as a controversial PoMo classicist, in the '90s he shifted the target of his stark anti-modern stance from figure and form to the technical logic of industrial modernism itself. In his tirades against what he then called 'the method called concrete' Kuma fulminated against the (deceptive) structural continuity of cast-in-mould concrete, and against the new tools for computer-based design that architects were then learning to use in the pursuit of smooth and curving volumes and surfaces.[2] Then, starting with his seminal theory of the 'anti-object', first published in book form in the year 2000,[3] he went on to develop the non-figural, aggregational, atomised or 'particlised' style for which he is now famous, and which has become his trademark and rallying call. For, as he claimed back then, particlisation is way more than an architectural style:

> it is a view of the world, a philosophy itself. [...] In the past, such a flat [particlised] world was only thought to be a mess, and unaccountable: something that could not be handled. [...] However, contemporary technology makes it possible to process this mess of specific particles without the introduction of structure, hierarchy, or assembly. For this to function, each element needs to be relieved from contact or structure beforehand, and placed under free conditions. This is the image of what I call a particlised world; this is the image of what I call freedom.[4]



Kengo Kuma & Associates,
Yure Pavilion,
Tuileries Garden,
Paris,
2015

Construction drawing.



Dafni Katrakalidi, Martha Masli,
Mengyu Huang, Man Nguyen and Wenji Zhang,
AssemblerAssemble: Pizzabot,
B-Pro Research Cluster 4,
Bartlett School of Architecture,
University College London (UCL),
London,
2018

above: Pizzabot is a robot that has the same geometry as the elements it assembles. Using a simple, one-axis movement, the pizza-box-shaped robot can move and pick up a passive building element with an identical geometry. A computational process has been developed for coordinating the assembly of hundreds of pizzabots in parallel.

Kengo Kuma & Associates,
with Marco Imperadori (Milan),
Marco Clozza (D3Wood), Jun Sato
(structural engineer, Japan)
and Ri-Legno (Italy),
Kodama Pavilion, Arte Sella,
Trento, Italy,
2018

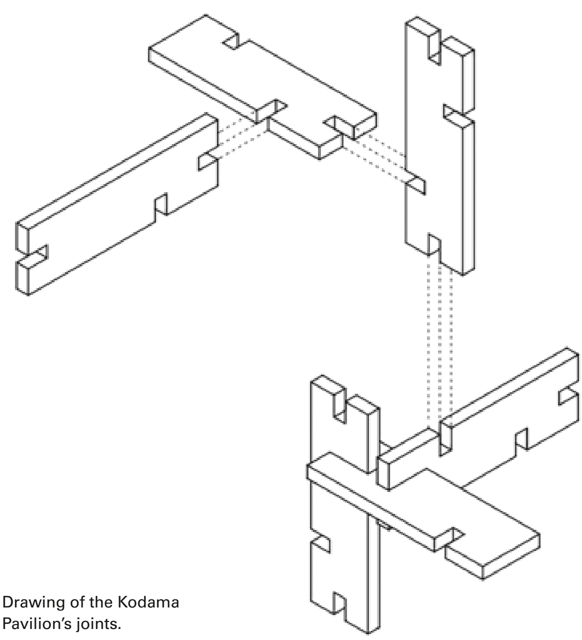
right: The 4-metre- (13-foot-) high temporary pavilion was made of an assembly of identical sticks of solid larch, each 5.8 centimetres (2.28 inches) thick, joined without any metal fitting or glue.

Simply put, Kuma's project of particlisation goes counter to, and upends, all scientific principles and technical foundations of modernity.

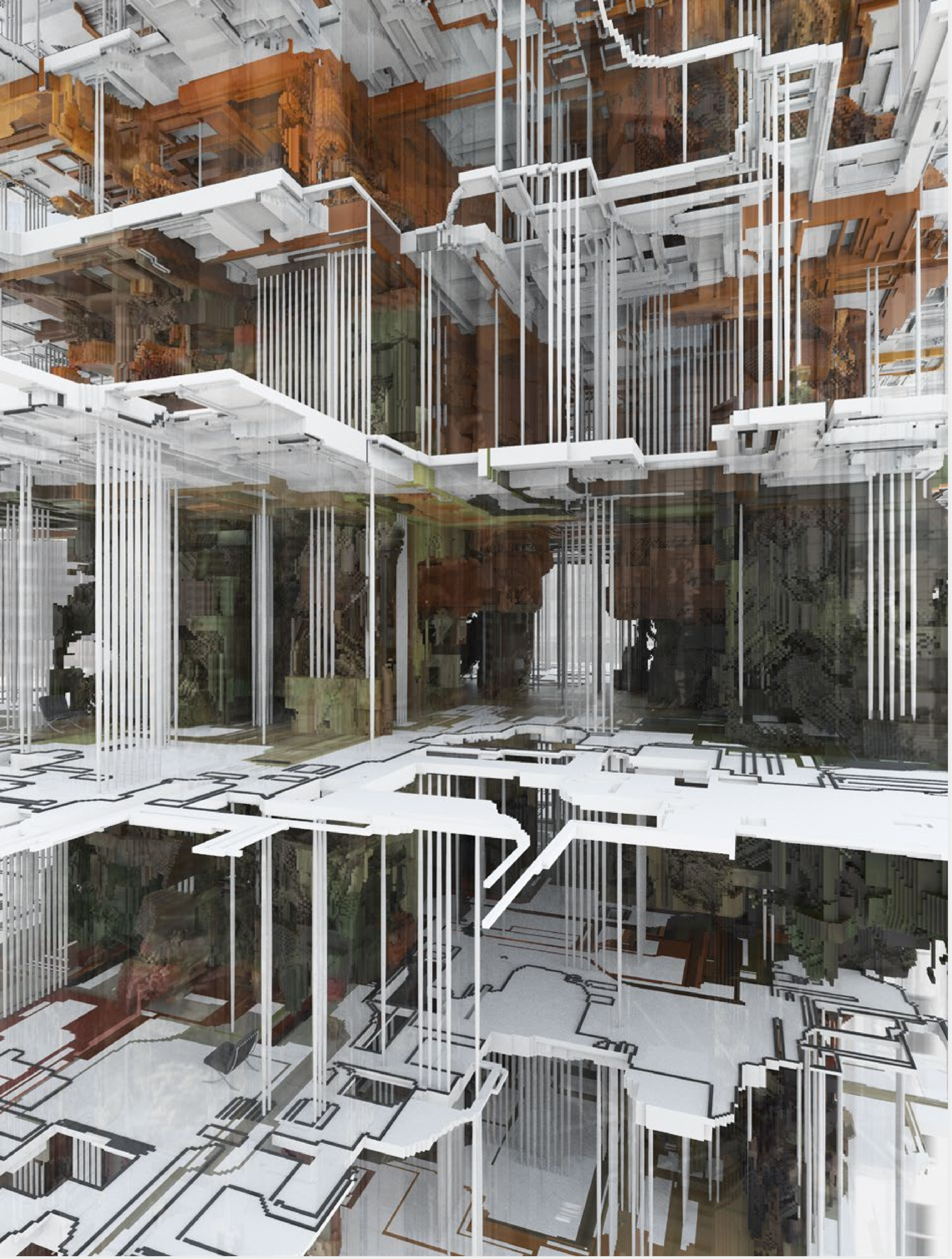
Thus it will be seen that, following an independent, almost idiosyncratic itinerary, entirely motivated by his aversion to industrial modernity, one of the protagonists of contemporary architecture ended up advocating a theoretical stance very similar to that shared by today's computational avant-garde. At the same time, it is impossible not to notice that some of Kuma's world-famous buildings look at times remarkably similar to some of the experiments currently pursued by the young digital avant-garde featured in this issue of AD. Indeed, there is a logic in that. Kengo Kuma and the young designers of the second digital turn have a common enemy: industrial modernity. One can avoid the technical logic of industrial modernity by looking back at the artisanal logic that preceded the industrial mode of production; or by fast-forwarding to the computational logic that is now superseding it. But, as we all learnt long ago, post-industrial, digital making and pre-industrial, artisanal craft have much in common. And if in some cases, as in Kengo Kuma's recent architecture, the finished work seems to mysteriously bridge the gap between the non-quantitative intuition of a traditional craftsman and the post-human logic of electronic machines, it is because AI today is just that: the pre-scientific logic of the non-mathematical mind powered by the post-scientific speed of advanced computation. AD

Notes

1. Mario Carpo, 'Breaking the Curve: Big Data and Design', *Artforum*, February 2014, www.artforum.com/print/201402/breaking-the-curve-big-data-and-design-45013; Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*, MIT Press (Cambridge, MA), 2017.
2. Kengo Kuma, *Materials, Structures, Details*, Birkhäuser (Basel), 2004, p 9 (first published in Japanese in 2003).
3. Chikuma Shobo (Tokyo), 2000. English translation: Kengo Kuma, *Anti-Object*, Architectural Association (London), 2008, transl Hiroshi Watanabe. The original title in Japanese roughly translates as *Anti-Object: Melting and Crushing Buildings*.
4. Kuma, *Materials, Structures, Details*, p 14.



Drawing of the Kodama Pavilion's joints.



M Casey Rehm

COMPLICIT

The Creation Of and Collaboration With Intelligent Machines

M Casey Rehm / Kinch,
Saturate Tower,
2015

The tower was a competition entry attempting to conflate media-based behaviours with performative behaviours in a shared data space. Primarily a formal exercise, the tower preferences local moments of clarity over legibility of figure.

How do the biases, constraints and opportunities inherent within contemporary models of intelligence lead to new aesthetics? Artificial intelligence has been central to the work of designer and algorithmic consultant **M Casey Rehm** for over a decade. Here he presents recent results of his efforts, produced within his Los Angeles multidisciplinary practice Kinch – from speculative cityscapes to a single-family house.

We live in an era where algorithms can perform apparently subjective decisions on complex data. Instagram's algorithm will sort the dead rat photos out of your kitten-centric feed … or vice versa, depending on your interests.[1] Using the app also transforms the user's behaviour to better suit the app's sorting methods. Lev Manovich describes the emergent 'designed' category of images on Instagram and documents their defining characteristics. Users employ these characteristics, possibly subconsciously, to improve their performance in Instagram's scoring system.[2]

The ability of intelligent software to manage complex datasets has immediate application in the building industry. SoftBank Vision Fund recently invested $865 million in Katerra, a vertically integrated design–build company that digitally tracks its building materials to ensure efficient delivery and installation.[3] As intelligent platforms begin to expand into architecture through economic pressure, how do we produce designs that resist the homogenisation inherent in other cultural platforms?

In *The Stack* (2015), Benjamin Bratton states: 'As discrete human individuals believe themselves in charge of their tools, they nevertheless represent an increasingly particular, even marginalised type of User-agent with a diverse throng of alternatives.'[4] Through the text he exposes the quantity of nonhuman agents operating within our networked society, and the significant impact they make on contemporary life. If we are to produce an architecture which embraces the potential of these agents to access a more sophisticated understanding of the world, we need to understand the specifics in how they view it.

The Pixel/Voxel as Raw Material

The pixels of a digital image exist in programming as an array of discrete numerical data. Of interest to the designer is how an algorithm can interpret, or superimpose a structure on that data which allows it to be utilised by both human and nonhuman agents. Also of interest is how the differences in the two sets of intended audiences produce divergent effects. Kinch's *Narcissism of Small Differences* (2012) is a composite of two works by the 18th-century Dutch painter Rachel Ruysch, generated through two competing sets of agents. The first is operating as an advocate for the human observer, utilising methods like contour and blob detection to identify and repair recognisable regions of the two compositions. The second operates to expose underlying structures of colour relationships between the two paintings, utilising a constrained version of a motion-interpolation algorithm. The latter produces an opaque yet coherent effect of intricacy rather than serving a didactic purpose.

M Casey Rehm / Kinch, *Narcissism of Small Differences*, 2012

The composition is part of a series of graphic explorations into the embedding of aesthetic intention into the underlying code of common image-based algorithms. This version utilises two competing intelligent agent types based on motion-interpolation algorithms used for extending video frames and object recognition respectively.

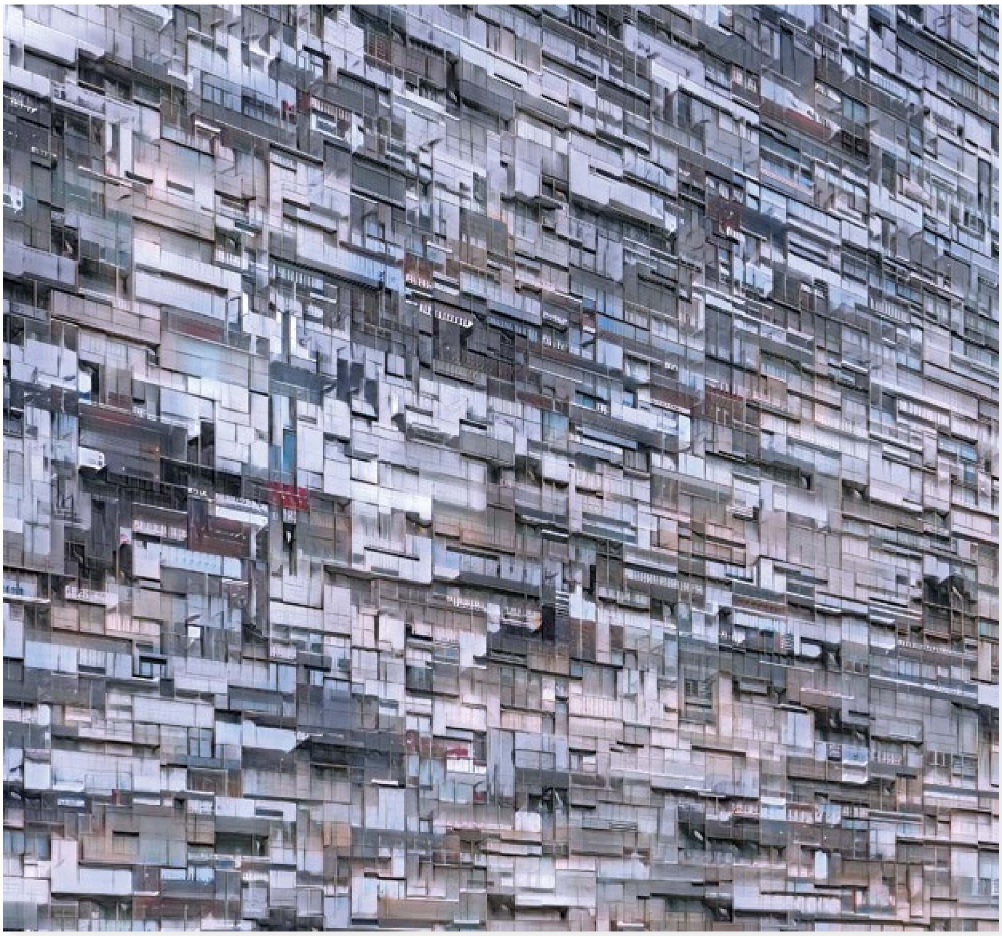
The algorithms utilised in the flower composition fall under the classification of a simple reflex agent per Stuart Russell and Peter Norvig.[5] The designer must directly programme the rules governing the agent's response to its inputs and its behaviours to modify its environment. Projects done in the studio utilising this form of agents tend to reinforce a reading of the underlying grid structure of the data being operated upon. Agents are constrained in their vectors to align directly with the gridded space, producing the distinct 45- and 90-degree striations. The discrete pixel/agent is preserved as an ingrained portion of the aesthetic.

Saturate Tower (2015) was Kinch's initial attempt to conflate the compositional behaviours of the graphic work with additional behaviours to explicitly form architectural elements like floor plates, column grids and cores. The tower begins to set a parallel agenda to the graphic work, moving the aesthetic agenda away from clarity of figure in favour of local intricacies. However, it also exposes the complexity of coding decision-making for all architectural realities in the compromised performance of each state and the highly hierarchical and repetitive relationships between individual behaviours.

Teaching Algorithms to Design

Advances in graphics processing unit (GPU) hardware and programming have accelerated the application of deep convolutional neural networks in terms of efficacy and availability. These models have excelled at solving seemingly subjective problems that are too complex to solve through explicitly coding the logic like in the previous examples. Since 2014 there has been a massive acceleration in performance in classification, excelling human error rates on benchmark image sets.[6] Google's DeepDream, which was initially developed to help visualise the otherwise opaque set of filters used in Google's Inception classifier,[7] kicked off a series of models specifically designed towards generation instead of analysis, like the generative adversarial network (GAN).[8] Unlike simple reflex agents, a deep learning network's decision-making is learned rather than coded.

The models used in *Hoax Urbanism* (2017) and *Automatic Ginza* (2018) are partially based on the cycle-consistent adversarial network proposed by Jun-Yan Zhu *et al.*[9] Their model extends a GAN, by pairing two sets of generators and discriminators together, and extends the generators with encoding layers to allow it to operate on images which have prior content. The Hoax Urbanism prints were shown in the 'Architecture' exhibition at A+D Museum, Los Angeles in June 2017. The image uses a series of models to transform high-resolution drone surveys of uninhabited deserts into anthropic landscapes. The ability of the networks to consider a pixel's value in relationship to multiple scales of context allows the machine to understand compositional hierarchies in more subtle ways than the methods used in the 'Narcissism' series. A pixel in two overlapping samples may indicate a transformation towards a building rooftop in one region and a farm field in another, depending on its relationship to the other pixels in that sample and to other hierarchies in the overall composition.



M Casey Rehm / Kinch,
Automatic Ginza,
'3-Ways' exhibition,
A+D Museum,
Los Angeles,
California,
2018

Automatic Ginza is a three-minute media installation utilising a neural-network model trained on cellphone videos of the Ginza district of Tokyo, to transform 2D greyscale rectangles into evolving architectural facades. The project explores the ability of AI image techniques to transform one location towards the aesthetic of another while remaining specific in terms of proportion and scale of the initial location.

M Casey Rehm / Kinch,
Hoax Urbanism,
'Architecture' exhibition,
A+D Museum,
Los Angeles,
California,
2017

The composition is part of a series exploring the use of machine-learning algorithms to generate speculative cityscapes from large-format drone surveys of uninhabited landscapes in the California desert. The project attempts to visualise the future impact of human expansion in transforming existing wilderness.

The *Automatic Ginza* image is a still from a video translating the qualities of one urban location onto another, shown in June 2018 at the A+D Museum exhibition '3-Ways'. The neural network maps learned aesthetics from a set of facades photographed in Ginza, Tokyo onto one in downtown Los Angeles. This type of network has gained media attention for its use in 'Deepfakes', producing hard-to-identify 'alternative facts' and celebrity pornography.[10] The application in this series is to explore aesthetic relationships between global urban contexts via aesthetics understood through the pattern recognition of a neural network rather than through the lens of architectural history.

Both images express the potentials of these networks to generate compositional hierarchy, as well as the impact of the input data on the final composition. The *Automatic Ginza* dataset is intentionally constrained in comparison to the *Hoax Urbanism* models, producing more consistent results frame to frame in the video. Additionally, the input images of the *Hoax Urbanism* model carry finer granularity and unique features. The consequence is a more repetitive aesthetic with fewer unique regions in the Ginza composition. However, both images express the reality that any design process which consumes massive quantities of pre-existing data will reinforce existing aesthetics at some level.

Spaces From/For Data

Control, an installation by Kinch at the Southern California Institute of Architecture (SCI-Arc) gallery in 2016, was designed by simple reflex-agent software integrating compositional behaviours modified for three dimensions, with behaviours responding to building constraints. The agents operate on a single three-dimensional data structure of 6,840,000 16-bit integers representing the volume of the gallery. Each value in the array could represent cost, structural loading, material differentiation, or the form of the piece depending on which agent was viewing the data. The quantity and diversity of decisions being made by the platform defies the ability to represent them.

This acceptance of an inability to represent process in a traditional way, allows for the designer to more precisely conflate the digital and the physical. *Control* operates as a living-room-sized selfie machine. The interactive media is scaled so that one pixel is 1/32 of the 1.5-inch (3.8-centimetre) grid of timber elements. The laser-etched patterns in the mirror panels' silvering scale reflections to the same pixel dimension, superimposing the reflected images of the visitor with the digitally transformed version. The virtually and physically gridded data structure allows for precise location of occupants through 3D scanners and web cameras. The scanners control slices of aligned perspectives taken from prerecorded drone videos, creating user-specific views. The cameras capture faces and motion, transforming the occupants on the rear projected mirrors. Surveillance becomes personalised view and ornamental surface, and the architecture remains incomplete until engaged by the occupant.

NN_House 1 (2018) is a single-family residence in Joshua Tree, California that expands on ideas explored in *Control* while also integrating concepts learned in the Hoax Urbanism project. The design of the house mines the relative values of intelligent agent algorithms, including 3D neural networks as well as simple reflex agent models operating on a single 1200 × 900 × 160 data array.

The density of material elements in perspective defines the architectural spaces in this project. Clarity of parti and legibility of a totalistic figure are dismissed. The NN models generating the plan and massing reference the definition of space through partial planes in Ludwig Mies van der Rohe's Brick Country House (Potsdam-Neubabelsberg, Germany, 1964), and the bundling of discrete elements to produce implied division in Alvar Aalto's Villa Mairea (Noormarkku, Finland, 1939). The machine's lack of concern for domestic norms, and fidelity to a high-resolution site model, dissolves the clear order visible in those houses' plans. Instead spaces and programme are defined though local moments of clarity or interface within a more complex whole. Implied volumes are created by the accumulation of wall-like elements. Shifts in colour patterns augment the reading of individual spaces.

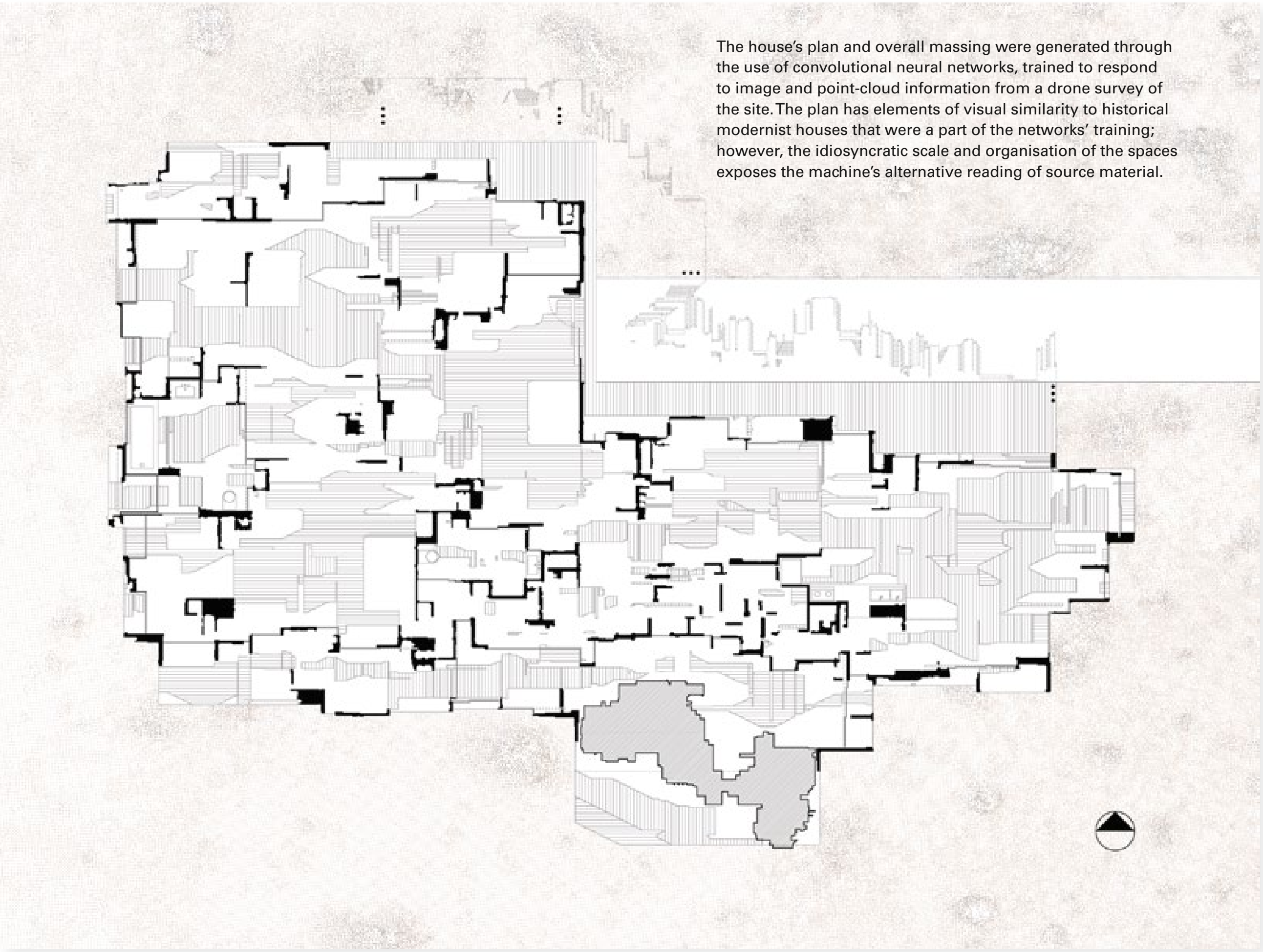
The aesthetics of the interior exploit lessons learned through the explorations with transformative neural networks mentioned above and through ongoing experiments with augmented reality. The patterns and forms of the architecture create a highly complex catalog of unique aesthetic features, in anticipation of digital overlay and nonhuman vision. The architecture becomes the irritant data as an input to digital perception. Its unique specificity becomes a residual feature in any augmented-reality overlay, while the abundance of elements isolating occupant figures in perspective and a vast array of distinct visual features amplifies the performance of house systems relying on machine vision.

M Casey Rehm / Kinch,
Control,
SCI-Arc Gallery,
Los Angeles,
California,
2016

Control was an installation designed and documented through the use of multiple intelligent agent types operating on a single three-dimensional data structure. The project creates a domestic-scale environment where interactive media on rear projected mirrors operate coherently within the voxel timber construction.

M Casey Rehm / Kinch, NN_House 1,
Joshua Tree,
California,
2018

Interior perspective. The house utilises a dense plan of architectural elements organised and generated through convolutional neural networks to create a simultaneously continuous and fragmented space. The deep layering of elements negates the hostile glare of the surrounding desert, while articulated patterns create coherent regions within the larger whole.



The house's plan and overall massing were generated through the use of convolutional neural networks, trained to respond to image and point-cloud information from a drone survey of the site. The plan has elements of visual similarity to historical modernist houses that were a part of the networks' training; however, the idiosyncratic scale and organisation of the spaces exposes the machine's alternative reading of source material.

The oblique worm's-eye view exposes the layering effect of the house's graphic elements to produce implied regions within the dense spatial dividers. The ceiling expresses the load-based layup schedule of the laminated timber roof plate.

Transforming Design through Nonhuman Collaboration

Kinch's work expresses a clear privileging of nonhuman agents' tendencies to produce coherent intricacy from complex inputs without relying on reductive or legible organising principles. The aggregation of understanding by convolutional neural networks from sets of discrete filters and a pixel-based reflex agents' tendency to expose discrete data's assembled aesthetic, suggests an architecture that questions the value of legibility in representation and clarity in form. As our means of engaging the world transform our behavior, we should reconsider what is significant in architecture. Designers should be complicit with the superficially banal algorithms which surround our daily life. As automated intelligence continues to expand its presence, architecture should leverage it to produce new cultural meaning while at the same time allowing it to reshape how we understand value in the discipline.

Notes

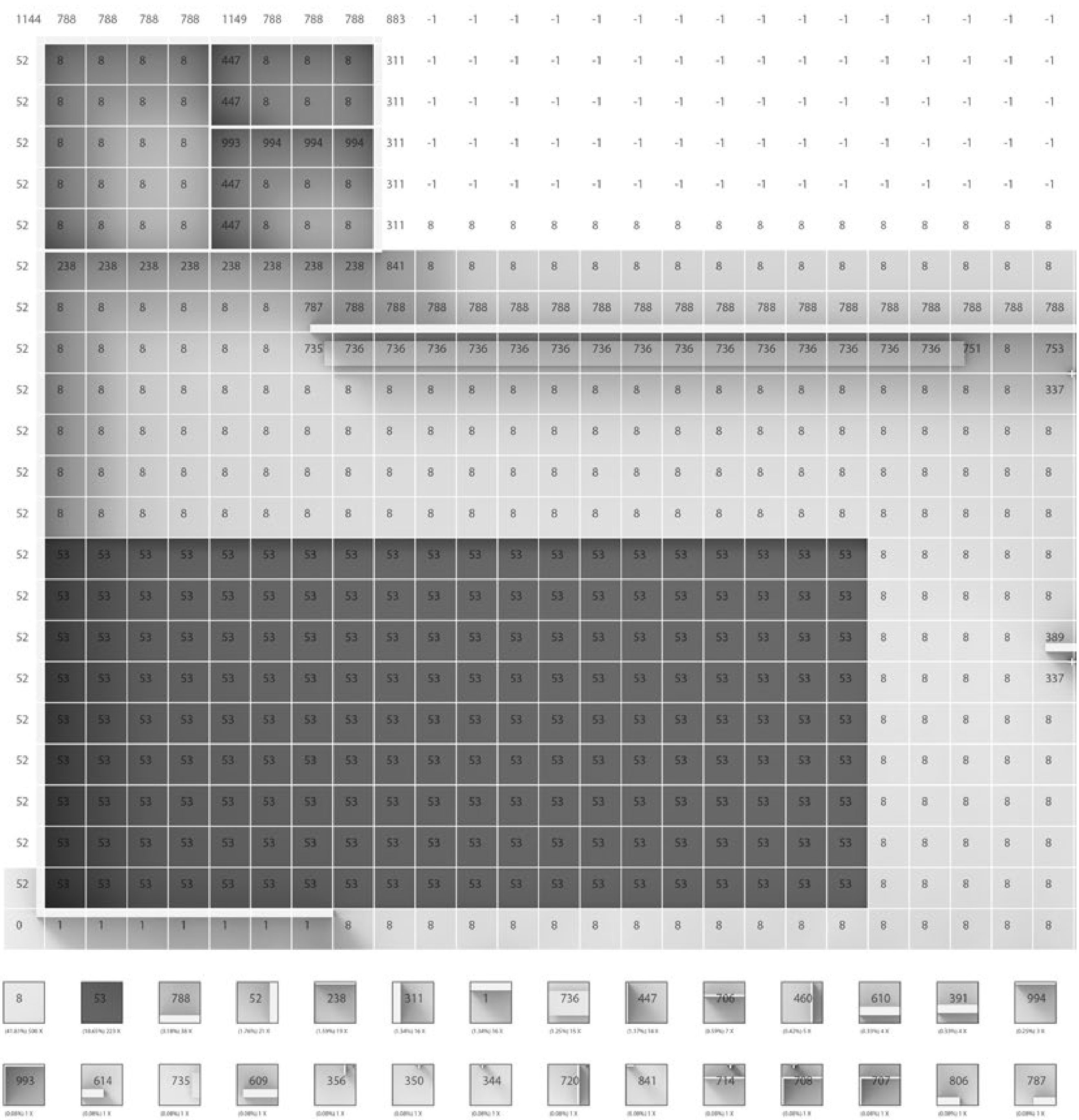
1. Josh Constine, 'How Instagram's Algorithm Works', *Tech Crunch*, 1 June 2018, https://techcrunch.com/2018/06/01/how-instagram-feed-works/.
2. Lev Manovich, *Instagram and Contemporary Image*, published online under Creative Commons License, 2016, http://manovich.net/index.php/projects/instagram-and-contemporary-image, Part 4, pp 114–44.
3. Michael J de la Merced, 'Investors Bet On a Firm Reimagining Construction', *New York Times*, 24 January 2018, p B7.
4. Benjamin H Bratton, *The Stack: On Software and Sovereignty*, The MIT Press (Cambridge, MA), first edition, 2015, p 260.
5. Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach*, Pearson (Harlow, Essex), third edition, 2009, pp 34–64.
6. Robert Geirhos, David HJ Janssen, Heiko H Schütt, Jonas Rauber, Matthias Bethge and Felix A Wichmann, 'Comparing Deep Neural Networks Against Humans: Object Recognition When the Signal gets Weaker', arXiv:1706.06969, 21 June 2017, https://arxiv.org/abs/1706.06969.
7. Alexander Mordvintsev, Christopher Olah and Mike Tyka, 'Inceptionism: Going Deeper into Neural Networks', Google AI Blog, 17 June 2015, https://ai.googleblog.com/2015/06/inceptionism-going-deeper-into-neural.html.
8. Ian J Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville and Yoshua Bengio, 'Generative Adversarial Networks', arXiv:1406.2661, 10 June 2014, https://arxiv.org/abs/1406.2661.
9. Jun-Yan Zhu, Taesung Park, Phillip Isola and Alexei A Efros, 'Unpaired Image-to-Image Translation using Cycle-Consistent Adversarial Networks', arXiv:1703.10593, 19 February 2018, https://arxiv.org/abs/1703.10593.
10. Kevin Roose, 'It was Only a Matter of Time: Here Comes an App for Fake Videos', *New York Times*, 4 March 2018, p A1.

Exterior perspective. The house presents an ambigous envelope to the surrounding desert with deep-set fenestration, staggered wall-like elements and complex patterning. The elements combine to produce privacy and shade while allowing for moments of continuity with the landscape.

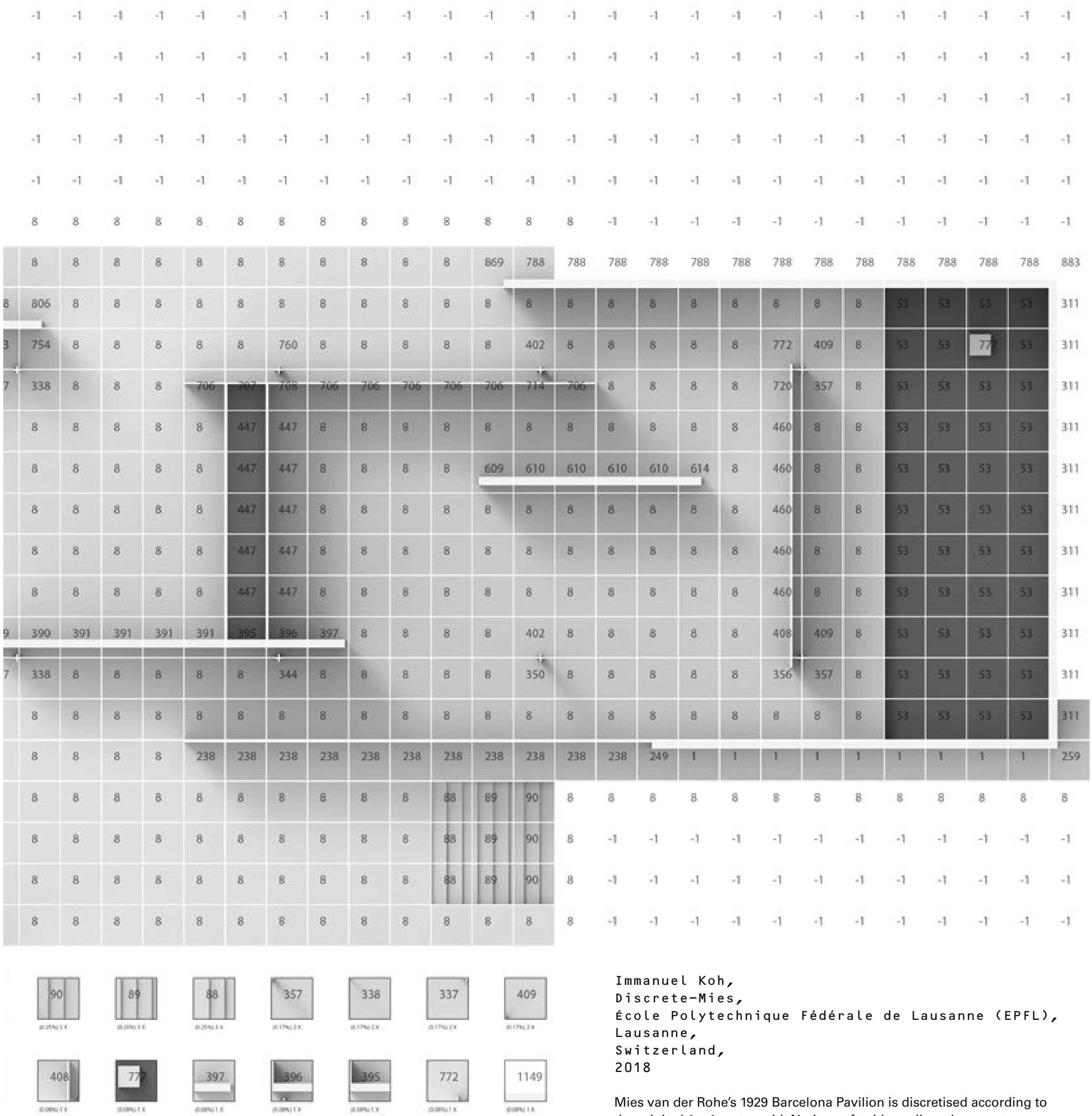
As automated intelligence continues to expand its presence, architecture should leverage it to produce new cultural meaning while at the same time allowing it to reshape how we understand value in the discipline.

Discrete Sampling

Immanuel Koh



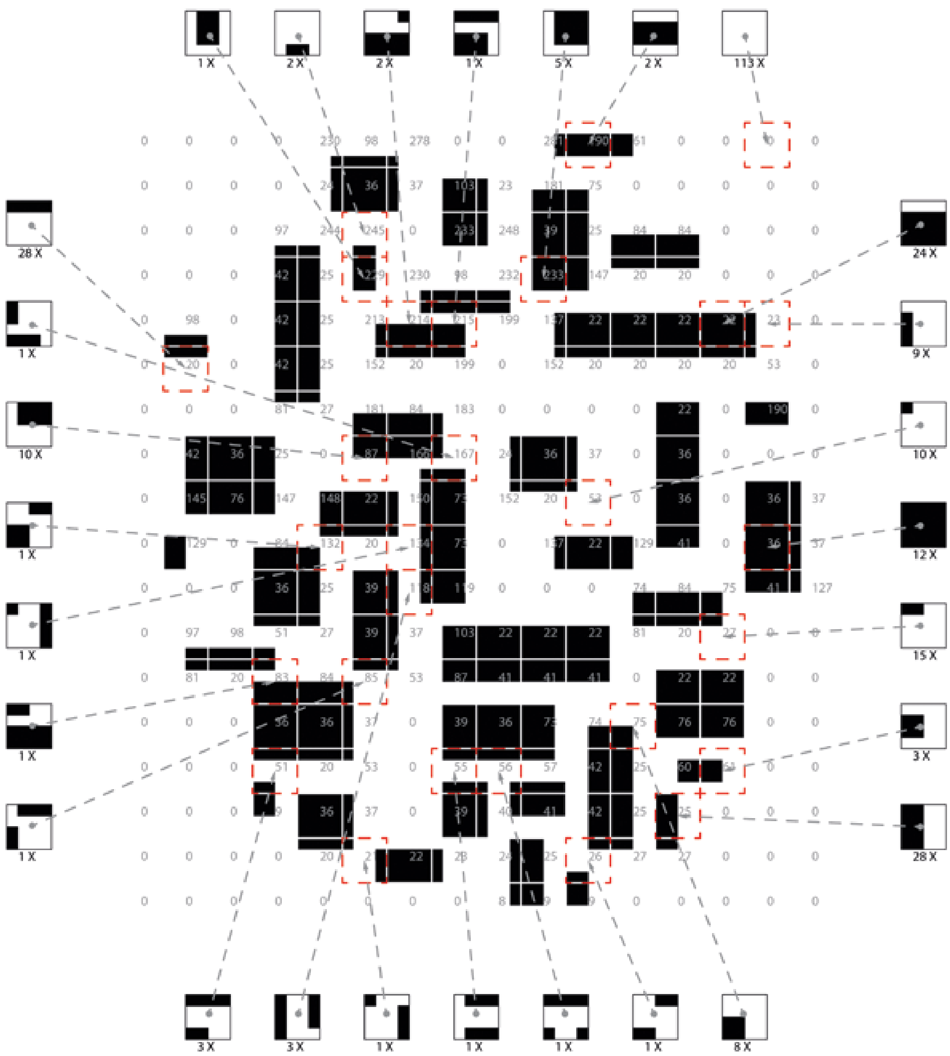
There Is No Object Nor Field … Just Statistical Digital Patterns



Immanuel Koh,
Discrete-Mies,
École Polytechnique Fédérale de Lausanne (EPFL),
Lausanne,
Switzerland,
2018

Mies van der Rohe's 1929 Barcelona Pavilion is discretised according to the original 1 x 1 metre grid. Notions of voids, walls, columns, steps, ground and furniture are all 'flattened' as a set of generic and uniformly sized discrete cells, sorted only according to their frequency distribution.

The analogue differentiation between figure and ground has long been a given in architectural design. Challenging this, **Immanuel Koh**'s doctoral research at the École Polytechnique Fédérale de Lausanne in Switzerland involves digitally decomposing existing designs into discrete figure-and-ground cells. These can then generate new configurations with similar spatial features to the iconic structures they derive from: Walter Gropius's 1926 Bauhaus building in Dessau, Mies van der Rohe's 1929 Barcelona Pavilion, and Andrea Branzi's 1969 *No-Stop City*. He reflects on precursors to his work and on its relevance to architecture's future.



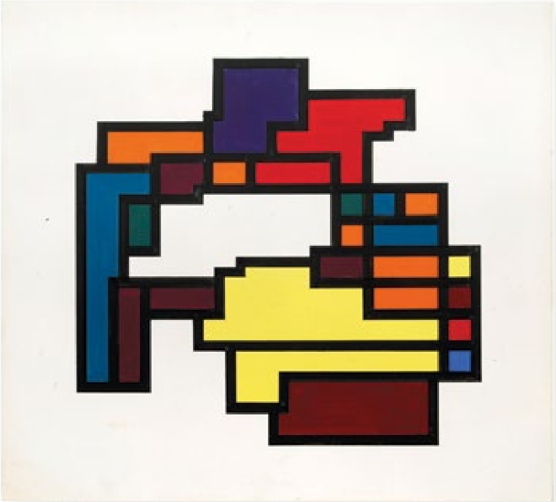
Immanuel Koh,
Discrete-Field Conditions,
École Polytechnique Fédérale
de Lausanne (EPFL),
Lausanne, Switzerland,
2018

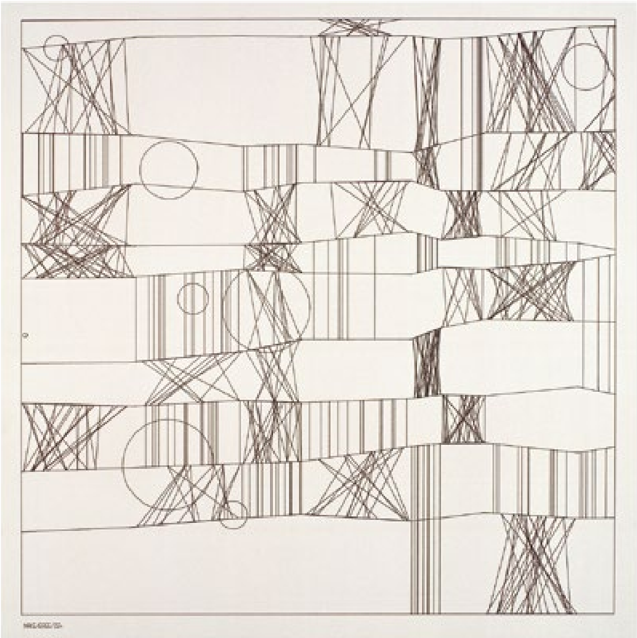
One of the many generic figure-ground field diagrams used by Stan Allen is here discretised and encoded as an instance of a combination from 28 unique part-figure/part-ground patterns. It is an alternative reading of the 1990s field conditions where the distinction of figure and ground is completely abandoned.

In the seminal 1997 *Architecture After Geometry* issue of AD, Stan Allen's article 'From Object to Field' decidedly heralded the algebraic field conditions in architectural discourse and indirectly signalled the supposed gradual disappearance of geometric objects.[1] In the section 'Digital Fields', quoting Vivian Sobchack's reading of the digital as 'discrete pixels and bits of information that are transmitted serially, each bit discontinuous, discontiguous, and absolute – each bit 'being in itself' even as it is a part of a system',[2] Allen proposed a field-to-field relation.[3] He argued that the empty space of the classical 'figure on ground' or the Modernist's 'figure against figure' is no longer a void, but equally filled. Ironically, after two decades of digital fields, we still witness the seemingly inevitable stronghold of the figure and ground, as evident in Allen's own Detroit Rock City project for the US Pavilion of the 2016 Venice Architecture Biennale – a proposed vertical botanic garden at Albert Kahn's Packard Factory – where a multitude of self-similar geometric figures were simply laid distributed in empty space. In other words, we architects are still held captive by the same old analogue figure-on-ground model. The key to truly activate this field condition is to flatten the ontological difference between the figures/objects in the foreground and the ground/field in the background. The continuous analogue human eye is to be supplanted by a 'discrete digital vision'. That is, the statistical seeing underlying today's machine learning and deep learning in artificial intelligence.

Hiroshi Kawano,
Artificial Mondrian,
ZKM|Museum of Contemporary Art, Karlsruhe, Germany,
1969

The work was among the earliest attempts in computer art to capture the implicit stylistic feature of an artist's works (in this case, Piet Mondrian) with statistical models. It is arguably digital in its conception, decomposing and resampling with colour blocks; and discrete in its production – using a line printer to print characters (themselves encoding colour data), before hand-painting them on paper as finished artworks.





Frieder Nake,
Hommage à Paul Klee 13/9/65 Nr.2,
Victoria and Albert Museum, London,
1965

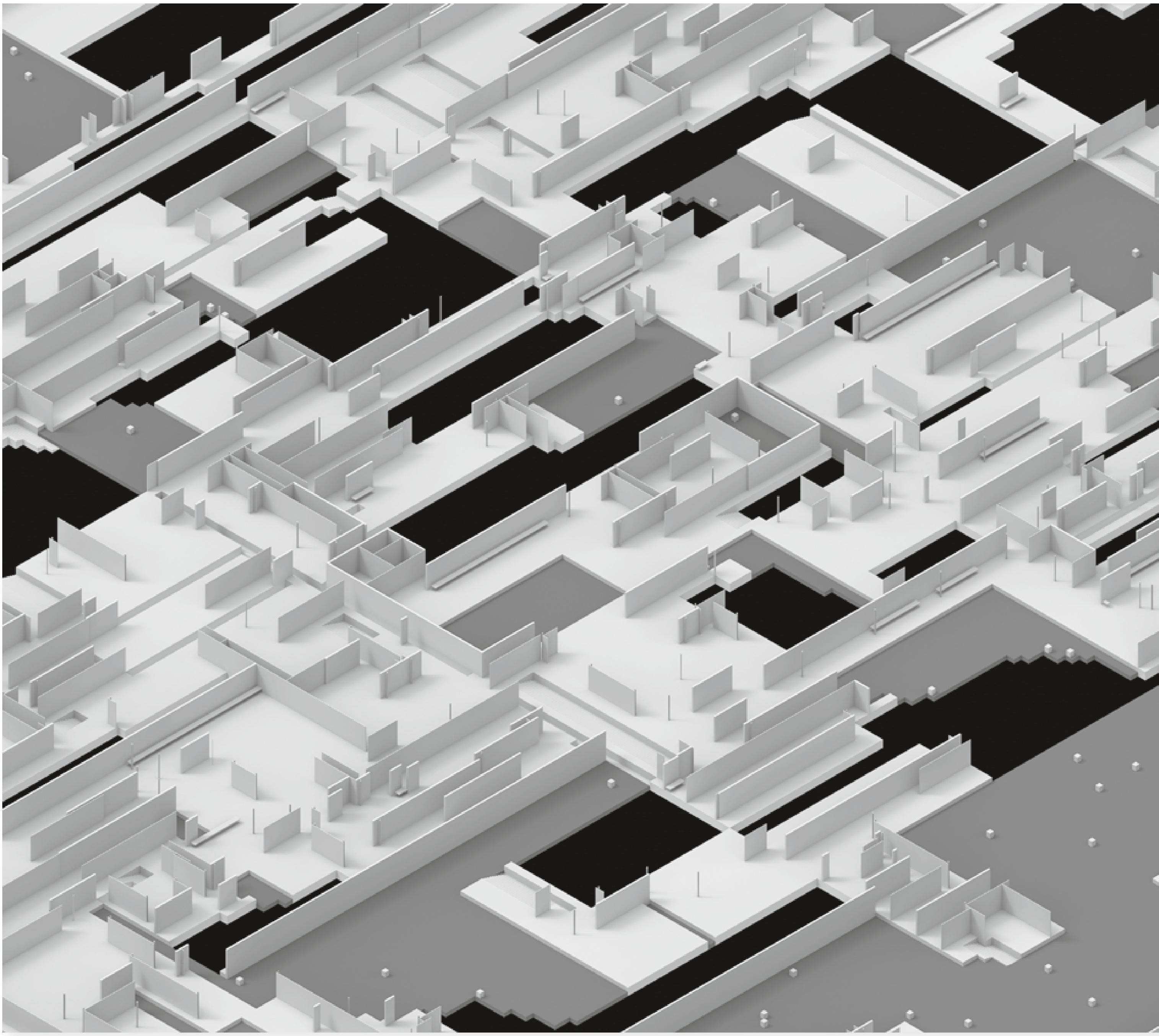
The work encodes the figural and compositional logic of Paul Klee's 1929 *High Roads and Byroads* with a set of explicit programming rules. It is arguably analogue in its conception, layering geometric lines and circles; and continuous in its production – solely visualising them as vector graphics with the pen plotter instead of the computer screen.

Statistical Seeing

What, then, should constitute this discrete digital vision in architecture? Before we attempt to answer this, it might be timely to first turn to the computer art scene of the 1960s and revisit the pioneering works of philosopher-programmer Hiroshi Kawano and mathematician-computer scientist Frieder Nake. Unlike many of his contemporaries, Kawano's early work was based on data-driven techniques rather than the explicit programming of rules. A striking comparison can be found between Nake's *Hommage à Paul Klee 13/9/65 Nr.2* of 1965 and Kawano's *Artificial Mondrian* of 1969. Nake first abstracted Klee's figural lines as explicit rules before plotting them on an empty background of continuous paper space. Kawano, on the other hand, neither differentiates the figure and the ground as separate entities nor attempts to write a Mondrian shape grammar. He simply decomposed Mondrian's painting into a grid of equally sized colour blocks for the computer to statistically learn their discrete probability distribution. He then sampled from that same distribution to infer new Mondrians. In fact, his discrete colour blocks are what Sobchack might have referred to earlier on as 'discrete pixels'. Interestingly, or even prophetically, this machinic pattern-recognition process of 'statistical seeing' is not too dissimilar to how today's deep neural networks are trained from big datasets of images to detect and recognise all sorts of objects. These training sets of images are simply 'discrete fields' of numbers with no prior ontological differentiation of the foreground objects and background scenes. A series of recent design projects developed at the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland shed light on what might indeed constitute these discrete fields in architecture.

Immanuel Koh,
Discrete-Mies,
École Polytechnique Fédérale de Lausanne (EPFL),
Lausanne, Switzerland,
2018

Mies's original Barcelona Pavilion is shown right in the middle among an infinite multitude of newly inferred ones. Each new pavilion retains, with varying degree of fidelity, the formal relationships among voids, walls, columns, steps, ground and furniture of the machine-learnt Barcelona Pavilion.



The Discrete-Mies project revisits Mies's pavilion to investigate the design consequences engendered by such a conceptual denial of the figure-ground with that of the discrete fields.

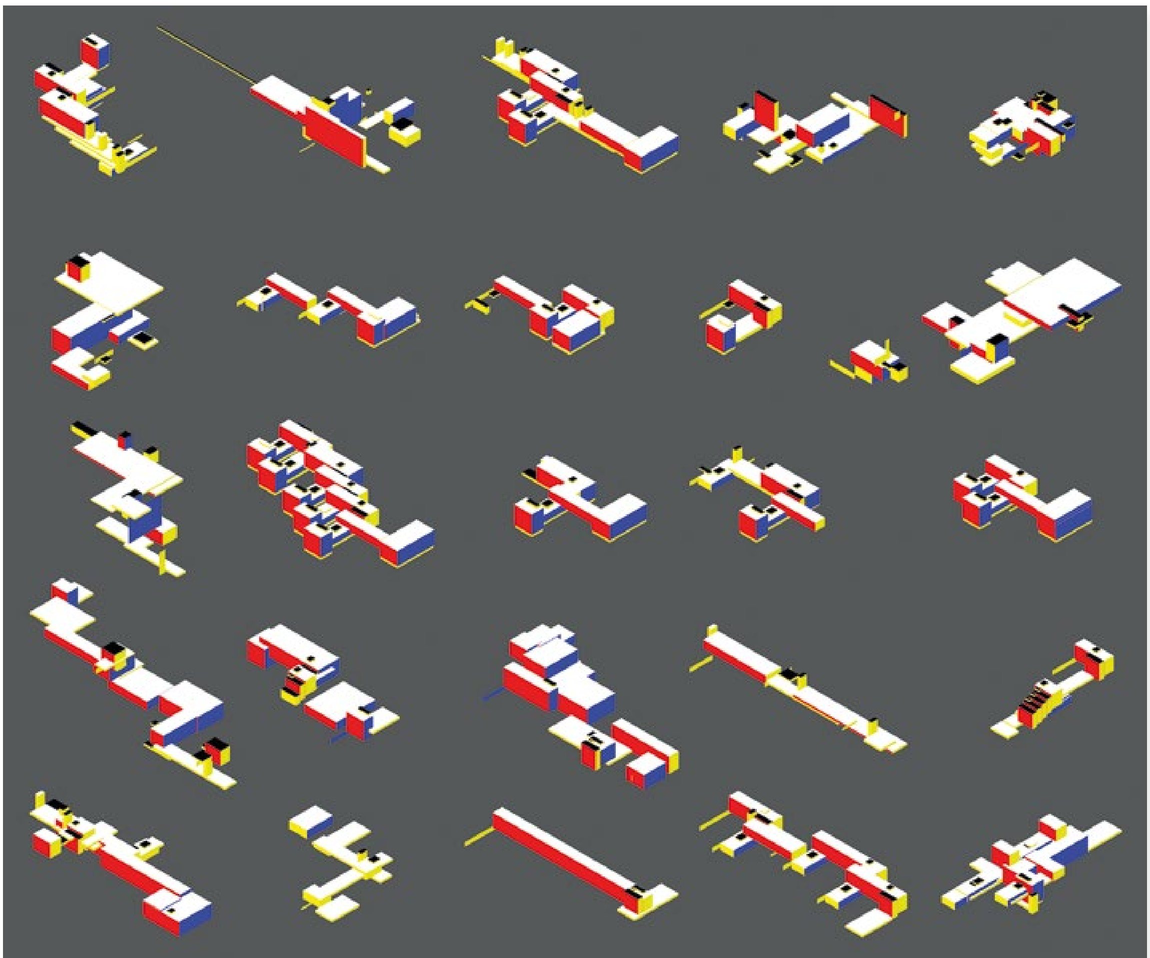
Discrete Fields

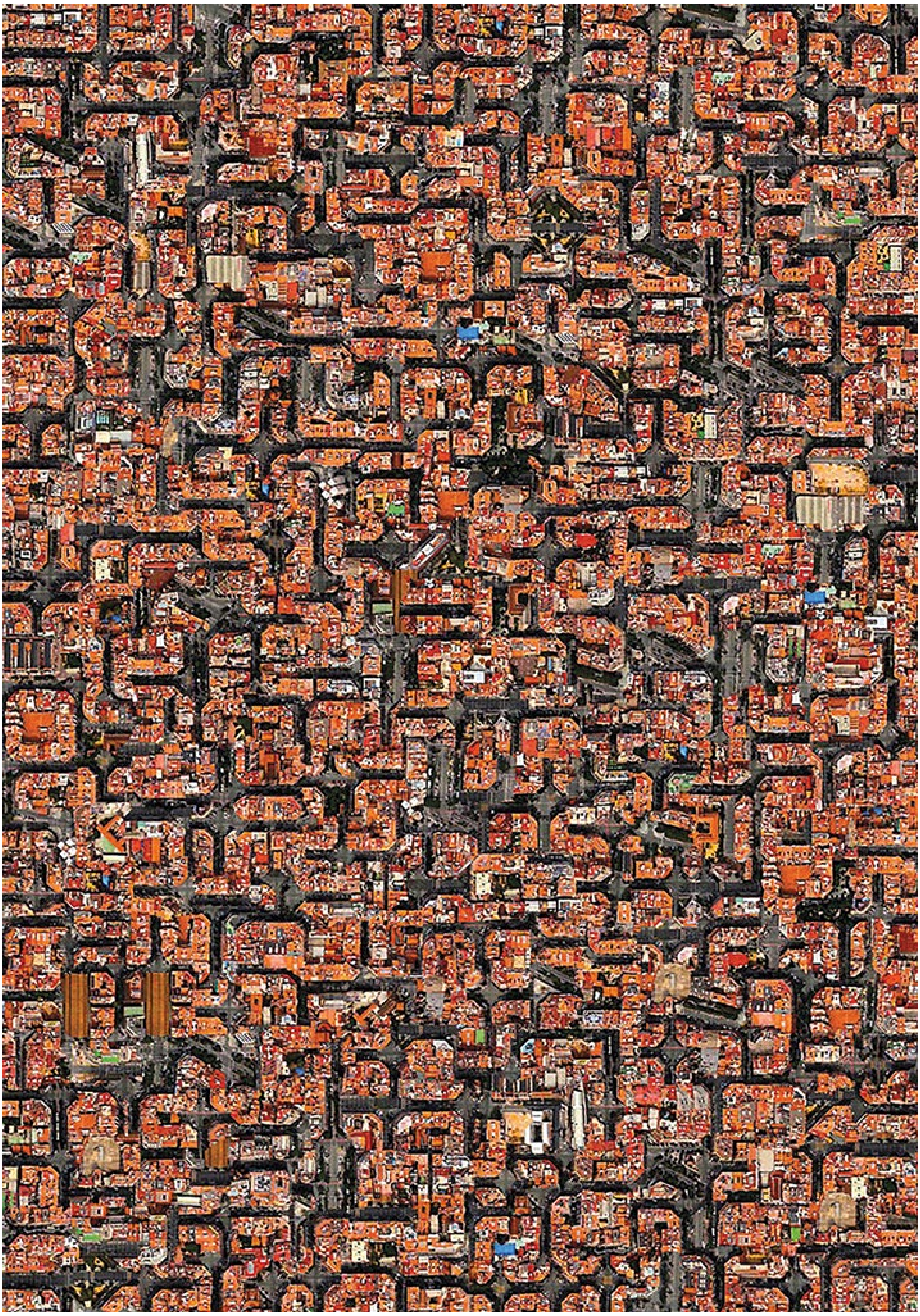
Mies van der Rohe's 1929 Barcelona Pavilion epitomises the Modernists' free composition of figure against figure in space. Following our proposed statistical reading, what if one is to deny both the independence of its figures and ground? The Discrete-Mies project (2018) revisits Mies's pavilion to investigate the design consequences engendered by such a conceptual denial of the figure-ground with that of the discrete fields. The pavilion is decomposed into uniformly sized discrete volumetric cells, each containing part-figures and part-grounds. A self-supervised learning model takes these cells as inputs and learns their statistical structure at various spatial scales. By dynamically sampling from the learned discrete probability distribution of this trained machine-learning model, the system infers new configurations while retaining varying degrees of the original learnt spatial features.

Quoting from De Stijl founder Theo van Doesburg's 1930 Concrete Art Manifesto:[4] 'The painting must be entirely built up with purely plastic elements, namely surfaces and colors. A pictorial element does not have any meaning beyond "itself".'[5] In the Discrete-Bauhaus project (2018), the concept of 'pictorial discrete fields' is explored via Walter Gropius's 1926 Bauhaus building in Dessau. The flat pictorial surfaces and colours of the Bauhaus axonometric are decomposed according to their respective projected planar grids to generate new Bauhäuser. The analogue perception of their third dimension is completely denied during the machine-learning process to probe the limits of the proposed statistical seeing.

Immanuel Koh, Discrete-Bauhaus ('Nicht ein Bauhaus, sondern viele Bauhäuser'), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, 2018

The original Bauhaus is shown in the middle and surrounded by other inferred instances – all represented as pictorial planar colours of De Stijl. Each of them bears a different degree of similarities to the original based on the specific statistical sampling methods and parameters used.

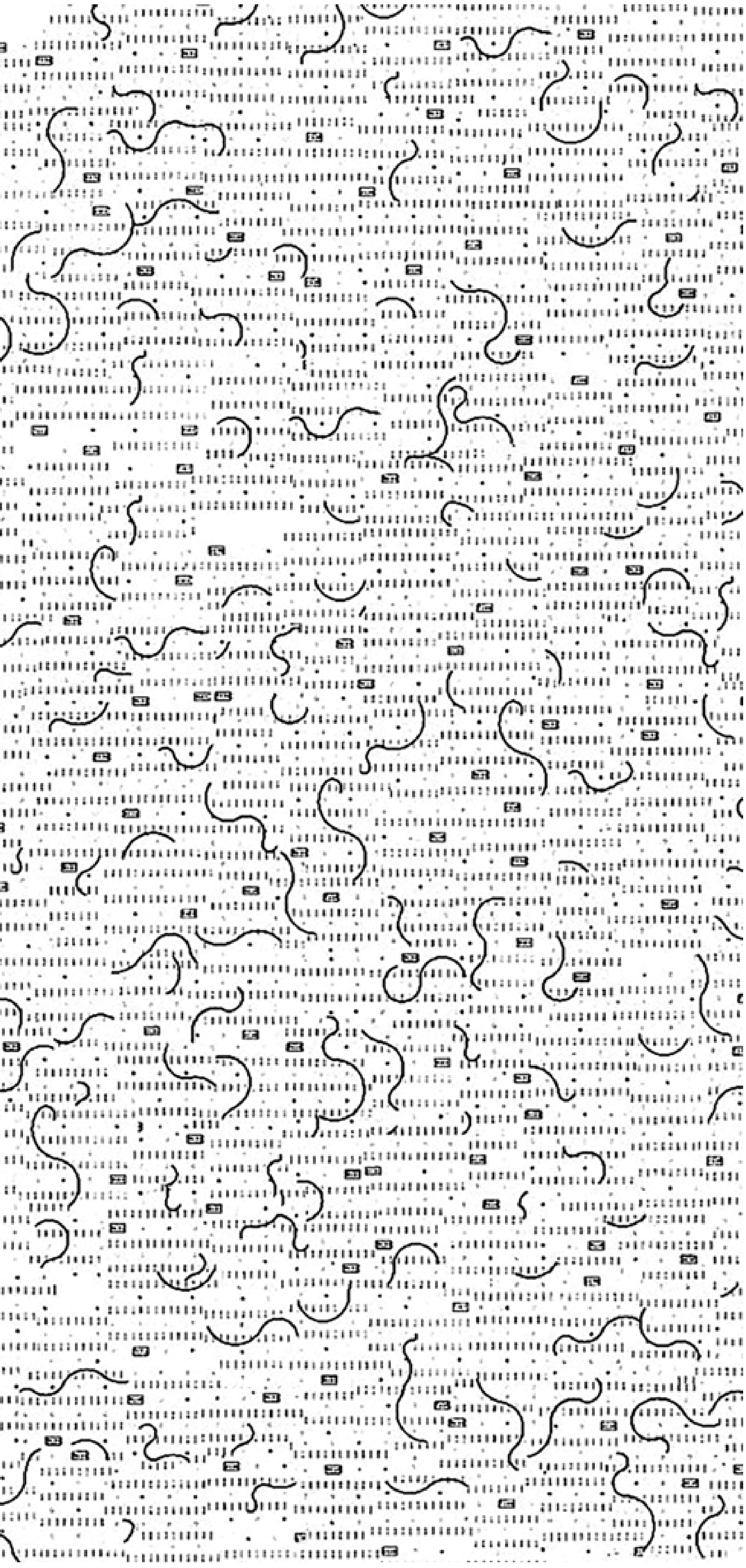




Immanuel Koh,
'Recombinant' series - Barcelona ++,
École Polytechnique Fédérale de Lausanne (EPFL),
Lausanne,
Switzerland,
2017

The 'Recombinant' series revisits the notion of form synthesis by using the discrete pixels statistics learned from one or more cities for further probabilistic recombination and extrapolation. Shown here is an example output inferred by a machine-learning model previously trained with satellite raster-map tiles of Barcelona.

The No-Stop City++ project from the ‘Infinite’ series not only references the non-figurative architectural language of Andrea Branzi’s *No-Stop City* (1969), but samples from it to generate fields devoid of their original graphical connotations.



Immanuel Koh,
'Infinite' series - No-Stop City ++,
École Polytechnique Fédérale de Lausanne
(EPFL), Lausanne,
Switzerland,
2017

The ‘Infinite’ series is a contemporary formal take on Andrea Branzi’s No-Stop City (1969), but implemented via a machine-learning apparatus that generates new No-Stop Cities without simply repeating or needing an underlying grid for their spatial organisation.

Two other projects investigate the concept of a quantitative city as a synthesis of discrete fields. The No-Stop City++ project from the ‘Infinite’ series (2017) not only references the non-figurative architectural language of Andrea Branzi’s *No-Stop City* (1969), but samples from it to generate fields devoid of their original graphical connotations. The Barcelona++ project from the Recombinant series (2017) extends this original binary implementation in full colour space, sampling from the discrete pixels distribution in a satellite map of the city’s Eixample district.

The discrete sampling proposed in the EPFL work is thus a theoretical claim to finally abandon the analogue figure-ground or object-field conceptual dichotomy. It is also a demonstration that the current explicit rule-based systems in architecture might soon be superseded by more generic and implicit pattern-inference-based statistical machine-learning models, anticipating a reformulation of the digital in architecture that begins with a shift from the continuous to the Discrete. Ð

Notes

1. Stan Allen, ‘From Object to Field’, in Greg Lynn (ed), *Ð Architecture After Geometry*, May/June (no 3), 1997, pp 24–31.
2. *Ibid*, p 29. Allen was citing from Vivian Sobchack, ‘Towards a Phenomenology of Cinematic and Electronic Presence: The Scene of the Screen’, *Post Script: Essays in Film and the Humanities*, 10, 1990, p 56.
3. *Ibid*, p 30.
4. Otto G Carlsund et al, ‘Base de la peinture concrète’, *Revue Art Concret*, 1, April 1930, p 1.
5. English translation of the original French manifesto taken from Lorenza Saitta and Jean-Daniel Zucker, *Abstraction in Artificial Intelligence and Complex Systems*, Springer (New York), 2013, pp 413–14.

Viola Ago

Series and Unit-Based

Notes on Contemporary Digital Operations

Viola Ago,
Drawing 1,
'Drawing Studies' series,
2018

Drawing Studies is one of six digital drawing series that interrogate the medium of architectural drafting as it relates to 3D modelling. The studies focus on line networks (clusters of line segments) and volumetric operations.

Other Alternatives

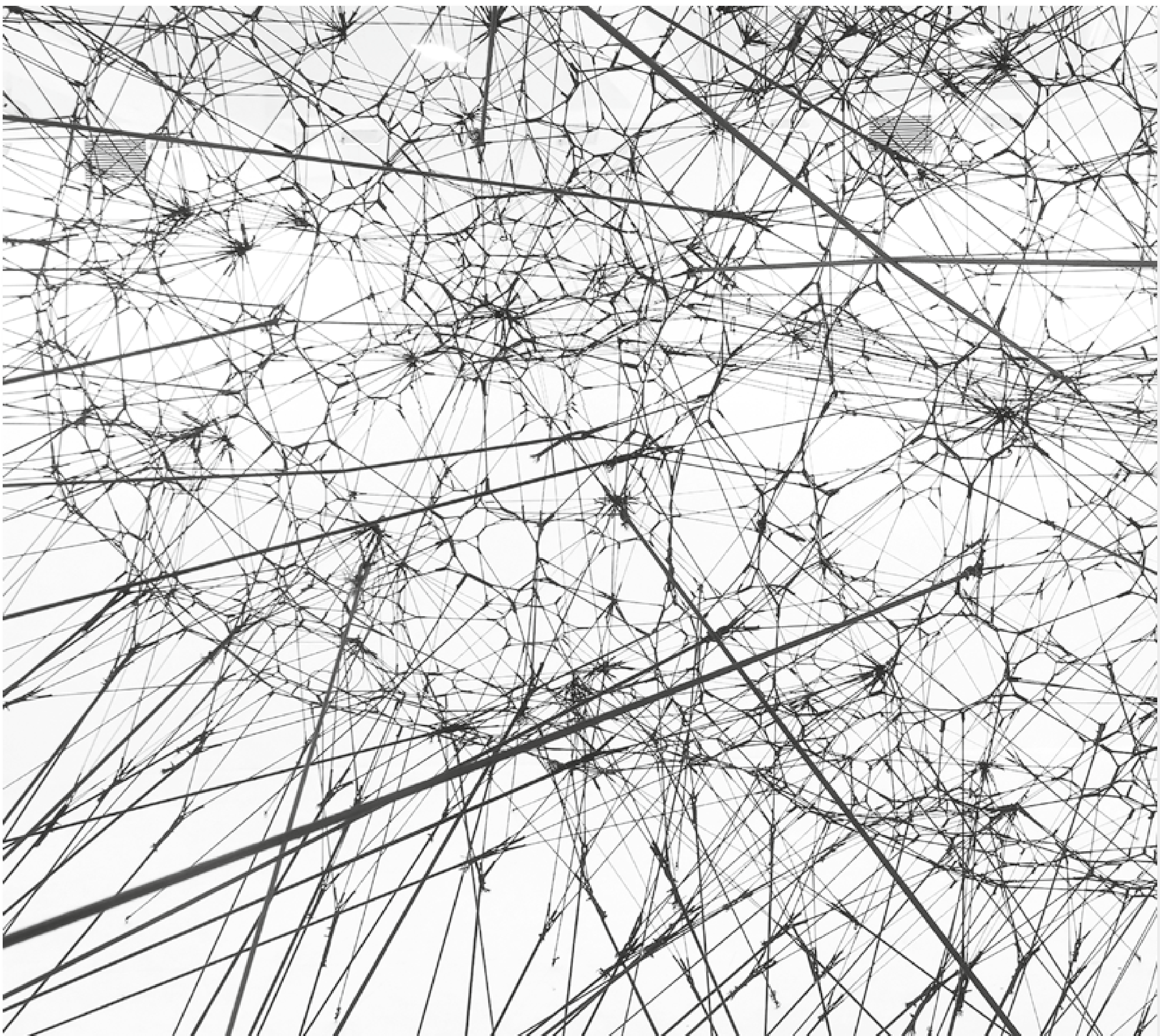
The digital era we are now embarking upon is less about the shock of the new, and more about non-hierarchical organisation. So argues architect and educator **Viola Ago** – visiting professor at the Ohio State University Knowlton School of Architecture in Columbus and lecturer at the Harvard University Graduate School of Design in Cambridge, Massachusetts – as illustrated by her own recent work.

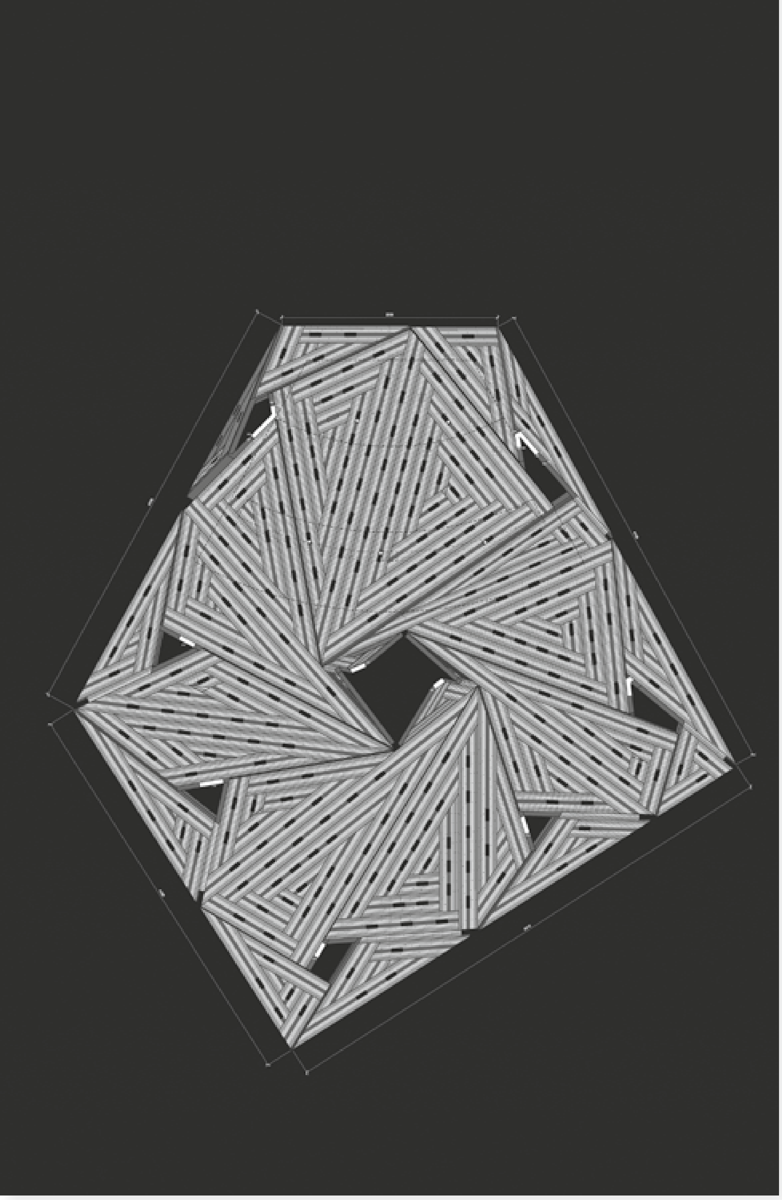
The volatile relationship between architecture and digital technology over the last two decades has produced a vast collection of design artefacts, research endeavours and cultural conditions. At this point, digital tools and processes are inevitable in the practice of architecture. The emergence and implementation of these tools, however, register a long and erratic history. Early examples of architects employing digital tools are characterised by linear relationships; these tools were meant to merely articulate and directly express (a priori) design thinking. Over time, the rapid expansion of the digital in architecture fundamentally altered its position within the discipline. In ever-changing, increasingly fast-paced design environments, the use of digital tools promised novelty and progress. However, the gratuitous pursuit of novelty – a shortcoming of architecture and other disciplines – remained unquestioned as digital technology evolved from a service tool into a primary driver of architectural design and visual thinking. The artefacts of the digital project that have accumulated over the last decade are symptomatic of an undirected, disoriented and confused state of affairs, with no critical background to effectively challenge the assured novelty of digital design's meta-formal project, materials research efforts and aesthetic culture.

Revisiting Systems Aesthetics

Until recently, digital tools have been wedded to the pursuit of the new. As the use of such tools begins to transition away from expressions of novel form, architects find themselves at a perplexing moment where evaluative self-reflection is imperative. Presently, architecture and other disciplines that value visual studies are struggling to construct critical criteria and aesthetic metrics. This condition is a familiar one in architecture, art, music and literature. For example, artists linked with the Conceptual Art movement of the 1960s and 1970s turned to non-visual operations in an attempt to defy the aesthetic prestige associated with the Abstract Expressionists and earlier chapters of Modernism. In his 1968 essay 'Systems Esthetics', artist, critic and curator Jack Burnham meditated on a new model for critique, referring to artists like Marcel Duchamp, Robert Morris and Andy Warhol as exemplars of the move towards art that takes its final form in the relationship between people and the components that compose the artwork, as opposed to art realised in autonomous objects.[1] In another seminal essay, 'The Serial Attitude' (1967), artist, theorist and curator Mel Bochner reiterated the drive of the Conceptual Art movement to remove individual artistic expression and instead employ methods of serial order and systematic relationships. Bochner, like Burnham, favoured serial (or system-based) logics over the singular finalised work.[2] In a similar fashion, contemporary architects might also look to systems and the conceptual utility of seriality as an alternative to the default pursuit of novel form.

The argument presented here is not advocating a return to Conceptual Art as a formula for new architectural styles (as in the architectural works of Dan Graham, and the artworks of Sol LeWitt). In her 2012 essay 'Merely Interesting', theorist





Aranda\Lasch,
Palais des Arts,
Libreville,
Gabon,
2013–

The proposed canopy roof is a prefabricated component-based system assembled on site as a kit of parts. An interlocking reciprocal pattern is utilised so that each plane of the roof acts as a two-way spanning slab to create the slender structure.

and critic Sianne Ngai suggests that systems aesthetics and serialised order can offer a critical lens for analysing visual currents in contemporary culture.[3] She asserts that Burnham's and Bochner's ideas are relevant today as our media-frenzied society struggles to articulate a collective need for novelty and repetition. She also examines philosopher and systems theorist Niklas Luhmann's writings on novelty, familiarity and seriality.[4] Luhmann argues that the pursuit of novelty is an all-pervasive cultural condition; the public is constantly craving the next new thing (products, news, economic status). In order for the novelty-appetite to be satisfied, he argues, a baseline of familiarity needs to be established.[5] As a result, present modes of production (as in the production of physical and digital artefacts) are based on serial methodologies; products are composed of self-similar parts and unified by familiar characteristics. In Luhmann's account of production, the 'new' is introduced in small increments in known component-families. Ngai observes that these three theorists have built evaluative criteria based on matrices of differences and similarities among units in a system, rather than based on the final form that these systems create. Late-capitalist novelty, according to Luhmann and Ngai, is not experienced as a narrative of avant-garde shocks and paradigm shifts, but rather as minor, piecemeal revisions to recognisable systems. If design driven by the use of digital tools previously operated on models of avant-garde novelty (the shock of the profoundly new), it is now time for architects to employ systems-driven approaches using self-similar components (part-to-part logics) and strategic micro-doses of variation.

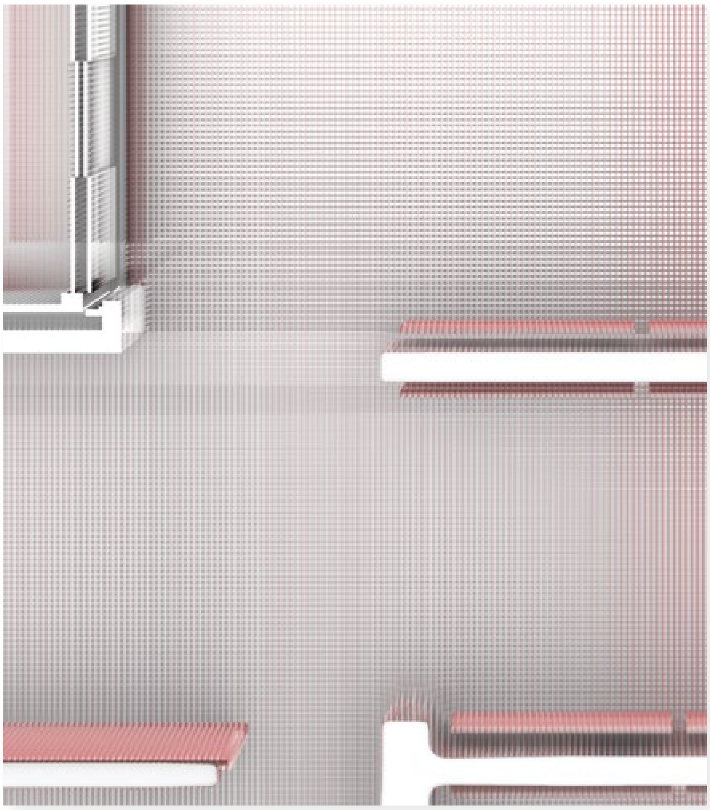
Tomás Saraceno,
Galaxies Forming Along Filaments,
Like Droplets Along the Strands of a Spider's Web,
Venice Architecture Biennale, 2009

Saraceno's piece can be thought of as a visual metaphor for the Discrete project. The installation demonstrates a systematic clustering of units (droplets) distributed in non-centralised networks.

Latourian Networks and Composition

An expansion of Ngai's and Luhmann's critique of the Modernist notion of progress and part-to-whole logics can be found in Bruno Latour's composition theory. Latour's theory is concerned with the immanent conditions of what is already in the world; the theory composes existing things in nonhierarchical and non-totalising organisations, as opposed to the Modernist/early-capitalist transcendental model.[6] To illustrate, he uses Tomás Saraceno's work *Galaxies Forming Along Filaments, Like Droplets Along the Strands of a Spider Web* (2009) as a visual metaphor that resists hierarchical order and centre points, and instead creates highly intricate conditions of nesting and interdependence in flat ontological schemas.[7] This composition-based method of working and evaluating is what makes Saraceno's *Galaxies* both contemporary theoretical diagram and visually enticing sculptural work.

More recently in architectural circles, the move towards discrete components in dialogue with systems-based operations has productively grounded new experimental work. One of the original ambitions of the Discrete project was concerned with the metaphysics of geometries that were native to the digital environment. At first the Discrete was a response to Greg Lynn's spline-based surfaces that characterised the rise of the digital in the late 1990s.[8] Unlike the discourse around Lynn's work, the Discrete project was working with 'things' that were already present in the digital world of architecture, and was not interested in proposing the next transcendental architectural movement. Discrete modes of operating are analogous to the Latourian composition project in that they both advocate assemblage and reconfiguration in place of creation. What is more, the Discrete mode has evolved beyond its original, purely geometric ambitions to include other architectural elements such as graphics, figures and tectonics. Exemplars include the works of Jose Sanchez (pp 22–9), Gilles Retsin (pp 38–45), M Casey Rehm (94–101), Tom Wiscombe (124–9), Ferda Kolatan and Aranda\Lasch.



Viola Ago,
Plan drawing,
'Blush' series,
2013

The Blush line drawing uses a representational technique that employs discrete lines in place of conventional digital rendering. The drawing represents depth and shadows by projecting vector-based information, and assigns colour accordingly. The technique is an alternative to default rendering practices that use pixel-based operations to define colour values.

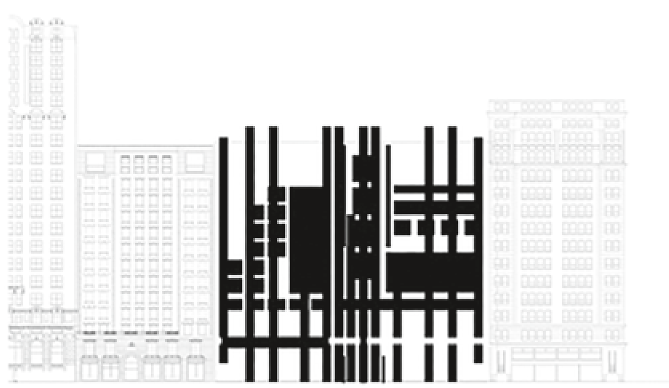
This experimental project organises volumes and lines (geometry and graphics) into non-hierarchical relations

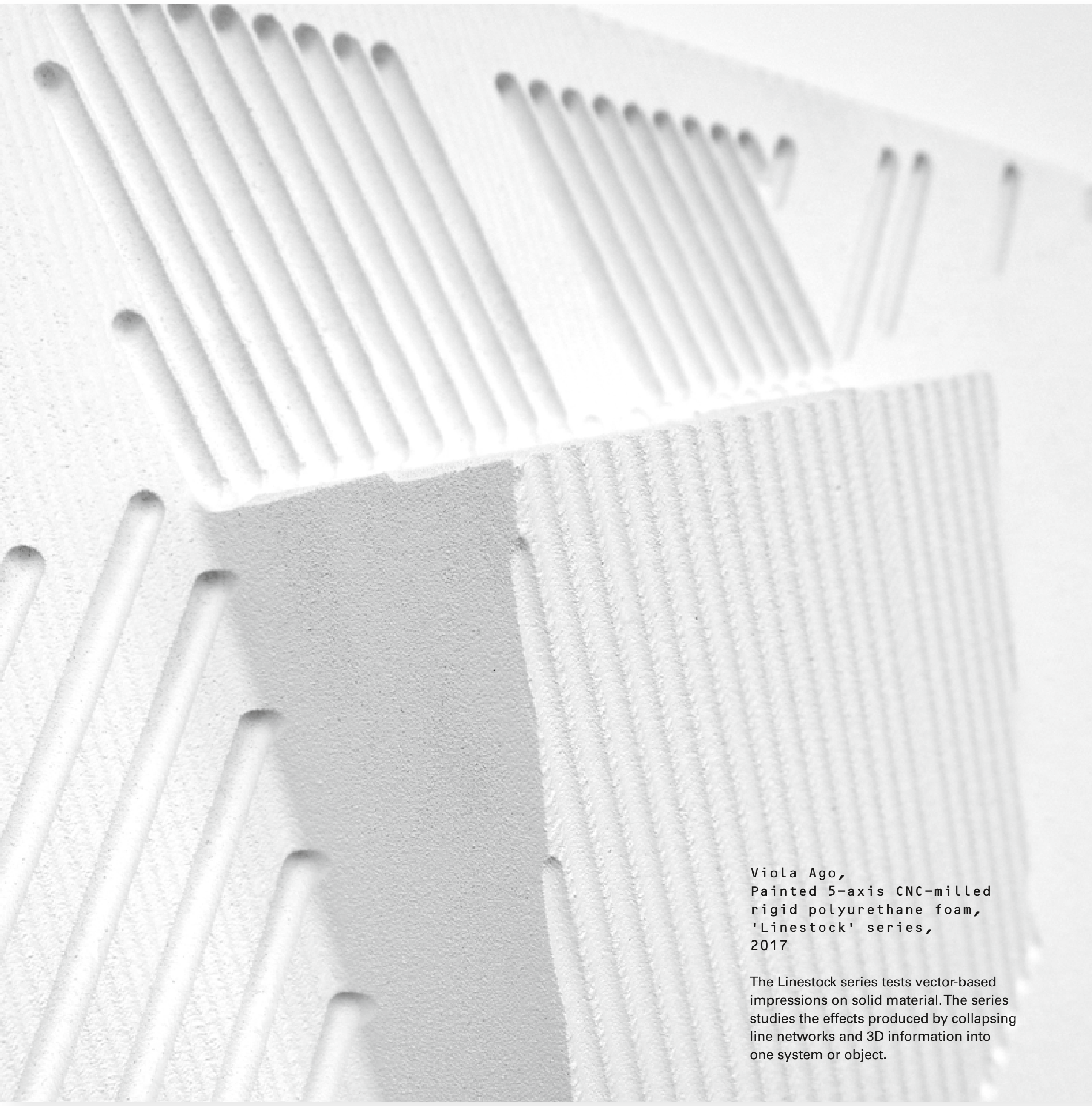
'Poppy Red': A Series-Oriented Study

The projects and work illustrated here happily participate in Discrete geometric thought understood as a play between series, systems and networks of units. 'Drawing Studies', 'Blush' and 'Linestock' are series-based visual exercises that use the line as a compositional catalyst. Conceptually, a piece like *Poppy Red #5* (2018) from the 'Poppy Red' model series attempts to situate itself in something close to a Latourian composition theory. In another work, the *Poppy Red* final study, three visual languages are mapped onto one another: discrete lines, inscribed geometries and volume-line networks. *Poppy Red*'s linework operates like Saraceno's filaments in that it implies an interdependent network, but the lines maintain their discrete nature within the overall assembly. The lines act as units that create local clusters while resisting any totalising hierarchy. As visual triggers they also act as vectors (with directionality and amplitude) meant to be read as avenues, bridges and even 'connectors' (a Latourian term). As vectors, the linework leads the viewer to different clusters and patterns through overlapping, bending and moments of abrupt aversion. The second visual language embedded in *Poppy Red* (a play between linework and three-dimensional form) subverts the viewer's understanding of the piece's sculptural volumetrics. The lines inscribe, or rather re-create, the underlying geometry of its primary volume. In other words, the geometric information would still be visible from the line network alone if the volumes the lines occupy were to be removed. In true Discrete geometric fashion, this further reinforces the argument that lines, when considered as individual entities, can create volumetric constructions. Lastly, and (for the purpose of this argument) most importantly, this experimental project organises volumes and lines (geometry and graphics) into non-hierarchical relations (as in Saraceno's *Galaxies*). *Poppy Red* operates on an aesthetic level with clarity and precision, while also acting as a conceptual metaphor for complexity, interconnectivity, clustering and movement.

Viola Ago,
Elevation studies,
'Blush' series,
2013

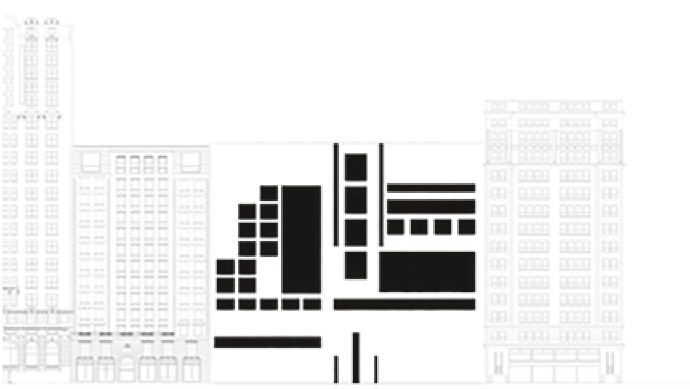
The elevation studies use graphic representations of simple mathematical sequences arranged on a single plane. They investigate part-to-part relationships within a defined boundary (or frame).

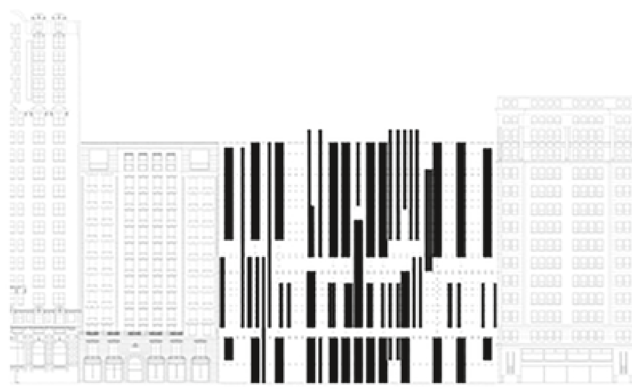


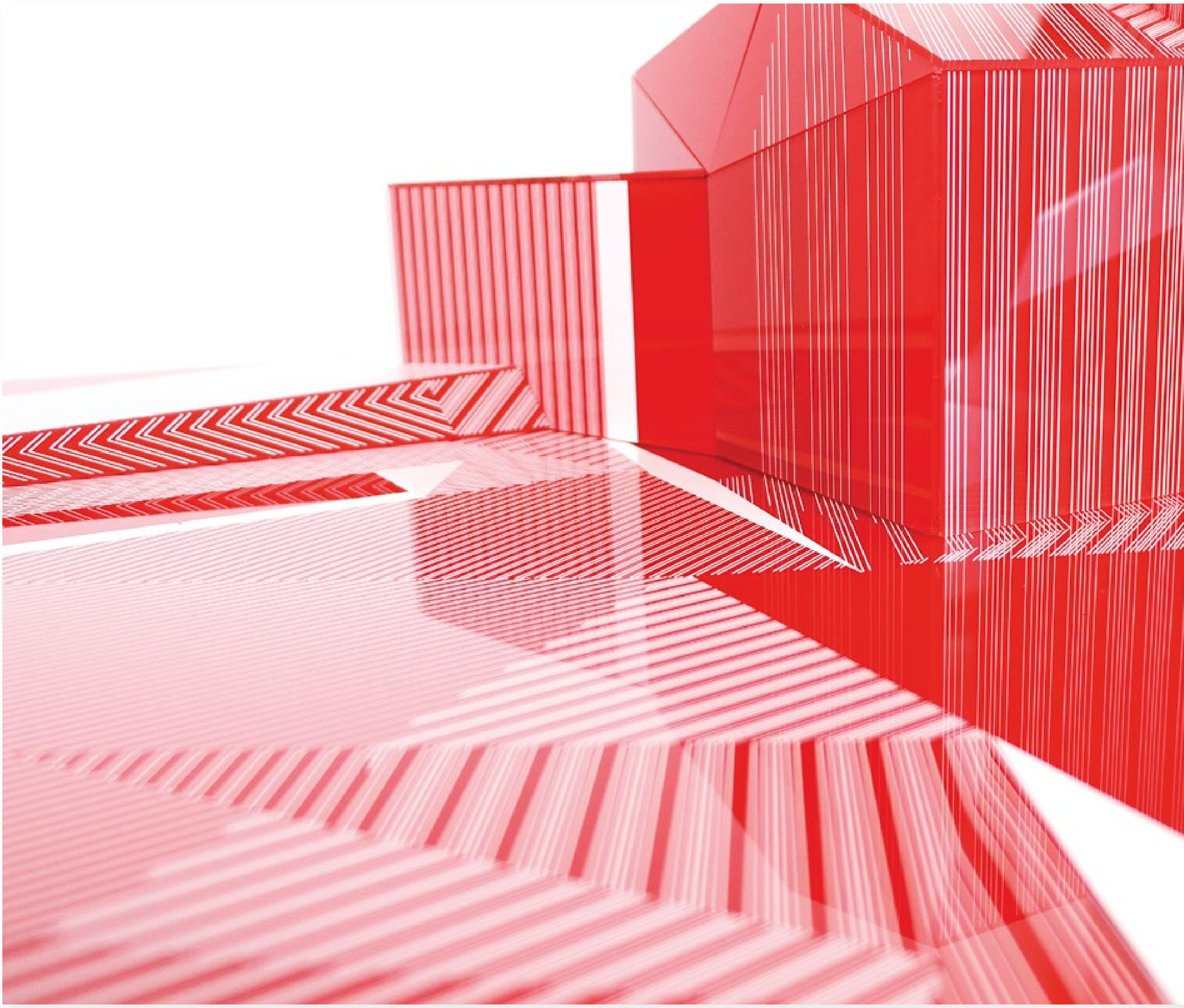


Viola Ago,
Painted 5-axis CNC-milled rigid polyurethane foam,
'Linestock' series,
2017

The Linestock series tests vector-based impressions on solid material. The series studies the effects produced by collapsing line networks and 3D information into one system or object.

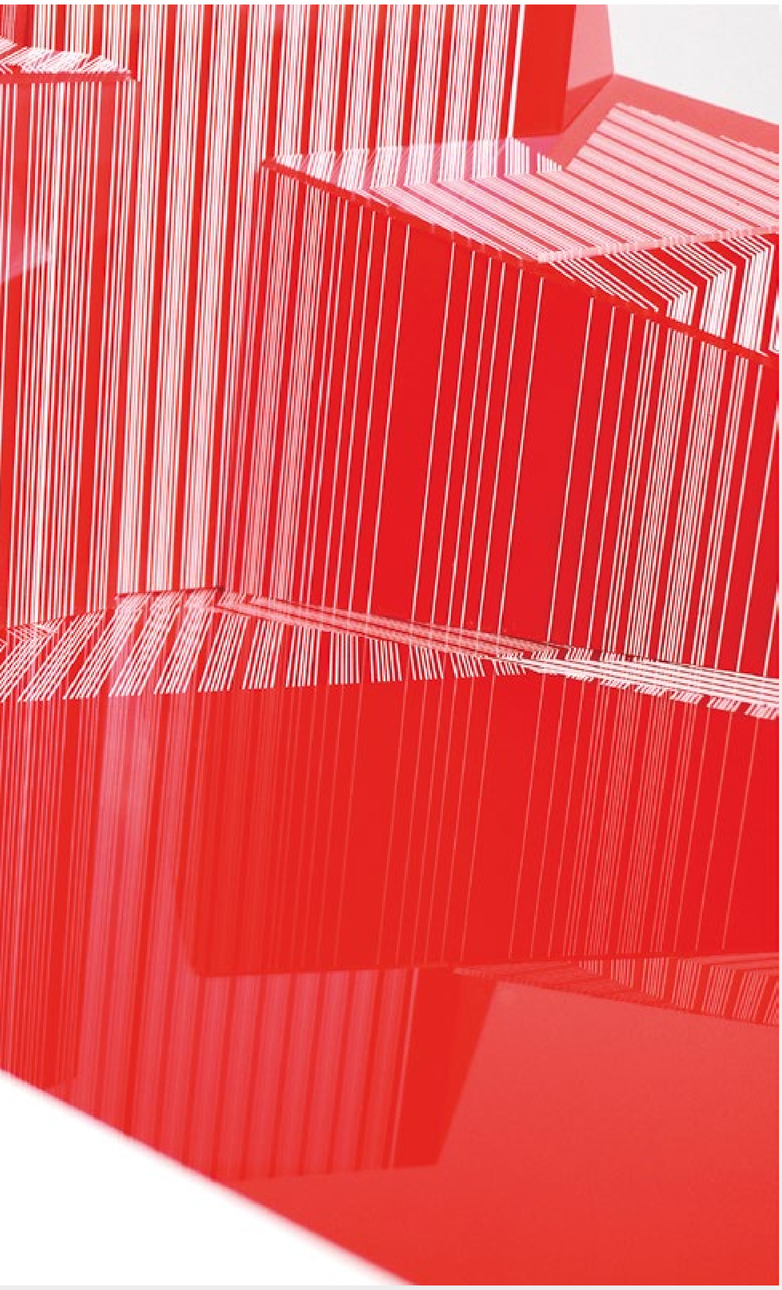






Viola Ago,
Poppy Red #5,
'Poppy Red' model series,
2018

Poppy Red #5 is one of a 12-part set that tests relationships between units in a series. The components are produced in a recursive manner, with small variables taking effect from one unit to the next.



Poppy Red is a project conceived in the Discrete mode. As a conceptual endeavour, however, it favours repetition-in-series, and iteration within a closed system rather than illustrating an evolutionary tree of progressively novel discoveries and formal epiphanies (each piece building on, and evolving from the previous, inferior experiments). In this, *Poppy Red* is part of a larger question about architecture's collective obsession with digital tools as drivers of new formal and visual experiences. Ironically, has the pursuit of novel geometric and visual forms itself become banal? So much so that artworks such as Donald Judd's boxes, Sol LeWitt's incomplete cubes, and Dan Flavin's neon-tube arrays[9] read as profoundly novel? And can the series offer us an escape from the tyranny of the new? ᗡ

Notes

1. Jack Burnham, 'Systems Esthetics', *Artforum*, 7 (1), 1968, pp 30–35.
2. Mel Bochner, John Coplans and Mark Gisbourne, *The Serial Attitude*, Eykyn Maclean (New York), 2016.
3. Sianne Ngai, 'Merely Interesting', *Our Aesthetic Categories: Zany, Cute, Interesting*, Harvard University Press (Cambridge, MA), 2012, pp 110–73.
4. *Ibid*, p 145.
5. Niklas Luhmann, *The Reality of the Mass Media*, Stanford University Press (Stanford, CA), 2000, p 28.
6. Bruno Latour, 'An Attempt at a "Compositionist Manifesto"', *New Literary History*, 41 (3), 2010, pp 471–90.
7. Bruno Latour, 'Some Experiments in Art and Politics', *e-flux*, 23, 2011, pp 1–7.
8. Gilles Retsin, 'Discrete and Digital', TxA, 2016; https://www.academia.edu/33411405/Discrete_and_Digital_TxA_2016.
9. See Donald Judd, *Donald Judd: Complete Writings 1959–1975: Gallery Reviews, Book Reviews, Articles, Letters to the Editor, Reports, Statements, Complaints*, Press of the Nova Scotia College of Art & Design (Halifax), 2005, pp 181–9. First published in 1975.

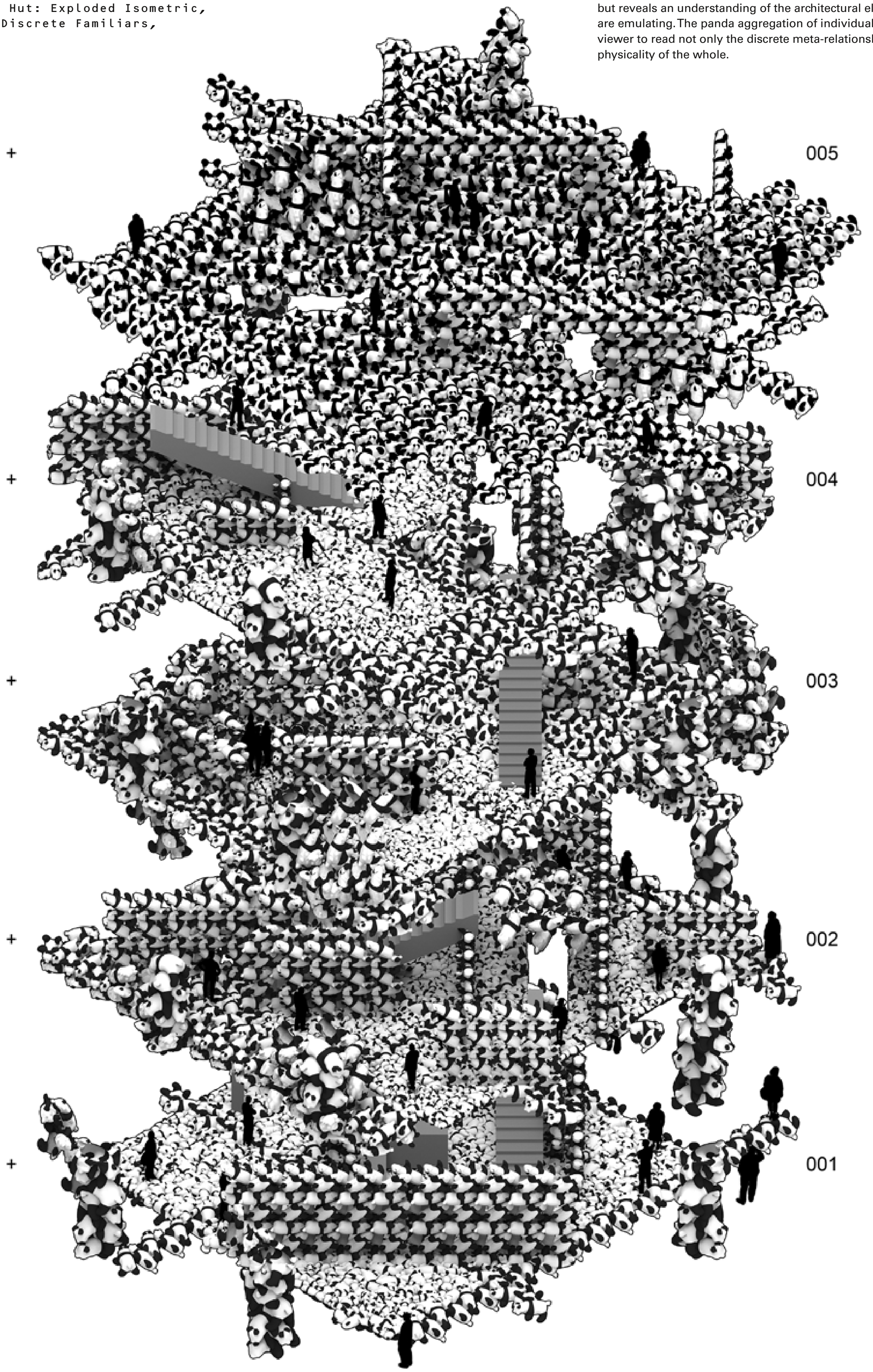
Viola Ago,
Poppy Red final study,
2018

Poppy Red examines the relationship between architectural line drawings and models. At times the lines regulate the formal transformations of underlying volumes in a coherent way, and at other moments they challenge a given geometric organisation.

Poppy Red is part of a larger question about architecture's collective obsession with digital tools as drivers of new formal and visual experiences

Quirkd33 (Ryan Vincent Manning with Fabian Partoll and Alexander Gasser), Panda Hut: Exploded Isometric, Soft Discrete Familiars, 2018

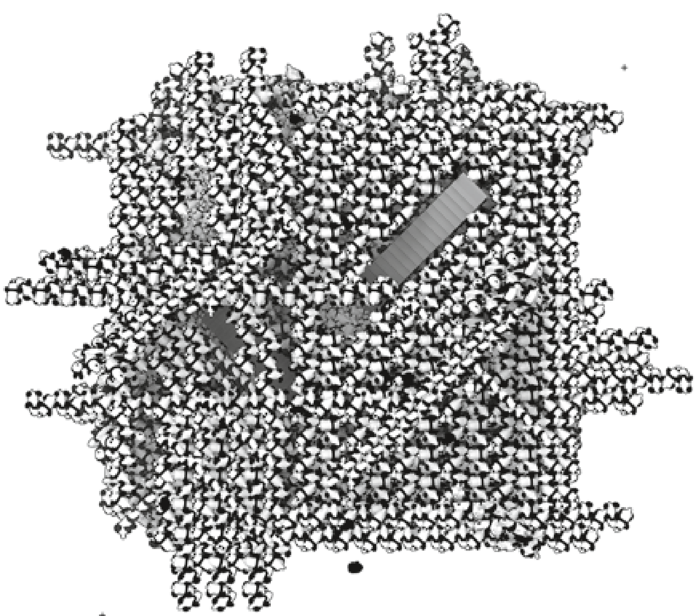
With the floors separated to display the building itself, the Panda Hut aggregation loses much of the form of Hejduk's *Diamond House A*, but reveals an understanding of the architectural elements the parts are emulating. The panda aggregation of individual floors allows the viewer to read not only the discrete meta-relationships, but also the physicality of the whole.



Soft Discrete Familiars

Animals, Blankets and Bricks, Oh My!

What if the Discrete took a playful turn? A series of investigations by Los Angeles landscape, film and architecture collaborative Quirkd33 has been exploring the idea of building blocks made not of abstract forms, but stuffed toys. Along with work by artists Tristan Lowe and Mike Kelley, Quirkd33's designer and owner **Ryan Vincent Manning** discusses how they test the boundary between familiarity and fuzziness.



Soft Discrete Familiars examines familiarity within architecture as soft discrete parts, through two paths of logic: Familiar Bricks and Familiarity in Architectural Form. Familiar Bricks is a close reading of stuffed animals to determine the exact point of recognition in form or fantasy. Paralleling this, Familiarity in Architectural Form breaks apart the initial stages of education into a base understanding of what our tactile objects are in architectural education. In combination, these two modes of logic act upon each other in a constrained aggregate that looks to question form and its use of soft discrete objects.

Quirkd33 (Ryan Vincent Manning with Fabian Partoll and Alexander Gasser), Panda Hut, Soft Discrete Familiars, 2018

Plan view. The part-to-part relationships here are generated through the aggregation of the Panda Hut, rationalising the constrained fuzzy relationship between whole and part.

Tristin Lowe,
Mocha Dick,
Fabric Workshop and Museum,
Philadelphia,
2009

Large, soft and anthropomorphic, Lowe's *Mocha Dick* embodies not only the qualities of the white whale, but also the fantasies and stories surrounding Herman Melville's Captain Ahab and his encounters with the whale. We cannot see past these qualities; we see the object only for its physical attributes.

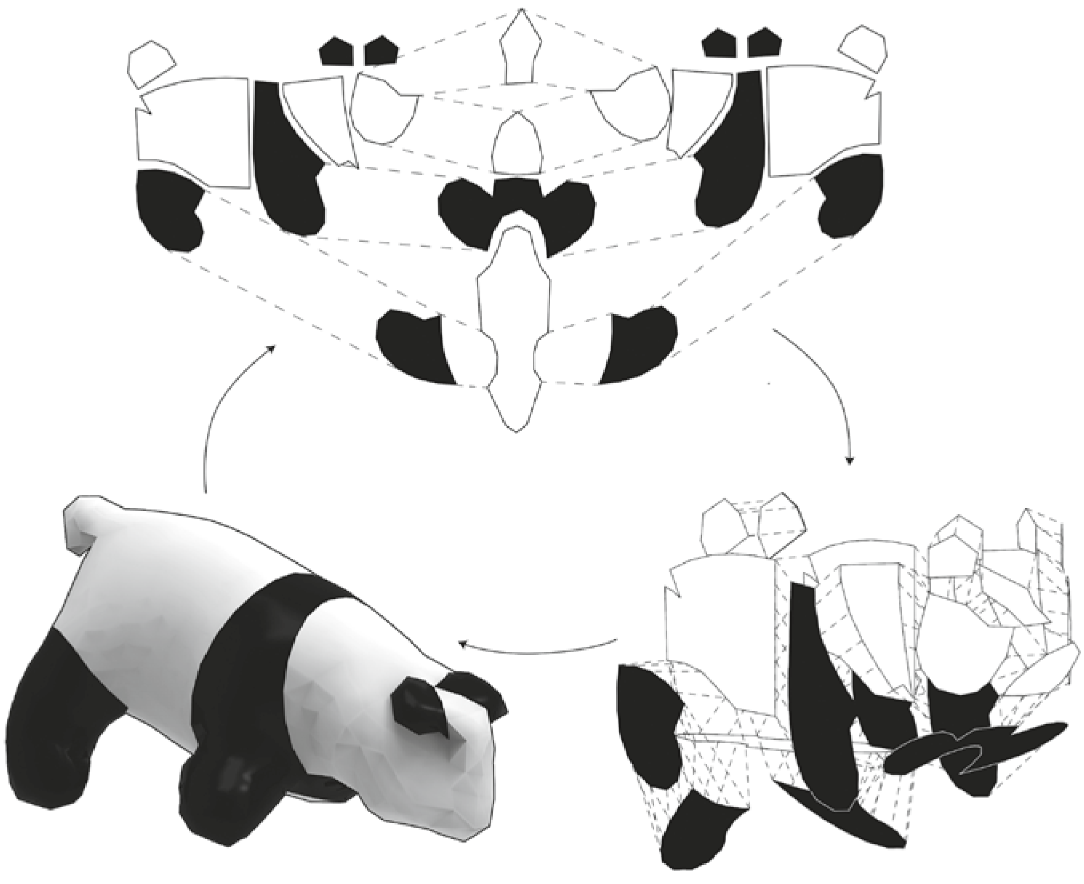
Quirkd33 (Ryan Vincent Manning),
The Panda,
Soft Discrete Familiars,
2018

The Panda is made from digital inflated flat patterns similar to clothing or stuffed plushies, stitched three-dimensionally and then sewn together with variations in their inflation, weft and warp.

Familar Bricks

When we are children, our best friends are often our teddies – soft, furry, cuddly and very real. Stuffed animals, or transitional objects, generate an empathic response to their uncanny features.[1] For a young child, a stuffed animal is not simply a model of some agreeable object, a friendly animal to weave fantasies around; it is primarily a tactile object associated with great physical pleasure linked to the presence of a mother or loved one.[2] Yet as an adult, our experiences in life begin to change this tactile effect and we project fantasies upon such objects, thereby subduing their physical presence.[3] When aggregated, the fantasies projected on the individual parts melt away, leaving only the physical presence of the new, aggregate form.

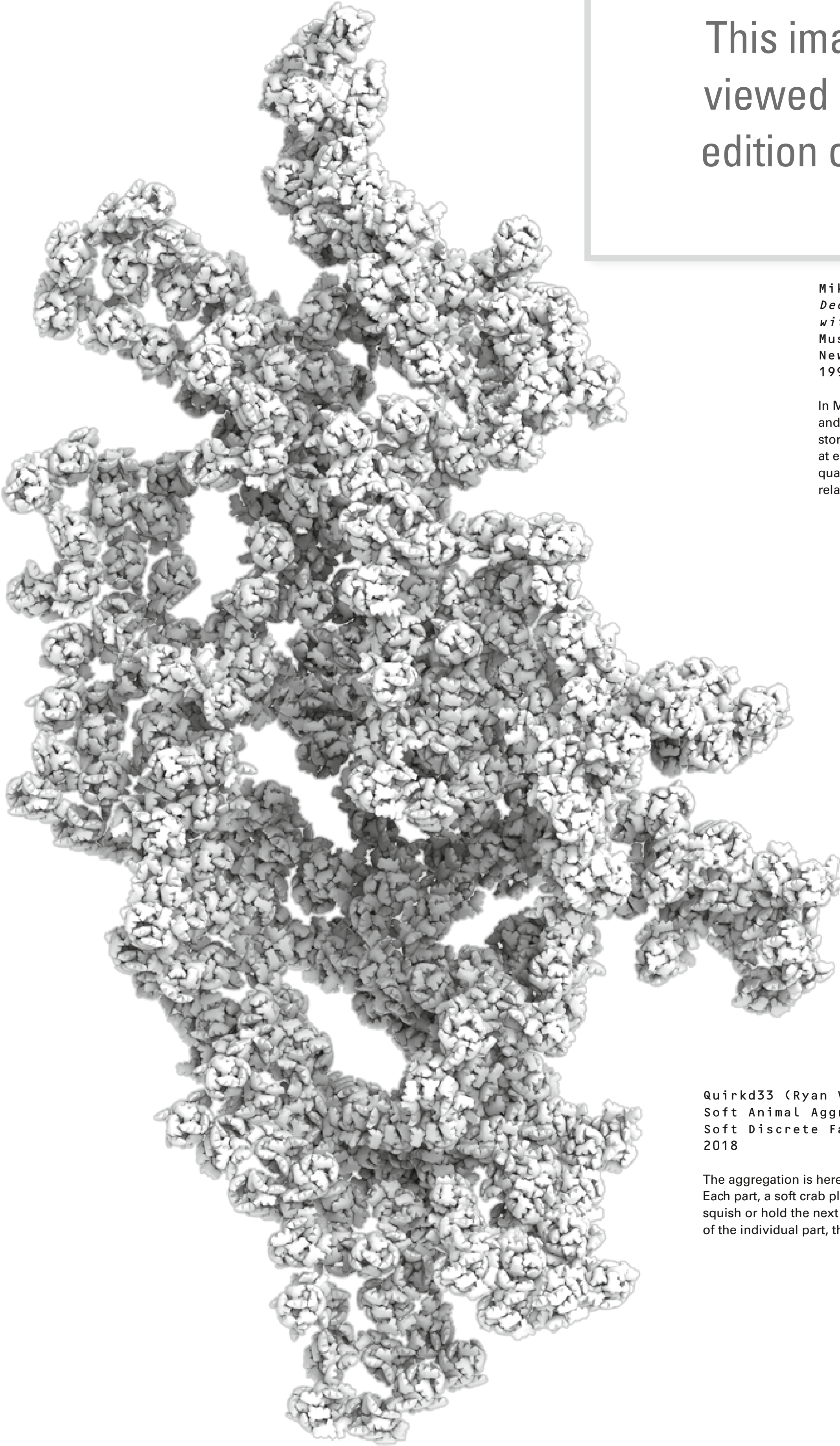
This comparison can be seen by juxtaposing the work of two artists: Tristan Lowe and Mike Kelley. Based in Pennsylvania, contemporary artist Lowe deals with familiarity and the surreal nature of the world through sculpture. In a handful of his projects, materiality and spatial concerns arise from soft sewn bodies that contort the reading of the objects they emulate. For example, in *Mocha Dick*, which was originally exhibited at the Fabric Workshop and Museum in Philadelphia in 2009, the whale evokes a direct relationship to the white whale in Herman Melville's 1851 novel *Moby Dick, or The Whale*.[4] We cannot see the whale as the object it is, but merely as the stories we project upon it. Similarly, in Quirkd33's Panda Hut (2018), part of their Soft Discrete Familiars investigations, the panda, in its three modes of representation – flat, sewn and inflated – can only be viewed through the stories and ideologies projected upon it; perhaps a cuddly panda at the zoo or the lead character in Mark Osbourne and John Stevenson's 2008 *Kung Fu Panda* animation.



This image can be viewed in the print edition of the issue

Mike Kelley,
Deodorized Central Mass with Satellites,
Museum of Modern Art (MoMA),
New York,
1991/1999

In Mike Kelley's large floating forms, the aggregation and materiality of the animals blur readings of the stories and fantasies we project upon them. Looking at each animal in isolation reveals its animal-like qualities, but Kelley's organisation of part-to-part relationships inhibits a direct reading.



Quirkd33 (Ryan Vincent Manning),
Soft Animal Aggregation,
Soft Discrete Familiars,
2018

The aggregation is here seen as only the part-to-part relationship. Each part, a soft crab plushie, is limited by its ability to attach, squish or hold the next part. The whole lacks the familiarity of the individual part, thus lending itself to pure abstraction.

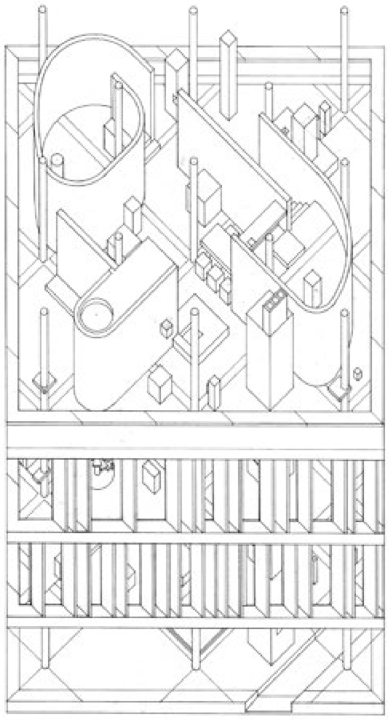
In contrast, a number of works by the late Mike Kelley, known for estranging the familiar and exposing the dark underbelly of society through his installation and performance art in the 1980s and 1990s, use aggregation to blur the discrete part. In *Deodorized Central Mass with Satellites* (1991), for example, a mixed-media installation comprising one central mass and 12 satellites consisting of found stuffed animals sewn over wooden and wire-mesh frames, the multiple animals are freed from the individual fantasies projected upon them due to their aggregation into floating forms. Here we can see that discrete parts can hold onto the fantasies and ideologies we project upon them, but as an aggregation the whole gains a physical presence bereft of the familiarity or fantasies of the individual.

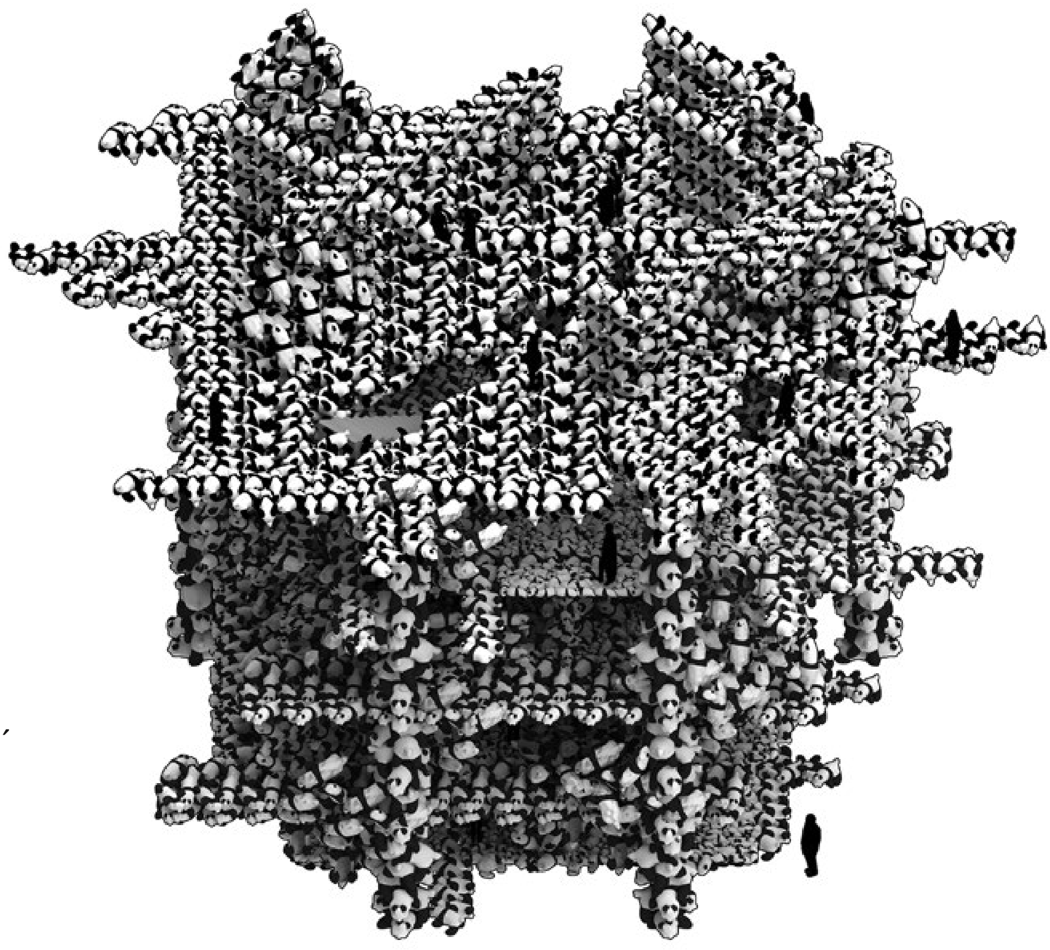
Familiarity in Architectural Form

Young architects have the same need for transitional objects as they grow into their careers. Instead of soft furry teddies, they embrace the elements and projects presented to them within contemporary academia, which vary according to where and when they receive their education. In John Hejduk's *Diamond House A* (1963–7), for example, the use of a discrete column becomes the volumetric divider to form rooms and divisions in a 45-degree-rotated nine-square grid. Here, one column is a column; two columns are an opening; and three or more columns make a space. This organisation can be interpreted as an early stage of understanding that continues to manifest long into an architect's career. The architectural parts – walls, floors and columns – are the crucial ingredients of other works the students will critique throughout their architectural lives.

John Hejduk,
Axonometric for Diamond House A,
1963–7

Hejduk's Diamond House uses a 45-degree-rotated nine-square grid to organise the spatial aspects of the floors. Here we can see how columns divide the spaces allowing walls to flow freely and each floor to be different due to the stability of the grid below.





Quirkd33 (Ryan Vincent Manning with Fabian Partoll and Alexander Gasser),
Panda Hut: Plan Oblique,
Soft Discrete Familiars,
2018

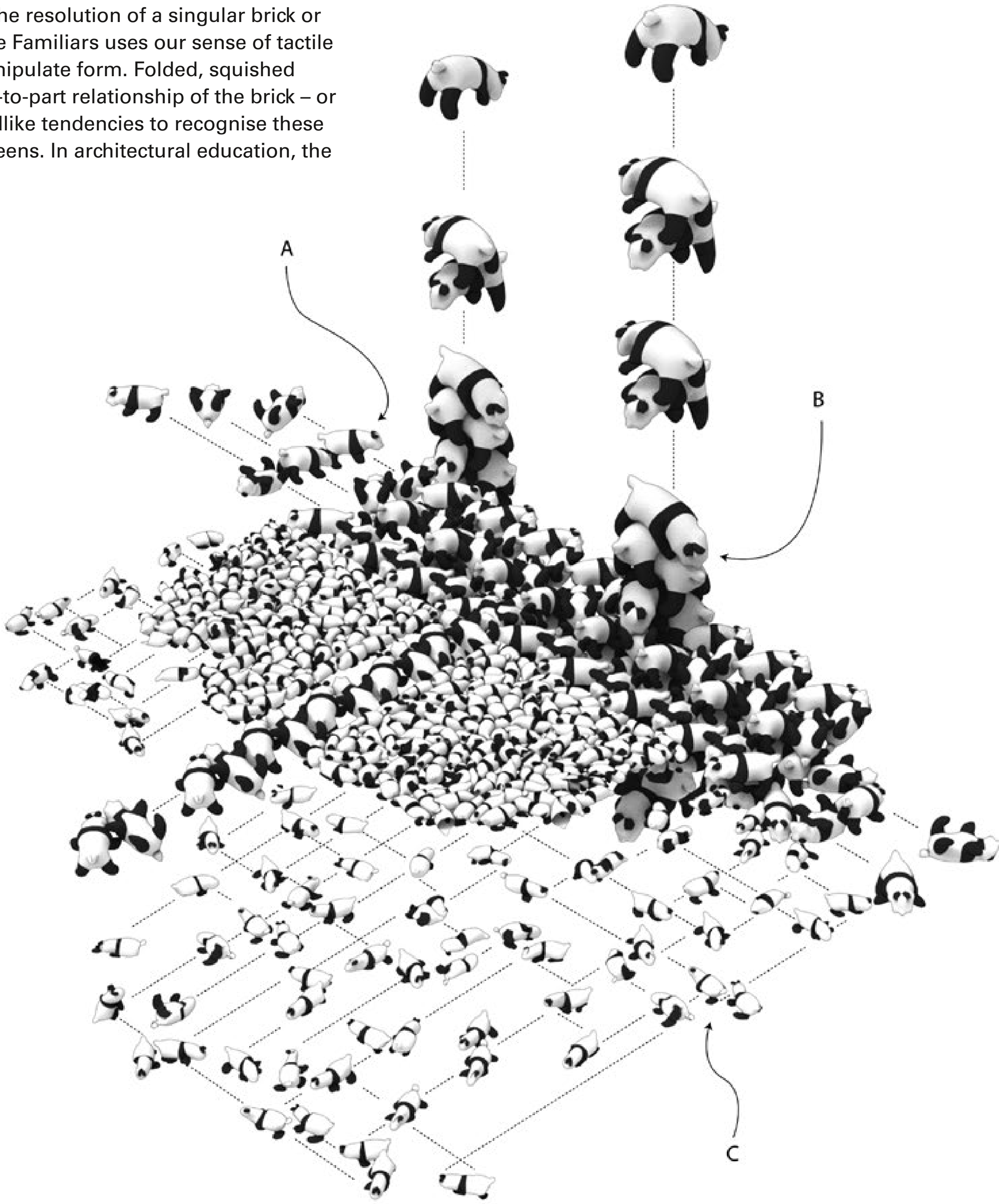
Taking its cue from John Hejduk's *Diamond House A*, this image shows how the materiality and form of the panda can become fuzzy within the logic of the aggregation. Yet the form of the *Diamond House*, although fuzzy, can be seen more clearly.

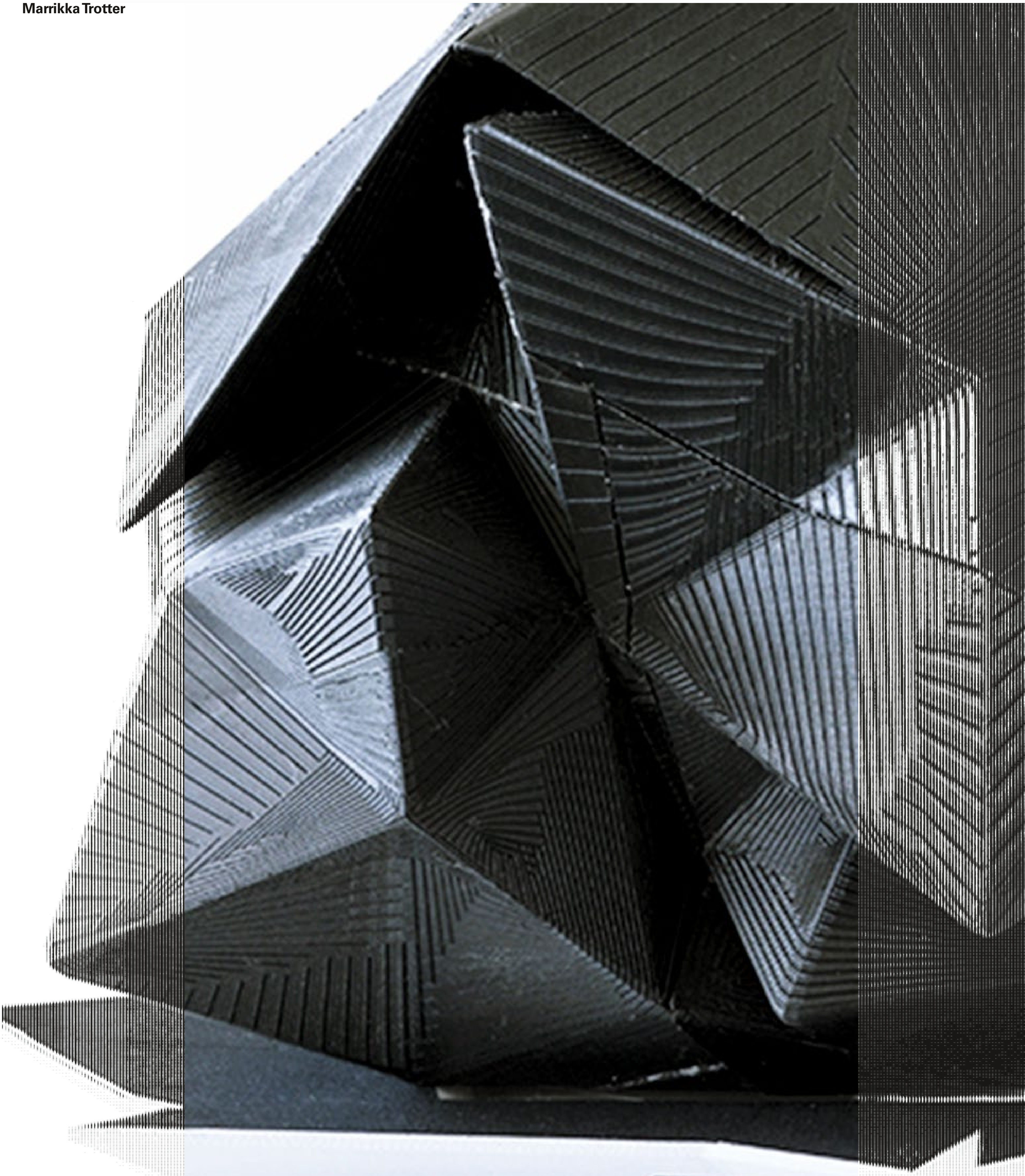
In Quirkd33's Panda Hut (2018), a single part (brick) or panda is used to investigate how soft discrete parts can begin to squish and nest to form walls, floors and columns. As a result we can see the uncanny features of the stuffed animal at close resolution, yet the reading becomes fuzzy as scale and porosity increase to form these elements. Three different connections playfully implemented by anthropomorphic postures, or yoga moves, limit the possibilities of too many connections, therefore restricting the aggregation's ability to become infinite in all directions. Yet at the same time, Hejduk's *Diamond House A*, as an overall form, gives the bricks a base logic for the formation of the Panda Hut. Oscillating between each posture and its need to simulate the whole, a fuzzy logic constrains aggregation of the soft discrete parts that implement not only a familiarity with the resolution of the individual brick, but with the overall whole.

Whether viewed at the resolution of a singular brick or a building, Soft Discrete Familiars uses our sense of tactile objects as a tool to manipulate form. Folded, squished and contorted, the part-to-part relationship of the brick – or panda – acts upon childlike tendencies to recognise these parts and their in-betweens. In architectural education, the use of tactile buildings enables a fuzzy constraint to emulate building familiarity within the aggregated form. Soft Discrete Familiars encompasses both types of familiarities to demonstrate how critical practice deals with part-to-part relationships in the context of the uncanny. For both child and architect, tactile objects present new possibilities within the realm of the familiar. ⌂

Notes

1. Masahiro Mori, 'Bukimi no Tani Genshō' [1970], trans Karl F MacDorman and Norri Kageki, 'The Uncanny Valley', *IEEE Robotics and Automation*, 19, 2012, pp 98–100.
2. Mike Kelley, 'Playing with Dead Things: On the Uncanny' [1993], *Foul Perfections: Essays and Criticism*, MIT Press (Cambridge, MA and London), 2004, pp 70–99.
3. Donald Winnicott, *Playing and Reality*, Routledge (London), 1971, pp 1–35.
4. Herman Melville, *Moby-Dick, or, The Whale*, Harper & Brothers and Richard Bentley (New York and London), 1851.





Tom Wiscombe Architecture,
Guggenheim Helsinki,
Finland,
2015

An obsidian form is complicated by a pleated surface texture, combining the self-containment of rock with the origami folds of tenting. As an example of the philosophical Discrete, the design represents an obdurate fragment of an alternate world; at the same time it presents a certain fragility in situ, as if its folds are in the process of slowly coming apart.

The Discrete Charm of the Glitch

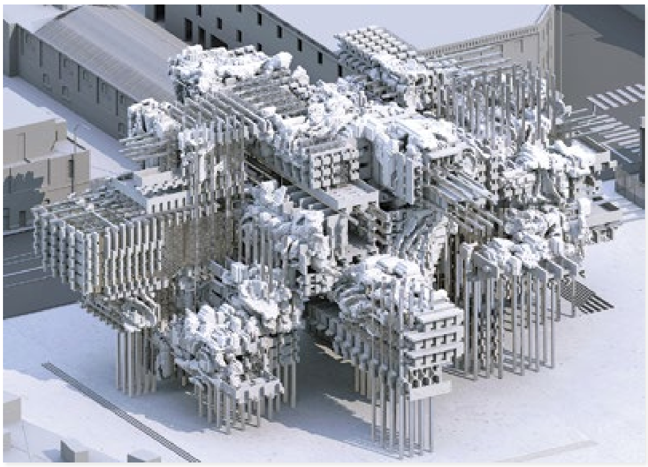
No process, however technologically advanced, is without its glitches. Architectural historian and theorist **Marrikka Trotter**, who teaches at the Southern California Institute of Architecture (SCI-Arc), sees this fact as a positive where the Discrete is concerned. Here she explores themes of continuity and becoming in the work of architects M Casey Rehm, Gilles Retsin and Tom Wiscombe, with reference to French philosopher Gilbert Simondon's theory of individuation.

The Discrete came into architecture from two directions at once. The first, via a set of mathematical and computational principles, is discussed at length elsewhere in this issue. The philosophical assumptions on which these 'hard' principles depend, however, merit closer scrutiny. The Discrete in philosophy has been typically used to counter the suggestion that time and space, as well as the processes that take place in them, are continuous; it opposes the conceit that everything is of a piece, and seeks to mind the gaps between distinguishable (and manipulable) entities. Keeping in mind that the interpretive margins architecture is allowed when dealing with philosophy and mathematics are unusually generous, this has two consequences for design theory: on the one hand, it highlights the useful fictions of the limit, the border and the edge. On the other, it directs attention to the density of infinitesimal inclusions in any given form, resulting in an architecture that is especially aware of its internal tensions.

Continuity in Discreteness

The mathematically and computationally inflected Discrete is represented by practitioners like M Casey Rehm and Gilles Retsin (see pp 94–101 and 38–45), and the philosophically oriented approach is best exemplified by the work of Tom Wiscombe.[1] In the case of Rehm and Retsin, the modular discreteness of individual bits of data is upsized to guide accretions of architectural-scale components, arranged in Jenga-block configurations that stress the autonomy of parts. Wiscombe's work, in contrast, emphasises the overall architectural object as a discrete entity in the world. It also registers a cross-grain of micro-discretenesses within each form through what Wiscombe terms 'supercomponents': visibly discontinuous figures that are simultaneously entities in their own right and parts of larger things. Taken together, each overall composition and its strange subdivisions form an ontologically ambiguous assemblage that resists legible modularity much like a model aeroplane assembled from a kit differs from one made of Lego.

Whether consciously or not, both approaches tacitly acknowledge the productive possibility that continuity and discreteness coexist. When Rehm and Retsin, for example, seek to translate certain efficiencies at the scale of pixels into the constructional units of the built, they are engaging with the world-as-it-is-becoming, not just with the world-as-it-is. But the world-as-it-is is also a moment in the world-as-it-is-becoming, even if the latter lurches forward unevenly and without the smoothness one would commonly attribute to a flow. It is not easy, and perhaps not even ethical, to come down on the side of autonomous components without situating their autonomy in their becoming, and to their credit Rehm and Retsin both produce designs that show signs of this. Rehm's neural networks and his other autonomous algorithms scrounge latent details from the extant surfaces of things, whether these be the planet itself, as in *Hoax Urbanism* (2017), or the city, as with Saturate Tower (2015) – see pp 95–9. In the former case, before-and-after image sequences highlight the process at work, while in the latter, architectural and urban elements are churned into a pixellated mush suggestive of an ongoing blur. Both give primary agency to the operation over the object. Retsin's stacked and stretched megapixels, as seen in projects like his Diamonds House (Wemmel, Belgium, 2016) – see p 43 – present the jagged-edged appearance of having been forcibly torn from a larger continuity; his winning installation for the 2017 Tallinn Architecture Biennale (pp 41–2) casually scattered several of the preassembled wooden units from which the entire form was built to one side of the finished piece, suggesting that the work was ongoing and that the installation could continue to develop. The implication in each of these instances is that enough parts and a sufficiently robust combinatory logic may lead not just to an actual whole, but to a potential process with no visible end in sight.



Yves Lu and Borna Nassab,
SCI-Arc 4.0,
undergraduate studio project,
Southern California Institute
of Architecture (SCI-Arc),
Los Angeles,
2016

Kept in the realm of the digital imagination, the computational Discrete tends towards coralline accretions of form, threatening to swamp efficiencies hypothetically gained via a modular, aggregative approach to architectural assembly. How this contradiction between too-dense materiality and economic viability is reconciled in built work remains to be fully tested.

Form in Four Dimensions

Wiscombe's philosophical Discrete achieves a similar insinuation of continuity by other means, and on two levels at once. On the one hand, his architectural objects pose as deliberate obstacles to the surrounding physical flows of the city. They also tend to form worlds of their own, uneasily balanced on their sites and visually disruptive of proximal scales and materialities. Part of this is due to Wiscombe's use of 3D-printed models, which he treats as integers of architectural possibility rather than as mere mock-ups of work to be effected at a full and 'final' scale. Deployed to suggest textural, programmatic and tectonic directions through sputtery, low-res material effects, and separated into gunky bits by self-imposed print-space limits, Wiscombe's models are aggressively incorporated into the design process. As a result, the office's 'full-scale' work tends to retain model-like qualities, such as toy-like finishes and proportions, or the sense that the final forms have been honed by hypertrophied instruments.

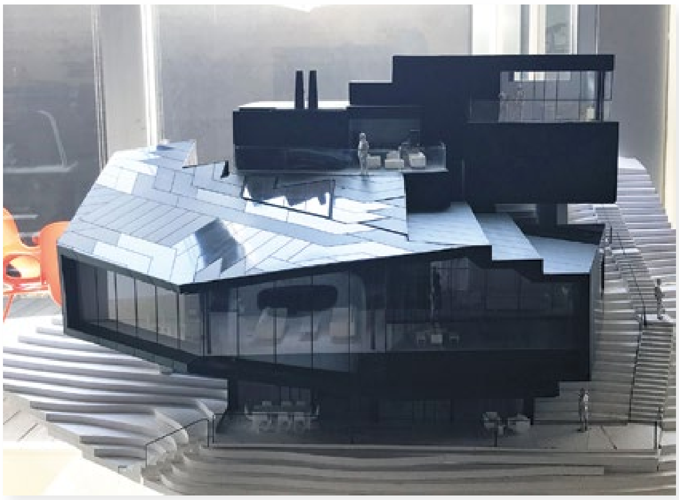
Agustina Alaines and
Galileo Morandi,
Unexpected Aspects of Control,
Edge Masters of Architecture
and Technology,
SCI-Arc,
Los Angeles,
2017

The neural-network-produced psychedelic geometries that spread outward from the design here combine the power of the computational and the philosophical Discrete into an active object capable of instigating difference in the world.

Joseph Michael Gandy,
A Bird's Eye View of the Bank of England,
1830

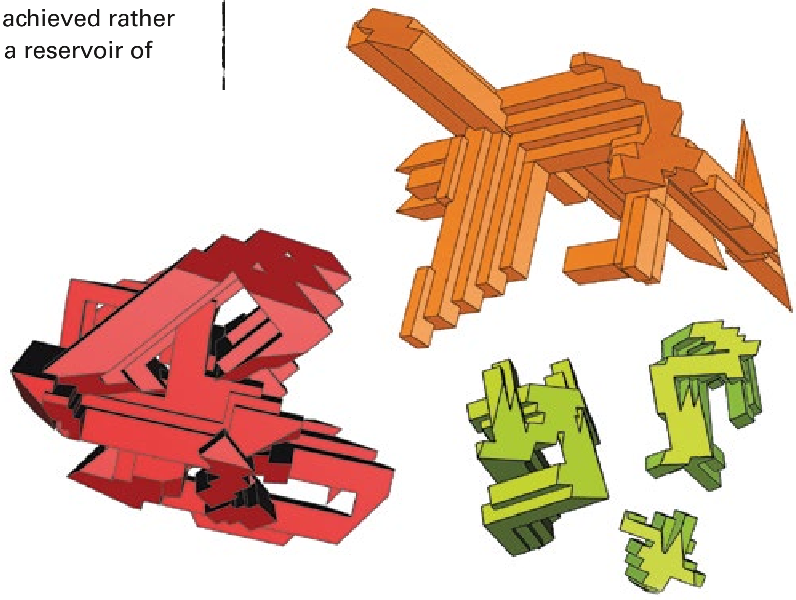
Sir John Soane's magnum opus is simultaneously presented in Gandy's rendering as a ruin and construction site, implying that this vast project is ultimately subject to the unsettling effects of deep time. If the view calls to mind the small scale of the model and the diorama with its out-of-scale accoutrements on the right and its tilted presentation, it also appears to patch test an urban catastrophe on the City of London.

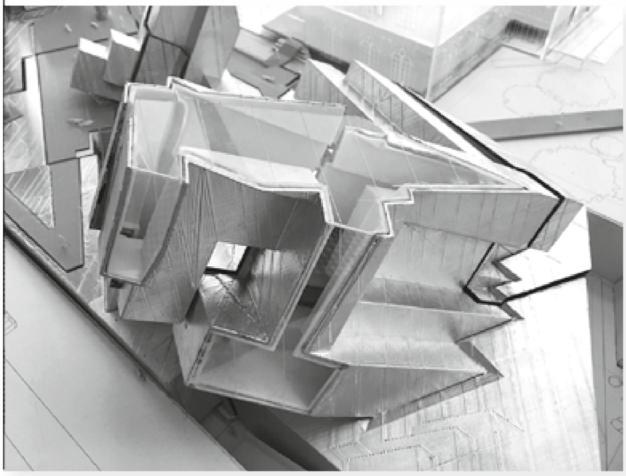
These effects are attained within a relatively narrow bandwidth of form. Wiscombe's architectural objects seem endlessly recyclable, rotatable and rescalable, yet they remain recognisable even as they acquire new configurations. The complex figure that pokes through the ground plane in his design for the Lima Art Museum in Peru (2015) is one of a series of closely related forms that Wiscombe calls 'tesseracts': that is, cubes caught in the process of four-dimensional becoming. A vertical version of one such form is essayed in between the outer flanges of the West Hollywood Belltower multidimensional kinetic billboard and cultural venue project he designed in 2016 for the Sunset Strip stretch of Sunset Boulevard, Los Angeles. In each of these cases, the un-seeable and non-Euclidean nature of the tesseract is conveyed by the withholding of total visual apprehension – in the Lima project, the form is shrouded by the intervening ground; in the Belltower by the luminous and animated planes that enclose it. Here, the notion of the 'withdrawn object' as discussed by the contemporary philosopher Graham Harman and embraced by Wiscombe in his own approach to design,[2] overlaps with French philosopher Gilbert Simondon's concept of individuation: namely, that entities attain a level of discreteness via a discontinuous process of internal lags. If Harman's object-oriented ontology reaffirms the autonomous project proposed by an earlier generation, Simondon's ontogenesic principle insists that such autonomy is only ever illusorily achieved rather than given – the individual always carries a reservoir of incompleteness and fragility on its back.



Tom Wiscombe Architecture,
Powder Mountain House,
Eden, Utah,
2017

Rendered in great detail and coming in at the approximate size of an armchair, this large model produces the uncanny effect of turning everything around it – actual pieces of furniture, desktop workstations, other models, humans and the like – into potential architectural compositions at the same scale. Its 'patchy' surface and discontinuous massing produce a composition that is easier to interrogate as an ambiguous example of strange mereology (à la Levi Bryant) than to comprehend as an assemblage of self-similar parts.





Tom Wiscombe Architecture,
Lima Art Museum,
Lima, Peru,
2015

above: These highly crystallographic components form the micro-discretenesses that structure the developing tesseract. The individuation at work in the Lima Art Museum project has little to do with unit-based modular systems; the design is only reducible to its parts insofar as these become temporarily distinguishable in the compositional process of falling out of phase with itself.

left: The intersection between the architecture and the landscape plane is marked with a 45-degree mitred gutter, as if the ground were dented on impact, while a series of glance-cut apertures suggest that the building's figure, in turn, has been sliced through by an alien blade. Such toy-like, tin-can effects deployed at the scale of architecture have the power to call conventional anthropocentric perceptions of relative size and final function into question.

Glitch Engines

Today it seems clear that while the concept of autonomy may no longer adequately explain how the world works, it does provide a more agential operating assumption for architects. In other words, we are at a moment when it may be more fruitful to think of architecture in terms of discreteness than in terms of continuity. One of the discipline's most invigorating inventions is its ability to cast itself as other, and the Discrete project allows us to conceive of architecture as something that takes place and stands out by virtue of its difference. In Simondon's writing, individuation is a process of becoming that relies on the ability of certain entities to temporarily 'fall out of phase' with themselves [*se déphaser par rapport à lui-même*] – that is, on their ability to harbour the same kind of inherent contradictions that we have identified as latent in Rehm's and Retsin's slow-speed accretions, and readily apparent in Wiscombe's glitchy objects. For Simondon, discreteness is not an attribute but an 'achievement', which means it is also always vulnerable to being undone, to falling back into step with itself and back into equilibrium with its environment. This is not something we want; equilibrium here not only erases difference but saps its very potential to come into being.[3] Counterintuitively, then, discreteness functions as a negentropic difference-generator rather than a fixed set of objects. It follows that Discrete architecture is anything but disengaged: instead, it is so intensely active in the world that it approaches it with something like an oppositional vitality, as if possessed of an unsentimental, anti-utopian and inhuman life of its own. As such, it is less concerned with being in the world than with becoming world-like.

In the Simondonian discourse on technical objects, highly autonomous hybrids challenge and complicate, renege and extend the agency of human beings by channelling agendas of their own. Architecture falls within this category. These specialised objects tend to function as modal operators; that is, as engines of possibility. If we know that even the most seamless mechanical or computational processes are, like individuating flows, replete with gaps and glitches, then Simondon's take on the Discrete proves doubly useful. As he notes, the technical object's particular density of information, 'like life itself and together with life', makes it 'opposed to disorder, to the leveling of all things tending to deprive the universe of the power of change'.[4] Discreteness thus ensures the currency of difference, and it does so not just through the mastery of auteurs, but also through the wealth of glitches that ensnare all processes. In hacker speak, the bug may not be a feature just yet, but the feature before us is also a bug.[5] Ꭰ

Notes

1. Wiscombe publicly began discussing the philosophical Discrete in relation to his own work in 2013. See Tom Wiscombe, 'The Structure of Subdivisions', public lecture, SCI-Arc, Los Angeles, 30 October 2013; https://youtu.be/QlycDYUa26g, and 'Discreteness, or Towards a Flat Ontology of Architecture', *Project 3*, Spring 2014, pp 34–43. Retsin has since lectured and published widely on the computational Discrete, beginning in 2015. See, for example, Gilles Retsin, 'Discrete Assembly and Digital Materials in Architecture', *Fabrication: Robotics: Design and Assembly* I, 2016, pp 143–51.
2. Graham Harman, *Prince of Networks: Bruno Latour and Metaphysics*, re.press (Melbourne), 2009, p 195. See also Todd Gannon *et al*, 'The Object Turn: A Conversation', *Log 33*, Winter 2015, pp 73–94.
3. Gilbert Simondon, 'The Genesis of the Individual', in Jonathan Crary and Sanford Kwinter (eds), *Incorporations*, Zone Books (New York), 1992, p 300.
4. Gilbert Simondon, *On the Mode of Existence of Technical Objects*, University of Minnesota Press (Minneapolis, MN), 2017, p 21.
5. Nicholas Carr, '"It's Not a Bug, It's a Feature." Trite – or Just Right?', *Wired*, 19 August 2018; www.wired.com/story/its-not-a-bug-its-a-feature.

Stefan Svedberg,
Geomorphic Aggregates,
Edge Masters of Architecture and Technology,
SCI-Arc, Los Angeles,
2016

A cross between grounded space-junk and a dry shipwreck, this project probes the connections between the heterotopian dimension of the philosophical Discrete and post-apocalyptic science fiction. The context lacks sufficient information to indicate scale, and the image itself conveys a sense of hyperreality, destabilising easy human projections into the scene.

Discrete architecture is so intensely active in the world that it approaches it with something like an oppositional vitality.

Lei Zheng

Meta-Utopia and the Box

Two Stories about Avant-Garde Projects

'Meta-Utopia: Between Process and Poetry' exhibition, Zaha Hadid Gallery, London, 2016

The work exhibited at 'Meta-Utopia' makes use of cheap materials and robotic processes. Rather than glossy surfaces, it is characterised by volumetric stacking and aggregation – sometimes bulky, sometimes porous.

Over a century after the box became a staple of avant-garde art and design, can it still be a useful tool for pioneering projects today? Architectural and structural engineer **Lei Zheng**, of Zaha Hadid Architects in London, explores its relevance to the Discrete generation, in the light of the shift from smoothness to aggregation demonstrated by the 'Meta-Utopia' exhibition which she recently curated at the firm's gallery.

The intention of the 'Meta-Utopia: Between Process and Poetry' exhibition at the Zaha Hadid Gallery in London, which ran from November 2016 to January 2017, was to mobilise cutting-edge design work from a diverse group of mainly London-based architects, designers and researchers at the fading end of 'the digital'. A number of the exhibitors were part of the Discrete spectrum featured in this volume: Philippe Morel (EZCT), Gilles Retsin, Daniel Widrig and Manuel Jimenez. Also participating were Robert Stuart-Smith's and Shajay Bhooshan's Master's studios from the Architectural Association (AA) School of Architecture; AiBuild; Automata Technologies; Eragatory; EZCT; Jelle Feringa; Minimaforms; Research Clusters 4, 5 and 6 and the AD Wonderlab from the Bartlett School of Architecture, University College London (UCL); and ZHA CODE / Patrik Schumacher. The show's title highlighted the ambiguous relationship the work has with the notion of utopia. It is also a reference to an earlier exhibition, 'Latent Utopias: Experiments within Contemporary Architecture', curated by Zaha Hadid and Patrik Schumacher in 2002 at the Landesmuseum Joanneum in Graz, Austria.[1]

Meta-Utopia

Compared to the computational work of 'Latent Utopias', this generation is substantially different. On the one hand, these emerging architects and designers seem to take pragmatic control of their horizon. Rather than waiting for the building industry to change, they develop their own tools and processes, from software to robotics and 3D-printing methods. They rarely make renderings but rather fabricate physical prototypes. On the other hand, they do not design large buildings or urban visions as in 'Latent Utopias', but so far have mainly developed chairs and other pieces of furniture to demonstrate their ideas. However, it could be argued that this hands-on pragmatism is in fact also utopian: the proposed technologies would take years to enter the real construction market. In the meantime, the technologies presented more than a decade ago at 'Latent Utopias' have moved on from the avant-garde to become mainstream.

Latent Utopias: Experiments within Contemporary Architecture exhibition catalogue, 2002

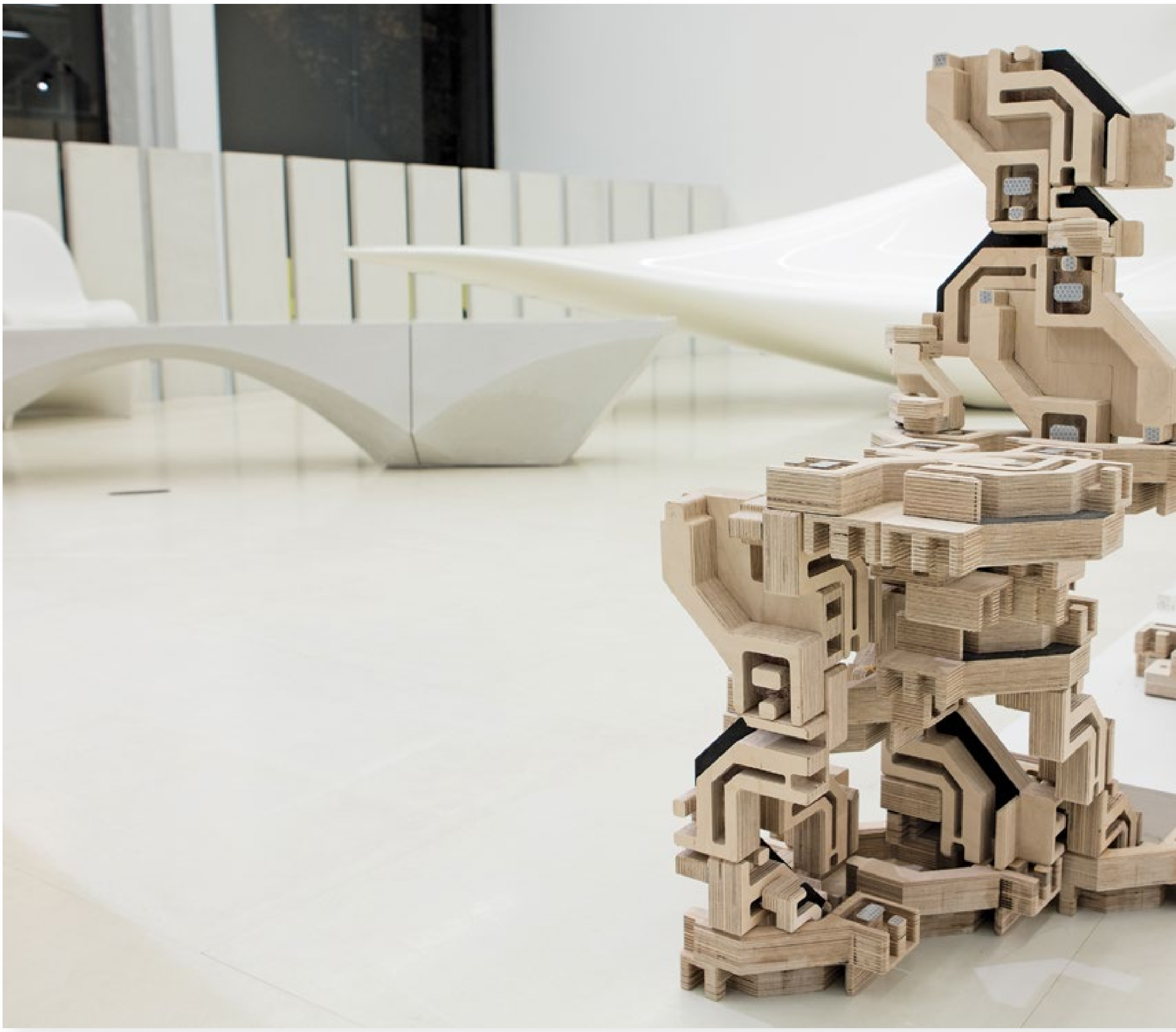
The cover of the catalogue for the exhibition, curated by Zaha Hadid and Patrik Schumacher at the Landesmuseum Joanneum in Graz, Austria in 2002 (published by Princeton Architectural Press, New York / Springer Verlag, Vienna).

Image from 'Meta-Utopia' poster, Zaha Hadid Gallery, London, 2016

The poster features a flying squirrel: a mammal that attempts to fly, and in fact almost can fly – but only for a limited distance between two trees.

Zaha Hadid Design, 'Seamless' collection, 2000

The 'Seamless' collection is a set of furniture created in 2000 by Zaha Hadid Design. It embodies early digital work, as also seen in 'Latent Utopias' – focused on fluidity, curvilinearity and smoothness.



Unlike the continuous and smooth work in 'Latent Utopias', the work in 'Meta-Utopia' was characterised by the aggregational and the Discrete, from the algorithmic chair by Philippe Morel (2004), to the INT chair and Mickey Matter chairs by Gilles Retsin and Manuel Jimenez's students from the Bartlett (2016), to the Stream chair by Daniel Widrig's students, also from the Bartlett. These chairs, using cheap materials and repeatable processes, are in sharp contrast with the smooth, continuously differentiated surroundings this exhibition is set in: the Zaha Hadid Gallery.

Likewise contrasting with the Discrete experiments is Zaha Hadid Design's 'Seamless' collection. A set of furniture designed in 2000, it attempts to articulate the formal dynamics of fluidity. According to Zaha Hadid Design, 'The *Seamless* collection for Established & Sons explores the limits of functional, aesthetic, and technological possibilities, fusing complex curvilinear geometries with detailed ergonomic research.'[2] While there is no doubt about the collection's aesthetic and technological value, which reflect the early 2000s, the application of a seamless aesthetic for the sole purpose of emanating luxuriousness seems questionable today.

The exhibited work is therefore in tension with the 'Seamless', the untested avant-garde versus a mature market product. The continuously differentiated surface, glossy materials and expensive craft versus the assembled, cheap materials of the new avant-garde – metals, timber, concrete.

The aggregated tables and chairs of 'Meta-Utopia' try to argue for the pragmatic, while the 'Seamless' collection does not need to any more. The Discrete's carefully developed robotic tools and dreams of ultimate efficiency have as an ironic consequence the fact that they are severely deficient in function, unsuitable and unable to compete with current practices or standards: chairs that are not suitable for sitting in, columns that cannot bear any load. The flying squirrel that adorns the poster of 'Meta-Utopia' symbolises a similar moment: it is a mammal that attempts to fly, and in fact almost can fly – but only for a limited distance between two trees. It is therefore a utopian but ultimately also pragmatic animal.

In contrast, the 'Seamless' collection is far less ambitious, created as a range of beautiful objects with a high market price. The 'Seamless' collection does not hide its purpose as a market product, not so different from other objects from the same collection sitting in other sleek air-conditioned galleries in London, Dubai or New York. It is not a utopian project any more but the successful end product of the continuous experiment, exhibited almost two decades ago as avant-garde at the 'Latent Utopias' exhibition.

Zoey Tan, Claudia Tanskanen, Qianyi Li
and Xiaolin Yin / Research Cluster 4,
Bartlett School of Architecture,
University College London (UCL),
INT chair,
'Meta-Utopia' exhibition,
Zaha Hadid Gallery, London,
2016

The Bartlett's Research Cluster 4 produced the INT system, which aims to introduce complexity in prefabrication. The team looked into robotic assembly of digital materials while also addressing the relationship between users and robots.

Aerial view of Beijing,
2015

This aerial view shows the vast sea of boxes, defined by logistical concerns of planning. Confronted with what Reinier de Graaf refers to as 'the inevitable box', should we reconsider the box as an avant-garde project, while at the same time also accepting the signification of projects such as Zaha Hadid Architects' Galaxy SOHO as urban 'confetti' – a moment of exception – within the vast grid?

The Box

The 'Seamless' collection and 'Meta-Utopia' have one thing in common: their apparent lack of scalability. Although the 'Seamless' collection is a mature market product on the scale of furniture up to buildings, it is still utopian and avant-garde on the scale of the city. The urban agenda of the 'Seamless' collection is best understood through Parametric Urbanism research, as carried out at the AA's Design Research Lab between roughly 2003 and 2008. It attempted to dissolve the fixed and static urban grid with fluid curves and fields. Yet when looking at a bird's-eye view of Beijing, we can see how difficult the confrontation with the repeating grid really is. Regardless of its lack of scale, the 'Seamless' collection and the Discrete's efforts disappear within the grid and become no more than 'urban confetti'. Developed by OMA for the 1981 competition entry for the Parc de la Villette in Paris, confetti is an architectural technique where small drops of more heterogeneous buildings and installations interrupt a regular field. Similarly, Zaha Hadid Architects' office, retail and entertainment complex Galaxy SOHO (2012) is almost like confetti in the vast sea of repetitive buildings along Beijing's second ring.

Zaha Hadid Architects,
Galaxy SOHO,
Beijing,
2012

No matter how fluid the building itself, it is still very much constrained in the boundary set out by the grid of Beijing. In this sense, it inevitably becomes urban 'confetti' within the grid of banal boxes that defines the city.

When looking at the contemporary megacities sprouting up across Asia, it is an equally scaleless and abstract geometry that has successfully conquered most of the built environment: the box. The box is both utopian and pragmatic, both real and yet also highly abstract. In China, there is a concept of *qiang pai* ('forced arrangement') that features in 99 per cent of the urban developments today. It is used to maximise the building arrangement to achieve the highest possible profit under current planning regulations. Not surprisingly, these 'forced arrangements' assume the form of a box as the most efficient planning and organisation tool. As Reinier de Graaf argues: 'The box is the natural outcome of all rational parameters combined, the form in which geometry and economy meet in perfect sync. The box doesn't resist; it complies. It is easy. It suits any use and any size. It offers multiple options to expand in length, height and width.'[3]

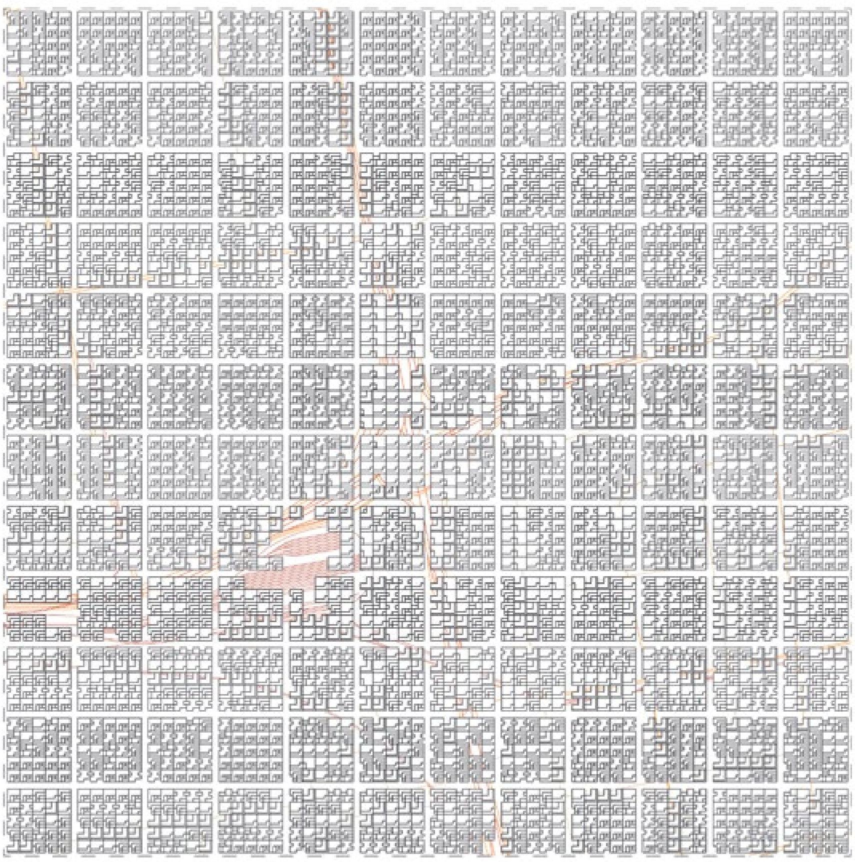
Just like 'Meta-Utopia' and the 'Seamless' collection, the box was in fact originally also an avant-garde project,[4] which flourished in the early 20th century, perhaps most famously with Russian artist Kazimir Malevich's *Black Square* (1915). However, the box became a sort of archenemy for the early digital, a symbol for conservative and 'boring' architecture. Ironically, though, the fluidity, continuity and freedom that the early digital associated with curvature was already largely achieved through the medium of the box in the bold, pixelated and gridded projects of the Italian Radical architecture firm Superstudio in the 1960s. Arguably, it is also the freedom of recombination and adaptability that makes the box such a valuable asset for city planning. Despite two decades of digital designers opposing the straight and the regular, the box proves to be rather resilient. With what Rem Koolhaas referred to in his book *Delirious New York* (1978) as a 'Mountain range of evidence',[5] does not the box's resilience also prove its own inevitability? Its ability to effortlessly repeat makes it so successful – and difficult to reduce to no more than urban confetti.

Re-instrumentalising the Box?

Instead of trying to defeat the box, maybe the new Discrete generation of 'Meta-Utopia' should decompose its love–hate relationship with the box, and re-instrumentalise it as an avant-garde design tool. As the box is inherently also Discrete, could it be looked at again as an actual avant-garde project? These two brief stories describe two avant-garde projects and architectural utopias at different moments in time, both trying to compete with the box's inevitability. Ultimately, application at the urban scale is something the 'Seamless' collection and the 'Meta-Utopia' exhibits have failed to address. ⌀

Notes

1. 'Latent Utopias' exhibition: http://latentutopias.steirischerbst.at/.
2. 'Seamless' collection: www.zaha-hadid.com/design/seamless-collection/.
3. Reinier de Graaf, *Four Walls and a Roof: The Complex Nature of a Simple Profession*, Harvard University Press (Cambridge, MA), 2017, p 73.
4. *Ibid*.
5. Rem Koolhaas, *Delirious New York: A Retroactive Manifesto for Manhattan*, Kindle edition, 2014, 'Introduction'.



Lei Zheng,
Urban Waffle,
Architectural Association (AA)
Visiting School Shanghai,
2018

An urban grid where every block is composed of an assembly of slightly differentiated boxes. This is a complex form of repetition, where a self-similar element creates an effortless level of variation throughout the grid.

There Is No Such Thing as a Digital Building

A Critique of the Discrete

COUNTERPOINT

NEIL LEACH

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What exactly is the Discrete? A style, or rather a design/fabrication method? And how does it relate to the continuous? Architectural educator and writer **Neil Leach** – who currently teaches at Shanghai's Tongji University, Miami's Florida International University School of Architecture, and the European Graduate School – challenges deficiencies and inconsistencies in its definition, and questions the very notion of digital materials.

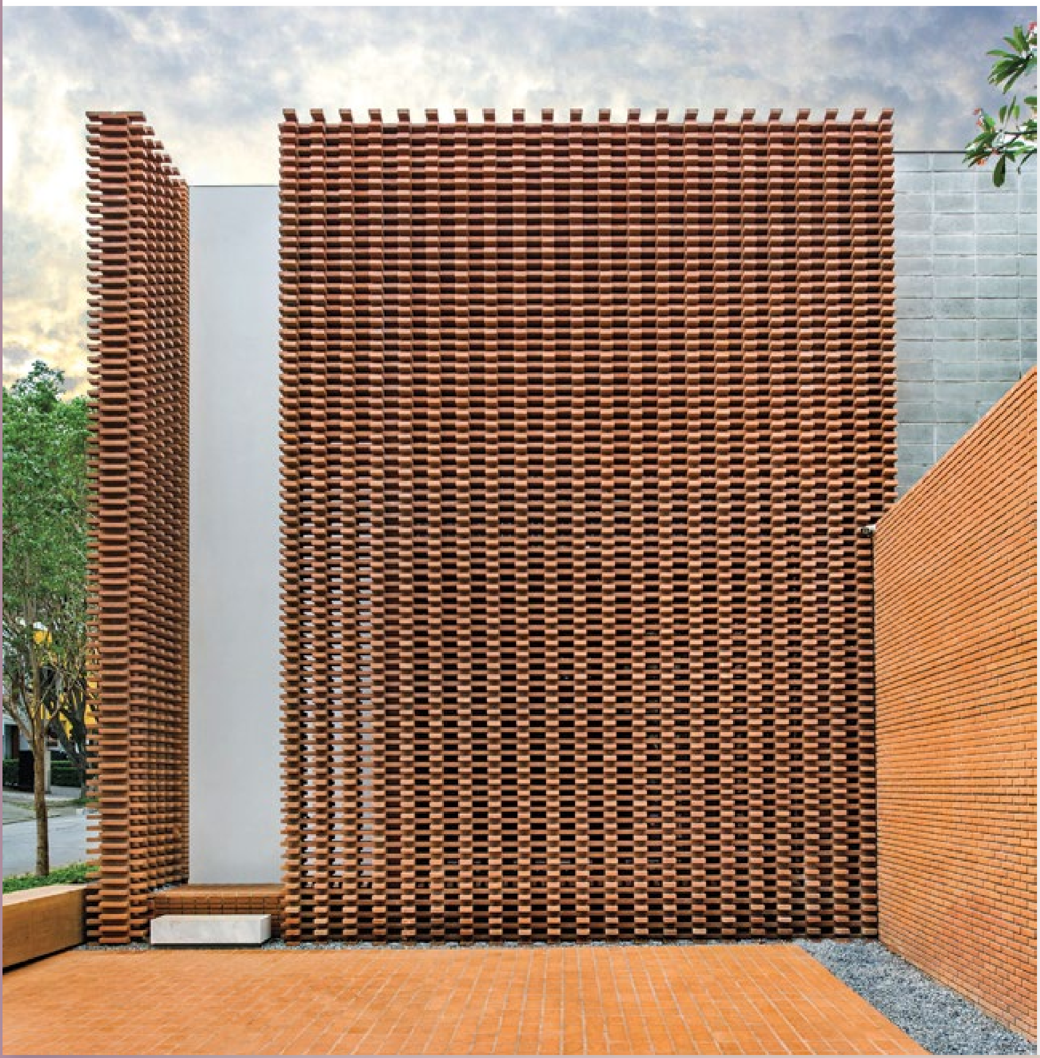
If you are confused as to the exact meaning of the Discrete, you are not alone. For some time I too have been trying to understand it. Admittedly there is some exquisite work being undertaken under the name of the Discrete by a discrete group of designers emanating mainly from the Bartlett School of Architecture at University College London (UCL). But the problem is that there is no concise definition of it.

Recently, however, I was informed that the Discrete is essentially a style in opposition to what Patrik Schumacher calls 'Parametricism'.[1] Whereas Parametricism is composed of continuous, curvilinear forms, the Discrete is composed of discontinuous, largely straight forms. In his Introduction to this issue of ᗡ, Guest-Editor Gilles Retsin, however, claims that the Discrete goes beyond mere style (pp 6–13). For sure discussions of the digital need to move beyond style. After all, the digital is already having a major impact on every aspect of our social, political and economic lives.[2] But for Retsin to claim that continuous forms of Parametricism are somehow aligned with neoliberalism, simply through association with Schumacher's personal politics, makes no sense. Moreover, if continuity is one of the stylistic hallmarks of Parametricism, then to counter it with the Discrete must surely be a stylistic move. In fact, in his article in this issue, Mario Carpo confirms that the Discrete is indeed a 'style'.

The discourse of the Discrete would appear to be somewhat compromised. For example, it would be challenging to sell the Discrete in terms of contemporary modes of fabrication. Neri Oxman has declared the Discrete an obsolete concept.[3] So too Greg Lynn rejects the Discrete in favour of 'woven or intricate layers of materials, blended or filleted connections, and smooth curvilinear transitions between elements'.[4] Moreover, some chairs designed by Retsin and Manuel Jimenez Garcia (pp 71–2) are themselves 3D printed – a process of continuous fabrication.

But it is the precise relationship between the Discrete and the continuous that is most confusing. For example, in this ᗡ Maria Yablonina and Achim Menges (pp 62–9) write not about discrete forms, but multiple discrete robots fabricating an elegant structure from a continuous filament. At the same time, Manja van der Worp (pp 54–61) refers to structures themselves – rather than their component parts – as being discrete, while the structural performance of projects such as the Continuous Line relies on 'continuous equilibrium'. Indeed Marrikka Trotter (pp 124–9) insightfully observes that 'continuity and discreteness coexist', and much depends on scale. Discrete components might themselves be fabricated from continuous materials, such as the plywood used in Retsin's 2017 Tallinn Architecture Biennale Pavilion (pp 41–2), whereas the continuous plywood itself might be seen as composed of discrete fibres. In fact anything might be deemed discrete – from atoms through to the planet Earth – when viewed at the right scale, as Charles and Ray Eames's 1977 movie *Powers of Ten* shows us.[5] The important message is that scale *does* matter, despite the frequent use of the problematic term 'scalability' in this issue.

It is as though the Discrete and the continuous are held in some kind of dialectical tension. Nothing can be connected, as German sociologist Georg Simmel reminds us, unless it is first separated, and nothing can be separated unless it is first connected.[6] Likewise, Slovenian philosopher Slavoj Žižek notes that a photograph is a discrete moment within an animated continuum, while a movie is simply a series of discrete moments stitched together to form an animated continuum.[7] One person's discrete brick, so the saying goes, is another person's component in a continuous wall.



One person's discrete brick, so the saying goes, is another person's component in a continuous wall.

Studio Guilherme Torres office,
São Paulo,
2017

This carefully controlled minimalist wall raises the question as to whether the bricks should be seen as discrete elements, or components within a continuous wall.

The Digital is Not a Style

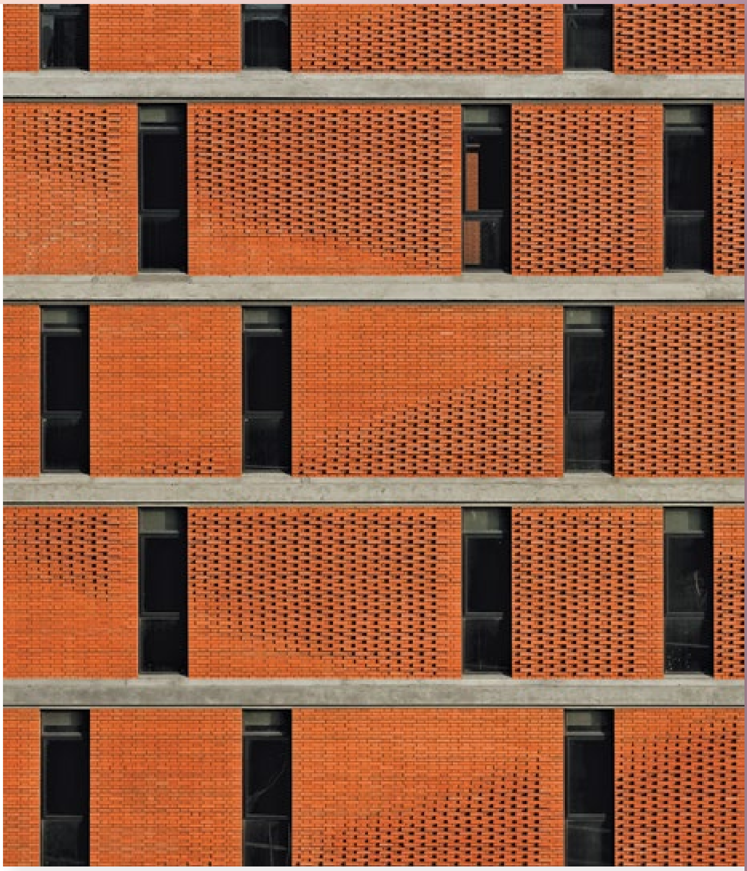
The problem of perceiving the digital as a style goes back to publications such as *The Digital Turn in Architecture (1992–2012)*, a collection of essays edited by Mario Carpo in 2004, which interprets the digital as a language of curvilinear forms growing out of the work of architects such as Greg Lynn and Bernard Cache.[8] However, the origins of the digital lie not in the curvilinear architectural expressions of the 1990s, but in the pioneering work largely – but not exclusively – emerging from the two Cambridges. In Cambridge, UK, Charles Babbage designed his 'difference engines', the first automatic computing engines, back in the 19th century.[9] Likewise, Alan Turing laid out the conceptual groundwork for his 'Turing machine' in 1936 as a Fellow of King's College, Cambridge.[10] John Frazer subsequently undertook pioneering research into the digital at the university's School of Architecture in the 1970s. Meanwhile, in Cambridge, Massachusetts, one of the first computers, Mark I, was installed at Harvard University in 1944, and figures such as Ivan Sutherland developed the first human-computer interface at the Massachusetts Institute of Technology (MIT) in the city in 1963.[11] Nicholas Negroponte, an architectural graduate of MIT, went on to found the MIT Media Lab in 1985. For a historian to overlook these historical precedents is remarkable.

Even more remarkable is the claim made by Carpo in his subsequent book, *The Second Digital Turn* (2017), that whereas splines had encouraged smooth curvilinear forms, 'big data' now leads to lots of messy forms.[12] What big data has to do with architectural form is unclear. After all, big data is about information, not form. A good example of the intelligent use of big data are Uber cars. Do Uber cars look any different to ordinary cars? No. Because Uber cars are ordinary cars. They just use new techniques to process information.[13] It is patently absurd to claim that there is an architectural style associated with big data.

The digital is not responsible for any style. Although it offers certain affordances, it has no agency.[14] It cannot force a designer to operate according to any particular style. Certainly, if we adopt the distinction made by Harvard's Kostas Terzidis between computation and computerisation, it is clear that digital computation (as opposed to material computation) harnesses computational power to generate outcomes through algorithmic processes, whereas computerisation merely uses the computer as a tool of representation relying on explicit modelling techniques.[15] Moreover, for Terzidis, the digital is objective rather than subjective: 'Digital is something objective, quantifiable, neutral and therefore non-subjective.'[16] Whereas the logic of style constrains any potential design to the framework of a personalised, subjective outlook, the logic of digital computation generates outcomes based on a logical, objective outlook. Of course, everything that is produced – no matter what process is involved – has an appearance, or an 'affect'. Style, however, is a predetermined template that frames an approach to a design in advance.

The Problem of Architecturalisation

Architects have a history of appropriating ideas from the domain of others and reinterpreting them in terms of architectural form – a process we might call 'architecturalisation'. For example, the term 'deconstruction' coined by philosopher Jacques Derrida in the 1960s to refer to 'a project that seeks to expose the paradoxes and value-laden hierarchies within Western Metaphysics' was misinterpreted by some architects as referring to twisted or distorted architectural forms.[17] Gilles Deleuze has suffered a similar fate. In the AD issue *Folding in Architecture* (1993), edited by Greg Lynn, his book *The Fold: Leibniz and the Baroque*[18] published the same year is taken as literally referring to physical folds in architectural form. In fact Deleuze is referring to philosophical issues, especially the production of subjectivity, as Simon Sullivan has observed: 'The concept of the fold allows Deleuze to think creatively about the production of subjectivity, and ultimately about the possibilities for, and production of, non-human forms of subjectivity.'[19] This is compounded by the inclusion in the same issue – without explanatory commentary – of what appears to be a section through a Baroque house, as though it were an actual architectural drawing. In fact it is an allegory used to theorise the baroque construction of the conceptual pair: reading-seeing, as Greg Lambert has noted.[20] Architects have also confused Deleuze's use of the 'diagram' with architects' use of the same term.[21] Likewise pixels and voxels – which do not express the digital as such, but are effects of strategies to 'visualise' it – are seen by Carpo as literally becoming 'digital' architectural forms, as in the case of the Bolivar series of chairs generated by Philippe Morel (see p 88). And let us not forget Carpo's mistake of translating big data into architectural form.



Archi-Union Architects,
Songjiang Art Campus,
Shanghai,
2015

Algorithms are simply 'instructions', and, as such, the instructions given to workmen regarding the placement of bricks – although analogue – could be described as 'algorithms'.

The digital discrete falls potentially into the same category. The digital is composed of zeros and ones, and is indeed discrete. But the digital itself is also immaterial. To simply appropriate the term ‘discrete’ from the discourse of the digital and use it to justify an architectural language of discontinuous material forms is questionable enough, but to assume that those forms are necessarily digital is clearly mistaken. The digital might be discrete, but the Discrete is not necessarily digital.

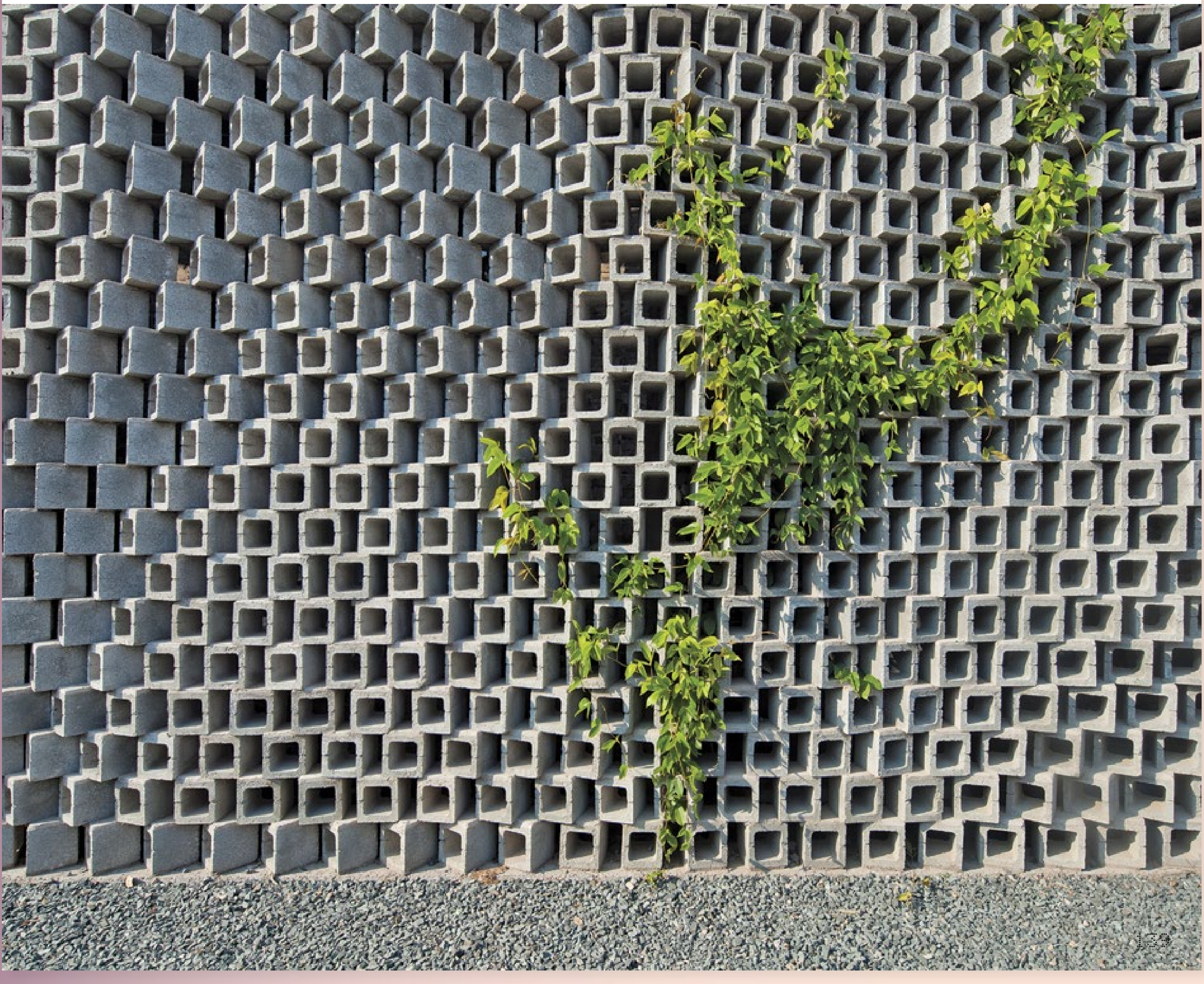
There is No Such Thing as a Digital Material

Materials are analogue. And so too are digitally controlled fabrication processes. Retsin acknowledges this: ‘Essentially, most current fabrication technologies are analogue processes, despite the fact that they are computer controlled. … Techniques such as CNC-milling are actually based on centuries old artisanal methods, just as additive manufacturing is a technique commonly found in pottery. These analogue techniques share the property of continuously adding or removing material – they are continuous fabrication techniques. These tools are computer controlled, but not “digital”.’[22] Sometimes it is even difficult to tell if computer-controlled fabrication processes have been deployed in a project, in that – technically speaking – there is nothing that can be drawn on a computer that cannot also be drawn by hand, and nothing that can be fabricated by a robot that cannot also be fabricated by hand.

The digital might be discrete, but the Discrete is not necessarily digital.

Archi-Union Architects,
Silk Wall,
Shanghai,
2010

The Silk Wall is composed of concrete blocks positioned in an analogue fashion according to a limited range of fixed angles using a physical template.



The confusion begins, however, when Retsin introduces the notion of 'digital materials', based on research undertaken by Neil Gershenfeld and his team at the MIT Center for Bits and Atoms.[23] The problem is that digital materials as such cannot actually exist. For, if we accept the commonly held perception that all materials are analogue, and the digital operates within an immaterial domain and merely controls fabrication processes, then by definition materials cannot be digital.

The confusion emanates, it would seem, from the way that Gershenfeld and his team use the term. Actually, in their early research it is used in inverted commas, since 'digital materials' are composed of analogue materials, such as resin.[24] Revealingly, one of the team, George Popescu, goes on to claim: 'Because the cement in a cement/brick wall isn't discrete, a cement/brick wall isn't a digital material.'[25] The logical inference here is that – by extension – a brick *must* be digital because it *is* discrete. This is clearly an absurd proposition. A brick might be a discrete component, but it is certainly not digital. In short, Gershenfeld's 'digital materials' are not actually digital.

Indeed, Gershenfeld and his team do offer a precise definition of a digital material that clarifies that the term 'digital' refers not to materiality, but to potential connectivity: 'We define a digital material as a discrete set of components that can be of any size and shape, made out of various materials and that can fit together in various ways (press fit, friction fit, snap fit, reflow binding, etc.).'[26] Thus a digital material should be composed of discrete parts, have discrete joints and be capable of being positioned in a controlled fashion – much like a Lego brick.[27] A good example would therefore be the universal plastic component designed by Jose Sanchez and Alisa Andrasek for their Bloom project (p 26).
The confusion spreads, however, when Retsin uses the term 'digital materials' repeatedly within his discourse of the 'digital discrete' without clarifying that it is being used in a highly idiosyncratic manner to refer not to materiality, but to connectivity. This is

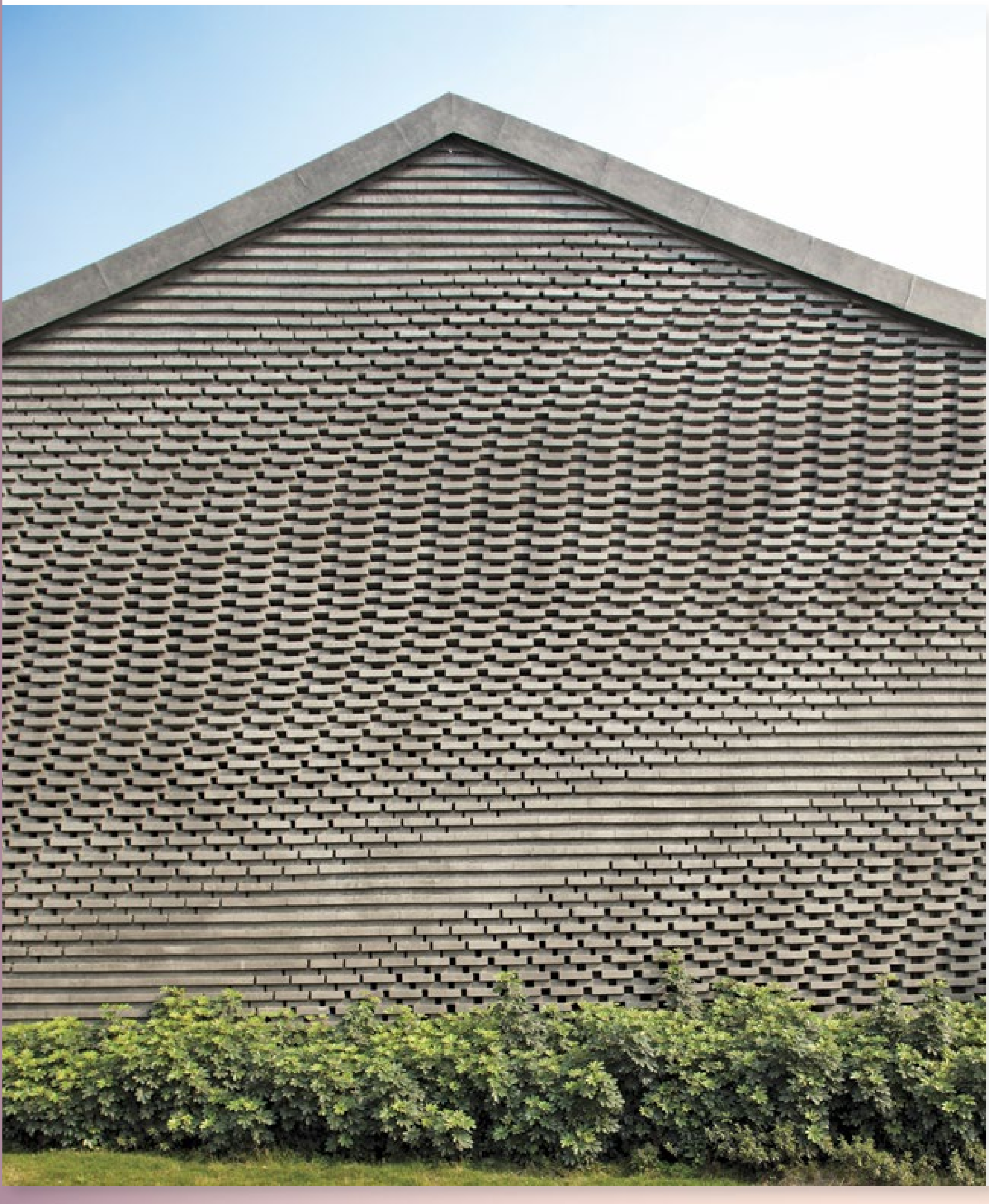
O'Donnell + Tuomey,
LSE Student Centre,
London,
2014

The design is carefully assembled to make one coherent volume from a complex set of interdependent component parts.

misleading. The plywood sheets used in the fabrication of the Tallinn pavilion, for example, are clearly analogue. Retsin notes in his later article in this issue that digital materials are superior to analogue materials: 'Digital Materials are efficient for robotic assembly and have structural properties that outclass normal, analogue materials' (p 41). But how exactly does the plywood in the Tallinn pavilion outclass normal, analogue materials, when plywood is itself a normal, analogue material? Although the design and fabrication of discrete architectural forms might involve the use of digital tools, in and of themselves the forms are not digital. There is no such thing as a digital material, if by 'digital' we understand the opposite of 'analogue'. By extension, there cannot be any such thing as digital architecture, if by 'architecture' we understand material buildings. This is not to say that there cannot be digital designs of buildings, but these designs are in effect immaterial models. Buildings themselves are analogue.[28]

Archi-Union Architects,
Lanxi Curtilage,
Chengdu, Sichuan province,
China, 2011

The positioning of the bricks in this wall follows a strict series of constraints not dissimilar to how Neil Gershenfeld at the MIT Center for Bits and Atoms sees his 'digital materials' positioned.



Notes

1. Patrik Schumacher, 'Parametricism: A New Global Style for Architecture and Urban Design', in Neil Leach, AD *Digital Cities*, July/August (no 4), 2009, pp 14–23.
2. For an appraisal of the role of politics in architecture see Neil Leach, 'There's No Such Thing as Political Architecture; There's No Such Thing as Digital Architecture', in Matthew Poole and Manuel Svartzberg (eds), *The Politics of Parametricism: Digital Technologies in Architecture*, Bloomsbury (London), 2015, pp 58–78.
3. Neri Oxman, Keynote Address, Acadia 2018, Massachusetts Institute of Technology (MIT), 2 November 2017.
4. Greg Lynn, 'From Tectonics (Mechanical Attachments) to Composites (Chemical Fusion)', in Neil Leach and Philip Yuan (eds), *Digital Fabrication*, Tongji University Press (Shanghai), 2017, pp 46–53.
5. Charles and Ray Eames (directors), *Powers of Ten: A Film Dealing with the Powers of Ten and the Relative Size of Things in the Universe*, distributed by IBM, 1977.
6. Georg Simmel, 'Bridge and Door', in Neil Leach (ed), *Rethinking Architecture: A Reader in Cultural Theory*, Routledge (London), 1997, pp 66–9.
7. Slavoj Žižek, *The Plague of Fantasies*, Verso (London and New York), 1997, p 88.
8. Mario Carpo (ed), *The Digital Turn in Architecture (1992–2012)*, John Wiley & Sons (Chichester), 2004.
9. Michael Lindgren, *Glory and Failure: The Difference Engines of Johann Müller, Charles Babbage, and Georg and Edvard Scheutz*, trans Craig G McKay, MIT Press (Cambridge, MA), 1990.
10. Andrew Hodges, *Alan Turing: The Enigma*, Princeton University Press (New York), 2012.
11. Ivan Sutherland, *Sketchpad: A Man-Machine Graphical Communication System*, Garland Publishers (New York), 1980.
12. Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*, MIT Press (Cambridge, MA), 2017.
13. Neil Leach, 'Informational Cities', in Neil Leach and Philip Yuan (eds), *Computational Design*, Tongji University Press (Shanghai), 2017, pp 102–11.
14. For the theory of affordances see James Gibson, *The Ecological Approach to Visual Perception*, Psychology Press (Hove), 1979.
15. Kostas Terzidis, *Algorithmic Architecture*, Architectural Press (London), 2006, p xi.
16. Kostas Terzidis, *Permutation Design: Buildings, Texts and Context*, Routledge (London), 2014, p 59.
17. Leach, *Rethinking Architecture*, *op cit*, p 317.
18. Gilles Deleuze, *The Fold: Leibniz and the Baroque*, trans Tom Conley, University of Minnesota Press (Minneapolis, MN), 1993.
19. Simon Sullivan, 'The Fold', in Adrian Parr (ed), *The Deleuze Dictionary*, rev edn, Edinburgh University Press (Edinburgh), 2012, p 107.
20. Greg Lambert, *The Non-Philosophy of Gilles Deleuze*, Continuum (London), 2002, p 45.
21. Ben van Berkel and Caroline Bos (eds), *ANY 23: Diagram Work*, 1998.
22. Gilles Retsin, 'Discrete Assembly and Digital Materials in Architecture', in Leach and Yuan, *Computational Design*, *op cit*, pp 77–88.
23. George A Popescu, Patrik Kunzler and Neil Gershenfeld, 'Digital Printing of Digital Materials'; http:cba.mit.edu/docs/papers/06.09.digital_printing.pdf.
24. *Ibid*.
25. George Popescu, 'Digital Materials for Digital Fabrication', Master of Science Thesis, Massachusetts Institute of Technology (MIT), September 2007, pp 12–13; https://dam-prod.media.mit.edu/x/files/thesis/2007/popescu-ms.pdf.
26. Popescu, Kunzler and Gershenfeld, *op cit*.
27. Popescu, *op cit*, p 6.
28. I am grateful to Nick Pisca, Behnaz Farahi and Claudiu Barsan Pipu for feedback on this article.

CONTRIBUTORS

Viola Ago is an architectural designer, educator and practitioner. She is currently serving as the Christos Yessios Visiting Professor at the Ohio State University Knowlton School of Architecture in Columbus, and as a lecturer at the Harvard University Graduate School of Design (GSD) in Cambridge, Massachusetts. She was the 2016–17 Muschenheim Fellow at the Taubman College of Architecture and Urban Planning in Ann Arbor, Michigan. She earned her Master of Architecture degree from the Southern California Institute of Architecture (SCI-Arc) in Los Angeles, and a Bachelor of Architectural Science from Ryerson University in Toronto. Prior to teaching, she was a lead designer in the Advanced Technology Team at Morphosis Architects in LA.

Mario Carpo is Reyner Banham Professor of Architectural Theory and History at the Bartlett School of Architecture, University College London (UCL). His research and publications focus on the relationship among architectural theory, cultural history and the history of media and information technology. His *Architecture in the Age of Printing* (MIT Press, 2001) has been translated into several languages. His most recent books are *The Second Digital Turn: Design Beyond Intelligence* (2017) and *The Alphabet and the Algorithm* (2011), a history of digital design theory, both published by the MIT Press, and the AD Reader *The Digital Turn in Architecture, 1992–2012* (John Wiley & Sons, 2012).

Emmanuelle Chiappone-Piriou graduated in architecture and history. She is an independent curator and author, and currently a PhD candidate and external lecturer at the Technical University of Vienna (TU Wien). She also lectures at the École Nationale Supérieure d'Architecture Paris-Malaquais. Her interest is in the relation of architecture to computation and visual arts, which she explores through collective and monographic shows, collaborative research projects, and through texts for catalogues and books. A member of the CIVA scientific council (Brussels), she has collaborated in numerous exhibitions and publications. From 2011 to 2016 she was Programme Curator of the FRAC Centre in Orléans, France.

Mollie Claypool is an architectural historian, theorist and educator. She is currently a lecturer in Architecture at the Bartlett School of Architecture, UCL where she co-directs the Design Computation Lab and coordinates History and Theory in the MArch Architectural Design. She has taught and lectured extensively in architecture schools across the UK and Europe. Her research interests include the history and theory of digital design and computation and the economic, social and political implications of new technologies on architectural production, experimentation and speculative practice. She actively writes reviews, criticism and books about architectural design, history and theory and has worked as an editor/author for Phaidon Press, the Royal College of Art, Laurence King Publishing, DETAIL and AA Publications. She is a PhD candidate at the Bartlett, supervised by Professors Mario Carpo and Barbara Penner.

Daniel Koehler is an urbanist, researcher and co-founder of lab-eds. He directs a research cluster at the Bartlett School of Architecture, UCL, and coordinates the B-Pro History and Theory programme. He also holds a postdoctoral research position at Innsbruck University in Austria. He is author of the book *The Mereological City: A Reading of the Works of Ludwig Hilberseimer* (Transcript Verlag, 2016), a study on the modes of part-relations between architecture and its city during Modernism. His current research focuses on the physical implications of digital logistics, which are being designed by means of sets, data, interfaces and their architecture.

Manuel Jimenez García is the co-founder and principal of MadMDesign, a computational design practice based in London, and of Nagami, a design brand and robotic manufacturing startup based in Spain. His work has been exhibited worldwide in venues such as the Centre Pompidou in Paris and the Victoria and Albert Museum and Royal Academy of Arts in London. He is a lecturer at the Bartlett School of Architecture, UCL, where he is a programme director of the MSc/MRes Architectural Computation, and co-founder of the Design Computation Lab. He also runs the MArch AD Research Cluster 4 and curates Plexus, a multidisciplinary lecture series based on computational design.

Immanuel Koh is an architect and programmer whose works investigate creative artificial intelligence applications in urbanism, architecture, design interaction and art. He graduated from the Architectural Association (AA) in London and has taught at the AA, Royal College of Art (RCA) and Bartlett School of Architecture, UCL in London, and at the Strelka Institute for Media, Architecture and Design in Moscow, University of Applied Arts Vienna, Bauhaus Dessau and Harvard GSD. He was a research scientist at the Singapore University of Technology and Design's Artificial Design Lab, in collaboration with the Massachusetts Institute of Technology (MIT) Artificial Intelligence Lab (CSAIL), and has practised as an architect at Zaha Hadid Architects. He is a PhD candidate at the Swiss Federal Institute of Tectonology (EPFL), where he teaches at the School of Computer Sciences and the Institute of Architecture.

Neil Leach teaches at Tongji University in Shanghai, at the Florida International University School of Architecture in Miami, and at the European Graduate School. He has also taught at the AA, Harvard GSD, Columbia University Graduate School of Architecture, Planning and Preservation (GSAPP) and Cornell in New York, at SCI-Arc and the University of Southern California. He has worked on two NASA-funded research projects to develop 3D-printing technologies for the Moon and Mars, and is a member of the Academy of Europe. His books include: *Designing for a Digital World* (John Wiley & Sons, 2002), *Digital Tectonics* (John Wiley & Sons, 2004) and *Digital Fabrication* (Tongji University Press, 2017). He is the guest-editor of the AD *Digital Cities* issue (July/August 2009), AD *Space* (November/December 2014) and also (with Behnaz Farahi) of AD *3D-Printed Body Architecture* (November/December 2017).

Ryan Vincent Manning is a designer/owner of Quirkd33, a landscapes, film and architecture design collaborative. He has worked in many offices including Tom Wiscombe Architecture, Terraform ONE and BuroHappold. He has worked at Heron-Mazy since 2008. He has been a critic/lecturer at SCI-Arc, the University of Texas at Austin, Technical University of Berlin, University of Innsbruck, University of Southern California and the Texas A&M University.

Achim Menges is a registered architect and professor at the University of Stuttgart, where he is the founding director of the Institute for Computational Design and Construction (ICD). He has also been a Visiting Professor in Architecture at Harvard GSD. He graduated with honours from the AA where he subsequently taught as Studio Master of the Emergent Technologies and Design graduate programme, as a visiting professor and as Unit Master of Diploma Unit 4. He was also previously Professor for Form Generation and Materialisation at the Hochschule für Gestaltung Offenbach in Germany. He has published several books on design research, and authored numerous articles and scientific papers. His work has received many international awards, and is in several renowned museum collections, including the Centre Pompidou.

Philippe Morel is an architect and theorist, co-founder of EZCT Architecture & Design Research and also the large-scale 3D-printing corporation XtreeE. He is currently an associate professor at the École Nationale Supérieure d'Architecture Paris-Malaquais, where he is co-founder and head of the Digital Knowledge department. He was previously an invited Research Cluster and MArch Diploma Unit Master at the Bartlett School of Architecture, UCL. Prior to this he taught at the Berlage in the Netherlands (seminar and studio) and at the AA (HTS Seminar and AADRL Studio). His long-lasting interest in the elaboration of a theory of computational architecture is well expressed in his numerous essays, projects and lectures.

M Casey Rehm is a designer and algorithmic consultant based in Los Angeles, where he is the head of the multidisciplinary practice Kinch. He received a MSAAD from Columbia University in New York in 2009, and his BArch from Carnegie Mellon University in Pittsburgh, Pennsylvania, in 2005. He is currently a full-time faculty member at SCI-Arc where he teaches design studios and seminars in programming and robotics in design.

Jose Sanchez is an architect/programmer/game designer based in Los Angeles. He is the director of the Plethora Project, a research and learning project investing in the future of online open-source knowledge. He is also the creator of Block'hood, an award-winning city-building video game exploring notions of crowdsourced urbanism. He is currently an assistant professor at the University of Southern California. His Gamescapes research explores generative interfaces in the form of video games, speculating on modes of intelligence augmentation, combinatorics and open systems as design mediums.

Marrikka Trotter is a Los-Angeles-based architectural historian and theorist. She is co-editor of the contemporary architectural theory collection *Architecture is All Over* (Columbia Books on Architecture and the City, 2017), and her writing has appeared in publications such as *Harvard Design Magazine, Log* and *AA Files*. She teaches at SCI-Arc, where she heads the history and theory department.

Manja van de Worp is the director of YIP Structural Engineering London (formerly NOUS Engineering). She holds Master's degrees in architecture, structural engineering and in Emergent Technologies and Design. She is a structural engineer with 10 years' professional experience focusing on structural geometry and fabrication, while teaching at the RCA and AA in London, and the Institute for Advanced Architecture of Catalonia (IAAC) in Barcelona. Current projects involve an FRP shell and a modular steel roof structure. YIP also focuses on structural product design and research-based projects, looking at innovative ways to use timber and 3D printing of concrete in the housing industry.

Maria Yablonina is an artist, researcher and designer working in the field of robotic fabrication with a focus on custom, task-specific machines for making. She is currently research associate and doctoral candidate at the ICD, University of Stuttgart. Her research focus is in the area of robotic fabrication and computational design in architecture. She works with bespoke tools, robots and methods designed to perform fabrication tasks in on-site environments. Her work includes the development of hardware and software solutions as well as complementing material systems intended to extend the existing catalogue of methods towards addressing the inherent scale, cost and barrier of entry limitations of conventional robotic fabrication processes.

Lei Zheng graduated as an architectural and structural engineer from the University of Texas at Austin and obtained an MSc in Emergent Technologies and Design at the AA. Her research is focused on the capability of new digital technologies to reinvestigate the relationship between architecture and engineering in buildings, as well as in urban scenarios. She has extensive work experience on engineering and architecture projects in China, and has participated as a consulting engineer in a number of international competitions. She currently works at Zaha Hadid Architects. She has taught many international workshops and seminars including at the Umeå University in Sweden, China Academy of Fine Arts and AA Visiting School in Shanghai.

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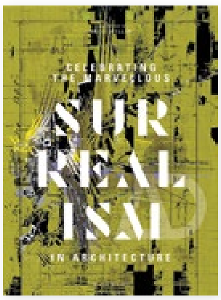

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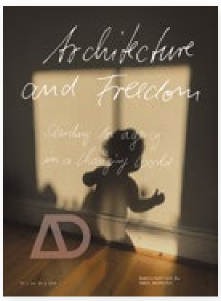

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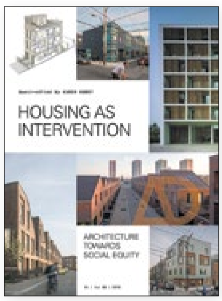

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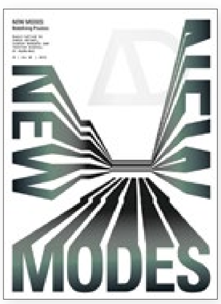

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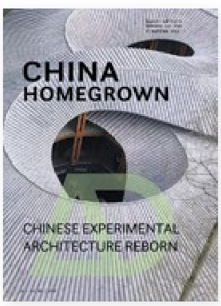

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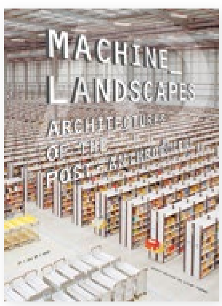

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