Making a Case for Modularity

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What we design and how it is made are intimately connected. The need to make modular components is a consequence of construction methodology and disposition in production and manufacturing. With the prevalence of digital modelling, designers and architects use modularity not only as design strategy but also to explore new aesthetics. This article examines design and architectural projects that prioritise geometrical and dimensional constraints at different scales, to highlight modular systems as essential areas of research. Here, Material Architecture Lab put together a series of speculative designs that investigate modular components and spatial configurations to accompany the written component. This article scans through a selection of discourses around modularity in architecture to contextualise, question and challenge the innovative potential of modular systems. By engaging with modular design of various types and materials, our aim is to articulate the value attached to a bottom-up design research, from digital modelling to fabrication processes.

#modularity

#digital fabrication

#making

#digital design

#part-to-whole

Introduction

The focus of this article is architectural design using many identical, or slightly varied components as modular assembly blocks. The key concepts here are modularity, combinatory design, and design techniques which prioritise aggregations of components. Within this extensive scope, it is helpful to further distinguish how architecture can deploy modularity, and to limit our investigation to its formal agency. The physical body of architecture is invariably made of parts. Standardisation of building elements, construction materials and manufacturing processes all contribute to how we make architecture, for better and for worse. A modular system refers to a series of components with interrelated dimensions and geometric relationships. As systems in design, they are often related to the cost of production and efficiency. With recent algorithmic and parametric design developments in the field of architecture, modular systems emerged as strategies for a new design aesthetic.

Together with this written component, we present a pictorial sequence of designs from our research laboratory at University College London (UCL), Material Architecture Lab (MAL).[1] This text sets out a design and architectural context for modular systems, while the images represent how our work interprets modularity through design and fabrication of prototypes and architectural fragments. Our design processes examine modularity through recursive structures that have the ability to grow, and spatial design through 3D fractal tiling algorithms such as Vicsek fractal also known as the "cross or box fractal" (Wolfram Mathworld).[2] These design experiments range from furniture, facades, pure formal and textural exercises carried out through geometric primitive arrangement processed in different degrees of abstraction, to modelling of grid densities or structural bundles using agent-based systems. Researchers then explored suitable fabrications of these design projects through established modes of production, such as slip casting and machine milling, in combination with digital tools including 3D printers and industrial robotics. This text describes the value that modularity's geometric and material constraints add to architectural fabrication practice. One can read a modular system in two ways: first, as in design and making with bricks, the repeated building blocks or the basic *units* are clearly identifiable within the final outcome's fabric. Secondly, the modular components are malleable *guides* to facilitate connectivity and continuity. For example, the Tatami mat, with height to width proportions of two to one, and dimensions around six feet by three feet in traditional residential Japanese architecture, is a basic unit used to determine other dimensions of the building, but not a full determination of the spatial, constructed outcome. Before continuing into different approaches of how architectural modules operate, it is important to highlight the core concern of working modularly: design through the smallest constituent and basic unit with more than one possible result achievable in the whole. Why is modular design in architecture relevant today? With the introduction of computational tools and digital fabrication technologies, the intrinsic quality, capability, and adaptability of modules in architectural design have undergone major shifts. Where is the added value in modularity via computation design? What is a digital building block in architecture?

Modular Rigour for Combinatory Freedom: Precedents Using the Module at Dwelling Unit Package Scale

Modular architecture, at the packaged dwelling scale, commonly builds with self-same elements. Designers regiment these elements to proportionally related dimensions. This geometric rigour at individual scale allows adaptability in their combination through simple numerical facts:

if module dimensions are multiples of each other, modules can pack in different ways efficiently, or stagger away from each other in ruled systems. A limited number of building blocks performs differently, depending on the arrangements of the blocks to suit different programmatic requirements. They adapt to site scenarios. Elements can be added to or taken away, and there is no one fixed outcome for aggregation. Components as large as prefabricated habitable units, as in Kisho Kurokawa's *Nakagin Capsule Tower*, can perform similarly to those as small as Danish LEGO bricks. Factory workers prefabricated the individual units of Kurokawa's tower with light steel welded trusses, covered with steel sheeting. All of the units were then mounted onto the reinforced concrete cores within a few weeks (Minami, et al 2015).

Moshe Safdie designed *Habitat '67* for the Montreal World's Fair 1967 in a similar way. Safdie's 1960 final year thesis at McGill university titled 'A Case for City Living' included all the concepts that would become Habitat '67 at the World Exposition in Montréal. The thesis explores three possible construction systems: (1) A structural frame with prefabricated modular units, (2) Modules assembled in a load-bearing arrangement, (3) Load-bearing modules arranged in a crisscross pattern. Safdie did not promote the project's modularity, but said in an interview that he "bought all the LEGO in Montreal" to study the different variations of modules within the overall design. He also directly compared the proportion of the LEGO bricks and his housing units, in particular the two-to-one ratio proportions of the brick.[3] The overall aesthetic of *Habitat '67* depends upon the arrangement of modular parts to both scale, in the construction economy sense of the word, and achieve its compositional goals. Neither Kurokawa nor Safdie aggregated the modular units of these projects to form a rectilinear prism. As both are large-scale dwelling projects, the underlying need for economies in design and construction suggests the definition of a standardised dwelling module. Subsequent freeform arrangement allows for gardens and other public spaces to take shape, in the case of *Habitat '67*, or a more freeform massing for *Nakagin Capsule Tower*. Diversity in the relationship between interior and exterior spaces, and informal massing as humanistic goals, play against economic imperatives in construction, with the module as mediator. The rigorous part enables the flexible whole. Structurally speaking, parallels between these architectural projects and LEGO break down: *Nakagin Capsule Tower* and *Habitat '67* both depend on rigid, regular substructures to support their free spatial arrangements. But at the building scale, the module lends great freedom to design, planning, and strategic spatial possibilities.

Digital and Nurbz Surface Resolution: Digital Modules in Tectonic Coherence

In his 2008 article "Beautiful Monster," Greg Lynn referred to digital designs in the 1990s, as a "lot of simply ugly, misshapen work" (Lynn 2008, 176).[4] At the time, digital modelling involving non-standard geometry and curvilinear shapes derived from mathematical functions seeking a more expressive form. For Lynn, these formal experiments fell short of resolving what digital technology had to offer. Digitally designed architecture simply allowed unfamiliar forms, while the underlying construction and fabrication realities remained unchanged. In the form-driven digital designs of the 1990s, the relationship between digitally-rational NURBZ surfaces and any premise of rational construction is fraught. Beneath the digitally rendered geometry of Frank Gehry's *Walt Disney Concert Hall*, for example, is a structurally-and-materially tortured network of vierendeel trusses and bending structures (Bechtold 2010, 169).[5] The scale necessities of industrial fabrication depend upon material standardisation in scale and geometry: *a certain range of lines and planes at a certain fabrication-justified range of sizes*. Lynn recognised, writing his article, that technology would change this construction industry condition. Technological design, shifting towards the realisation of digital forms and digital fabrication, opened up areas of design previously inaccessible to architects. Ten years after *Beautiful Monster*, Luciana Parisi reflected on the intelligence of digital design as, "concerned with a generic function of computation, involving a new synthesis of calculation and statistics, quantification and prediction, measure and hypothesis" (Luciana 2018, 228).[6] With these parameters, "structural behaviour of increasingly smaller parts has become central" (2018, 228). Parisi pointed out how computational design can operate at a granular scale, informing the composition of materiality, beyond volumetric shaping from a standard stockpile. Parisi's second point, on the granularity possible through digital fabrication, re-emerges through problematising and discretising today. In terms of fabrication *and* geometry, a digital module can *perfectly* subdivide a complex building surface into buildable elemental parts. Conceiving of these bespoke parts as a network module reduces the formidable expense of accomplishing this surface rationalisation. Geometric rigours imposed on a module *predispose* that module to sympathetically develop complex surfaces. As a result, modularity makes reductive digital surface simplification and construction complexity more manageable.

Another opportunity for design through modular components to show its usefulness is in accomplishing trabeation or span within one set of materials and tectonics. A standard brick is a simple and efficient module for assembling surfaces. The three key dimensions to each brick allow infinite permutations for walls with one unit. However, the imaginative leap from surface to *span* in Roman brick architecture, employing the arch and vault, makes this work unique as a total tectonic system. The silent, invisible partner to this imaginative transition is *falsework* or *centring*,[7] required for the erection of self-stable ceilings and full enclosures. If one were to rethink the shape of the humble brick to remove the necessity of this partnership, what would be the result? What permutations within surface and span would form new categories? Alisa Andresek and Jose Sanchez's Bloom Studio modular unit project in 2012 demonstrated how an algorithm could "quickly generate large aggregations and evaluate the design output implied in the angles of [a modular] unit," (Sanchez and Andresek 2014, 98).[8] An algorithm's ability to compose and evaluate the structural health of a modular arrangement becomes especially useful, as for modules more eccentric than a brick, an algorithm can perform evaluations faster than a human. More critically, even if a brick were fed into a modular assembly algorithm, without the presence of centring, a brick vault would almost certainly not be the optimised outcome. Transitions between vertical bearing and horizontal spanning surfaces evaluated through parametric designs are precisely why revisiting modular assemblies in architecture is so promising, and the redesign of something as elemental as the brick bears investigation.

From Packing Modules to Voxel Tectonics

Unless one is carving a building out of a solid block of material or casting a monolithic structure, most buildings are assembled from smaller components. With the advances of digital tools, engagement with design through to manufacturing processes has become ever more seamless. It is conceivable to make architecture with elements unique to that project alone. The digital model of a part or component, without thickness, without scale and materiality has become increasingly versatile. Designers and fabricators convert traditional patterns in the manufacturing industry into digital models. This means that fabricators can read the digital model as a positive form for 3D printing or a negative form for mould making, with no standardised, manifested precedent. As the elemental units are digital, there are broader implications for relationships between part and whole through *packing*. The smallest unit in digital 3D space is a Voxel, as opposed to a Pixel in 2D space. Voxels can aggregate in space without foreknowledge of the overall target geometry. Parameters govern the aggregation of Voxels with immediate adjacency. This allows for the computing of large amounts of data and infinite variations of outcome. These outcomes can go through health checks and feed back to the system for further refinements. The promise of such a workflow results in lean solutions that the human hand and mind cannot come up with through perseverance alone. As a result, relatively simple geometric packing mandates for modules allow increasingly complex form capabilities divorced from historical construction logic. The present research explores the potency of this optimisation capability through computation with simple and relatively minimal input constraints.

Developments in digital modelling and scanning software have brought into existence forms and textures we can only make sense of by peering into the natural world or a microscope. Today their existence in the digital realm as point clouds, meshes, NURBZ surfaces or many other formats means that they can practically exist physically at any time or location, as the facsimile of all matters digital can be 3D printed. The feasibility of this premise is just a question of materiality, scale, resolution and time. 3D printing is a powerful tool, but there are also disadvantages compared to more established processes such as injection moulding or dye casting. Speed of production and cost reduction make 3D printing almost impractical at a larger scale, in terms of quantity and size. More importantly, the manufacturing industry can offer architects and makers a much closer working relationship today. In a sense, designers can customise their design and explore non-standard elements in construction with greater ease. Mass customisation occupies an increasingly productive area of research and its prospects are on the near horizon. But for the time being, architects interested in exploring this way of working need to content themselves with a manufacturing industry that is largely geared toward mass production.

Designers can now digitally model things they cannot draw, and 3D print what they cannot make by hand. When clients and patrons are reluctant to accept the complexity that digital imagination affords, modularity helps designers realise more formally challenging projects by discretising larger surfaces or areas into smaller components. Scale negotiation becomes a matter of practice, bringing experiments into the designers' shop to test aesthetics too novel for outside participation. Far from a compromise, designers and architects recognise this as a design strategy to fabricate large numbers of unique components. Mario Carpo, in a conversation with Matthias Kohler during the 2014 *Fabricate* conference touched upon the limitation of scale in digital fabrication: "the theory we have in the digital domain is about making surfaces, or about making technical objects" (Gramazio et all 2014, 12).[9] The module within this scale jumps between surface and technical object requiring attention to production methods, logistics, assembly processes and site conditions that designers cannot delegate to an algorithm for predetermination. As modular relationships allow flexibility while these considerations unfold, they allow designers and fabricators to negotiate improvisation and decisions made on the fly.

Proximate and Remote Readings: Modular Texture and Encoding

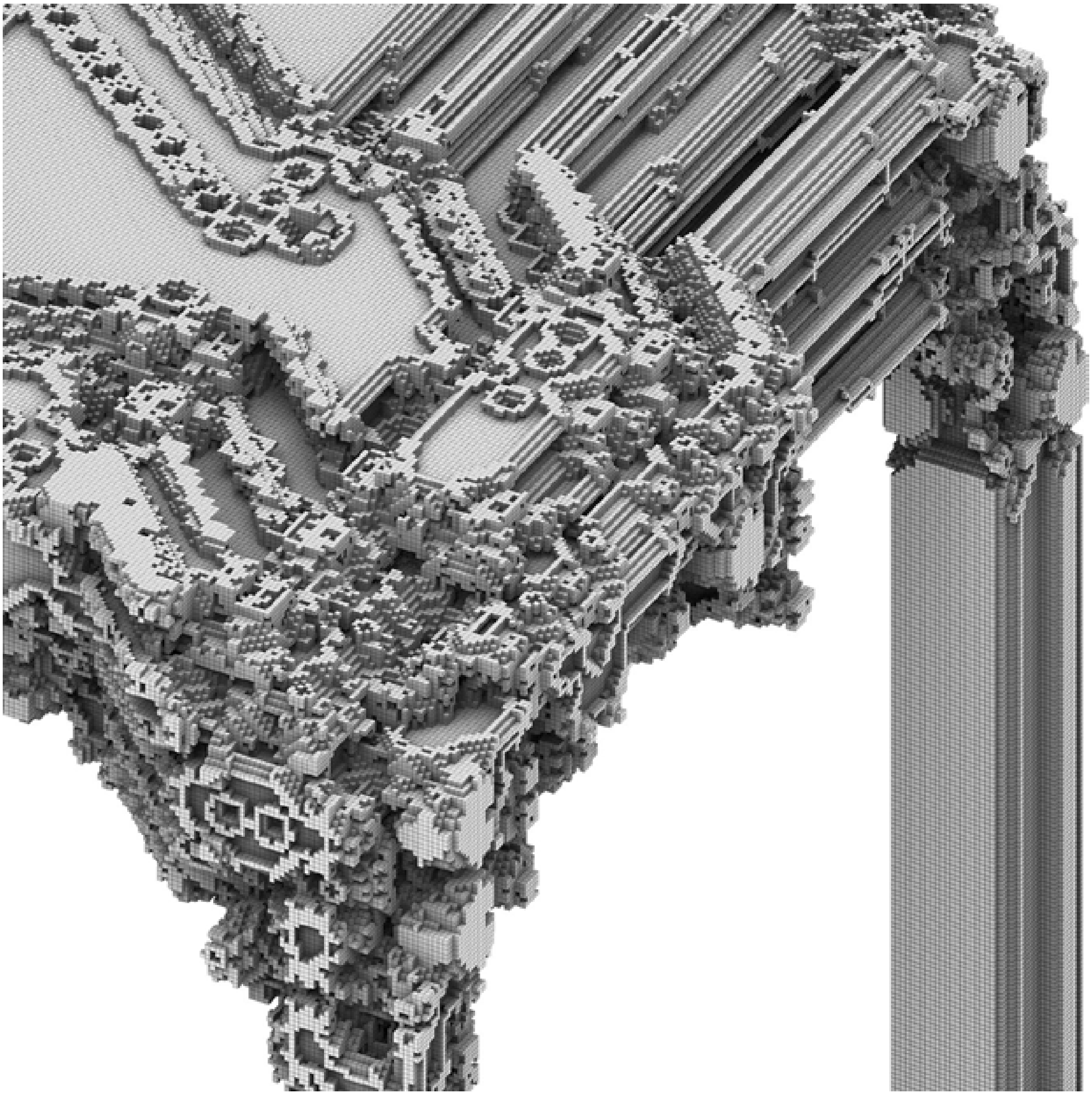
Design accomplished through self-same modules has a unique aesthetic quality as its constituent parts tangibly read in its overall fabric. Patterns and rhythm can be read locally, but when experienced from further away, additional design motives become apparent. Because of modular dimensions, the area without a component can read as negative space of the modular units. This can result in a distinct sense of depth on a relatively flat surface. Frank Lloyd Wright's ornamental designs, in particular during the 1920s, used mass-produced concrete blocks, also known as "textile blocks"[10] for a revolutionary series of houses in California. The blocks were arranged in grid-like mosaic tiles, and could be unlike bricks because they were reinforced at the joints. Wright's Millard house has one ornamental block repeated throughout to form a larger and seemingly continuous ornamental pattern. The variations of levels and perforations in each modular block when tessellated together acquired a vivid sense of space. They are further animated by sunlight, and juxtaposed against sections of blank blocks. Wright speaks of the pattern-like foliage and trees, spatial extrapolations of repeated patterns similar to the results of his modular textile blocks (Cilento 2010). Beyond ornamentation for these private houses, Wright also developed a system of building houses using concrete modular units. Wright called these houses, designed with inexpensive blocks and detailed for unskilled labour, *Usonian Automatic Houses*.[11] The intention was to lower the cost of building but be generous in spatial intricacy. The reality of these houses, built predominantly in the 1950s, did not live up to Wright's lofty ideals (Lind 1994). Nevertheless, his efforts in advancing modular design in houses are still relevant and alive.

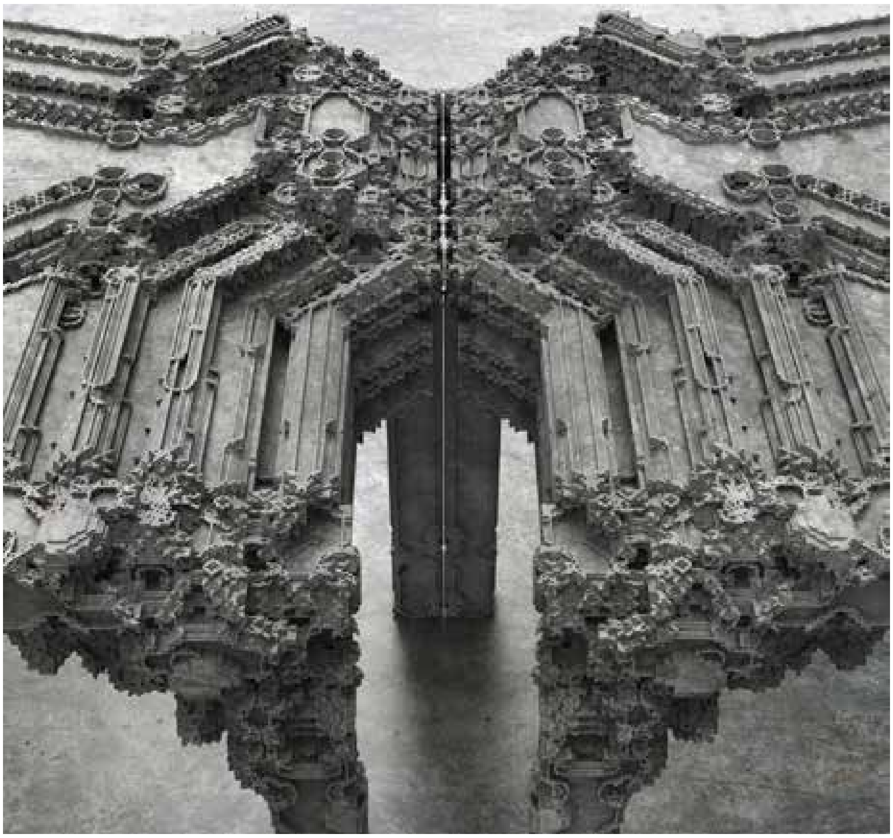
Modular designs are subservient to their parent geometry. The design of a modular system is a geometric exercise. A cube is a versatile module: it is the only platonic solid that is space filling, and has translational and rotational symmetry. If we subdivide space into a grid of cubic volumes, this virtual grid defines where all modules can occupy, proliferate, aggregate and arrange themselves into design outcomes. There are seven polyhedrons that can fill three-dimensional spaces with the self-same polyhedron as the only module. Apart from the cube, the tetrahedron is the other platonic solid commonly used in architecture. Different polyhedrons can also work together to fill space, in periodic or a-periodic fashions. Visualisation of vertices and edges of space-filling solids is fundamental to the design of working modular units and components. In between these rigid geometric constraints, there is ample room for design imagination. Freedom exists within the geometric framework: geometric arrangements are not freeform. A freeform surface can be rationalised into discrete components, but it is strategically the opposite of starting with a small number of modules in order to build up a design.

Modularisation and Digital Fidelity

Standardising construction components is an age-old aspiration. *Yingzao Fashi* (State Building Standards)[12] is a twelfth-century Chinese technical manual on buildings. It is a collection of illustrations outlining construction principles with structural patterns and building elements. The book gives standard units of measurement. Builders can adapt construction following this manual. The projects presented here engage with modularity in design, testing various parameters at different scales and investigating different aesthetic languages. Is modular design a necessary consequence of making? If we think of the production of components in architecture as more in line with our manufacturing industries, the fabric of architecture can be designed differently. With advancement of digital fabrication processes, mass productions combined with our increasing ability to customise repetition, may not be the dominant feature of modular systems. Aesthetic combining of form and efficiency of production can become evident in buildings and their surfaces. The designs presented here by MAL challenge the elements in a modular system and how they are assembled. It is conceivable that manufacturing processes common on the factory floor will migrate to construction sites of a building. *In-situ* robotics and digitally-enhanced manual assembly techniques, using holoLens[13] for example, will speed up the assembly process for complex designs. We can anticipate and challenge how something is made by first of all thinking of the design and modelling processes differently. Modular design is suitable for experimentation with language of surface texture and overall spatial configuration.

Rule-based design is another way to examine modularity. This is evident in Islamic art and architecture, for instance the decorative system *Muqarnas* structure. As a system, this standard set of components and guidelines creates designs where the rules are visibly manifested as textures with layers and depths. The intelligence of the geometric composition and arrangements of Muqarnas with a limited number of unique components is not coincidental but rooted in mathematics (Garafolo 2010). At MAL, our design research methodologies draw inspiration from arabesque art to compute intricate and decorative elements using voxel-based systems. The images presented make up a collection of MAL's research projects in modular design. We prioritise a hybrid of digital design techniques, favouring customised modular systems and designing processes, as well as products using recursive algorithms, to add noise to repetitive design language. Our design output is often the result of how something can be fabricated with digitally-controlled machinery as well as semi-automated processes. The nature of digital experimentations is coupled with cyclical prototyping, for iterative refinements of products or processes. In order to explore processes of making, modularity is and has become a characteristic of material design. Strategically component-based fabrication techniques inform and regulate the scales in which designs can be made physical.





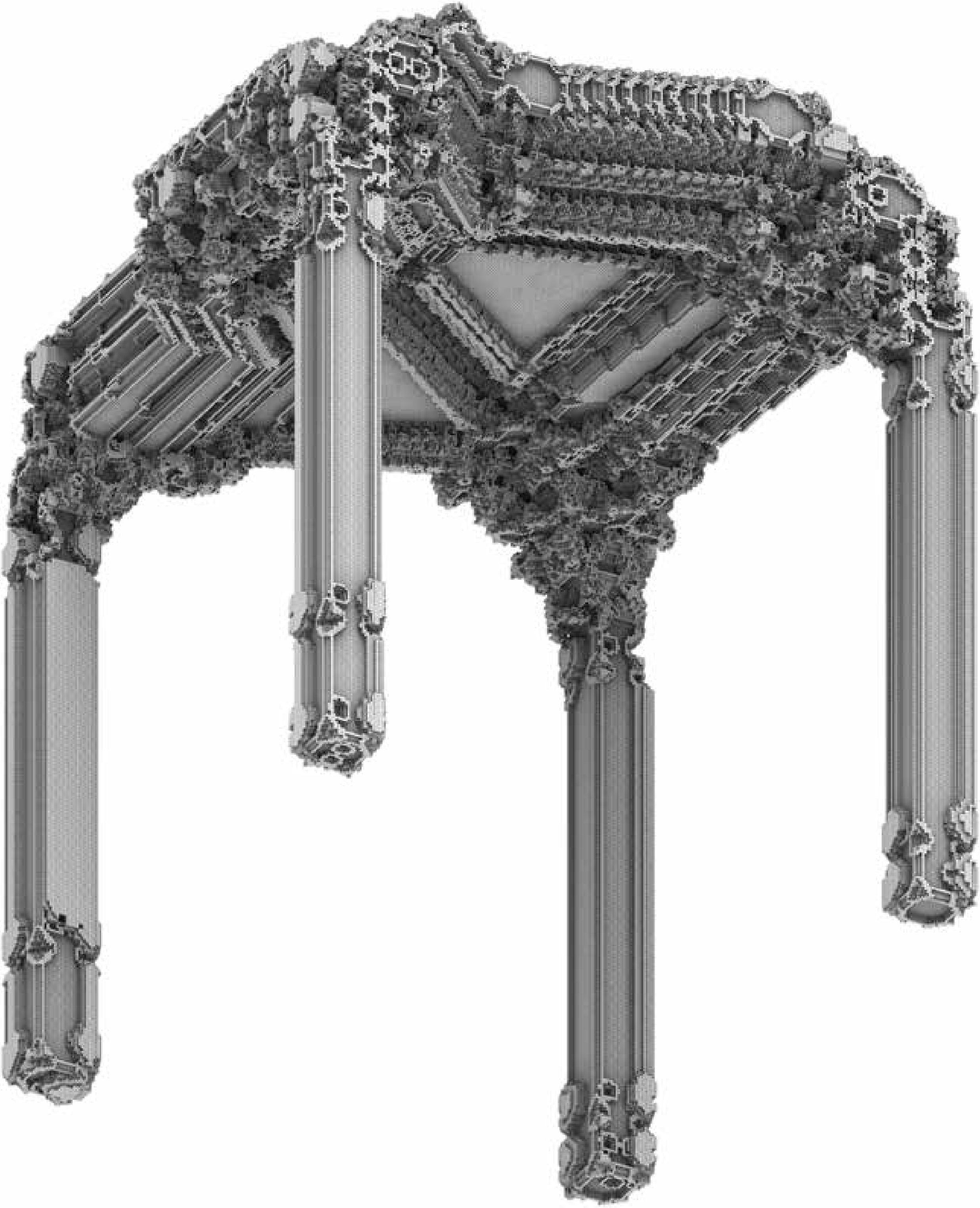
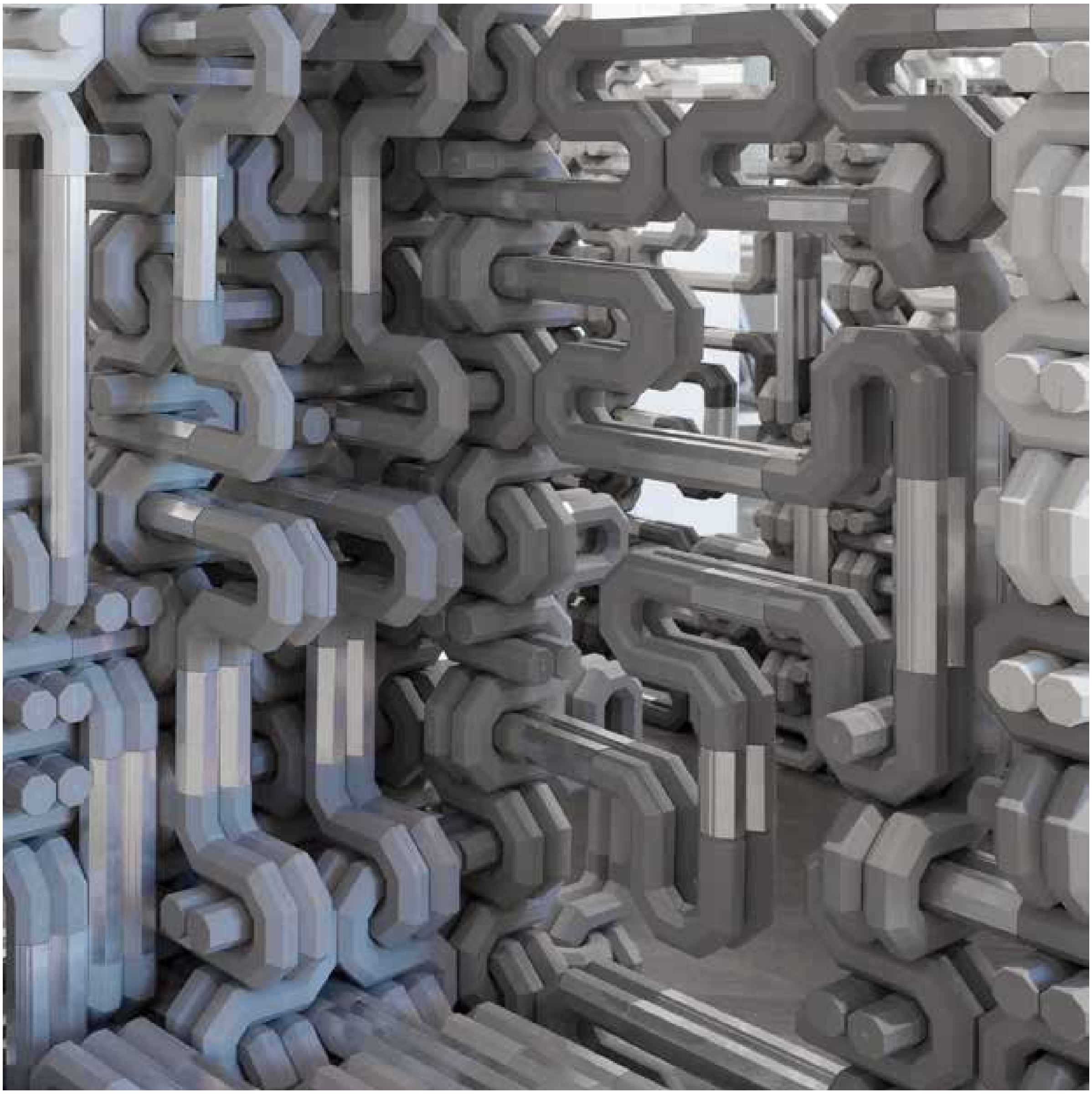
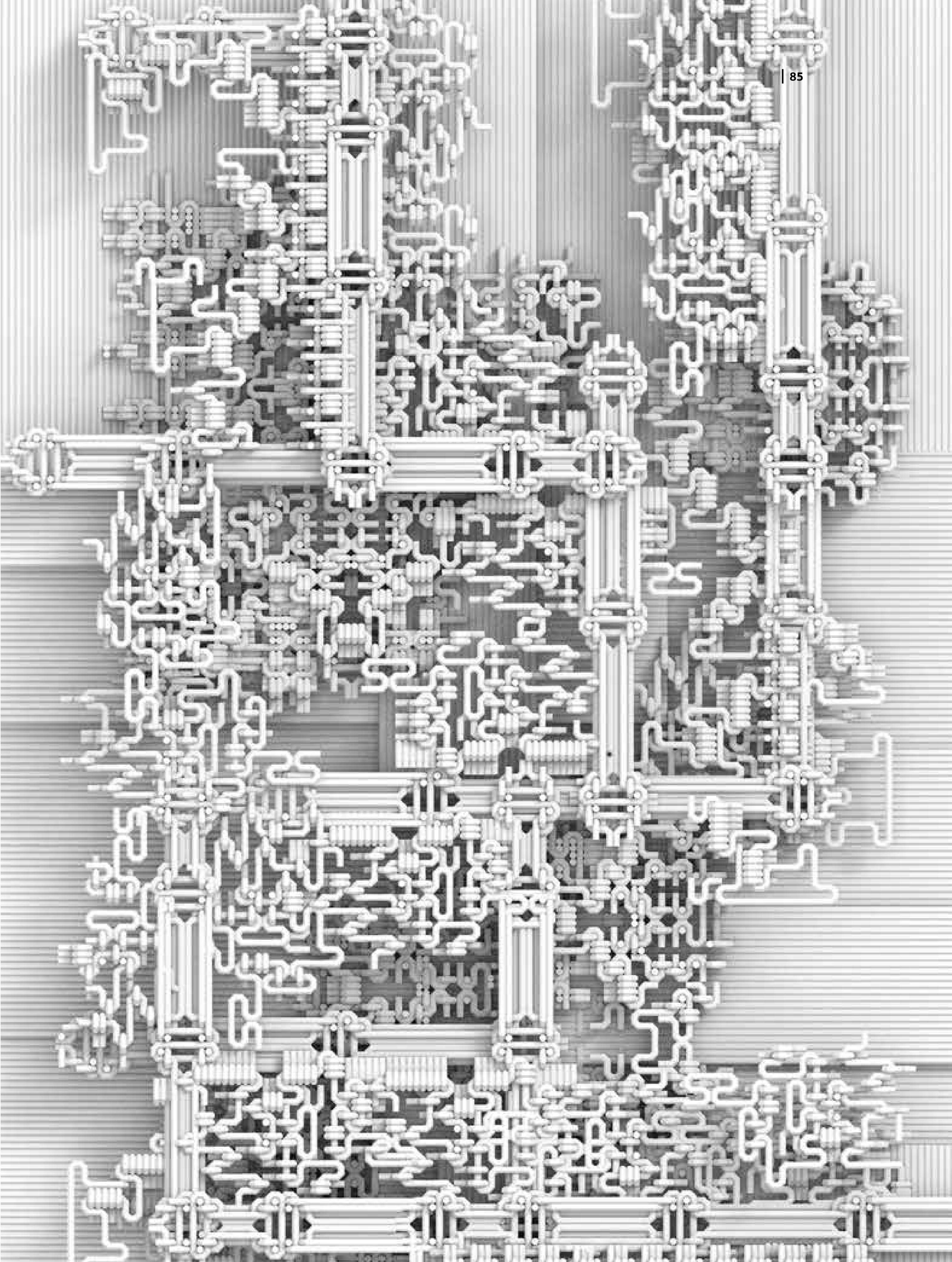


Figure 1–4 (page 81–83): Little Bit Chair (2016),
3D printed Cement. Design: Daniel Widrig Studio.
Source: *author.*





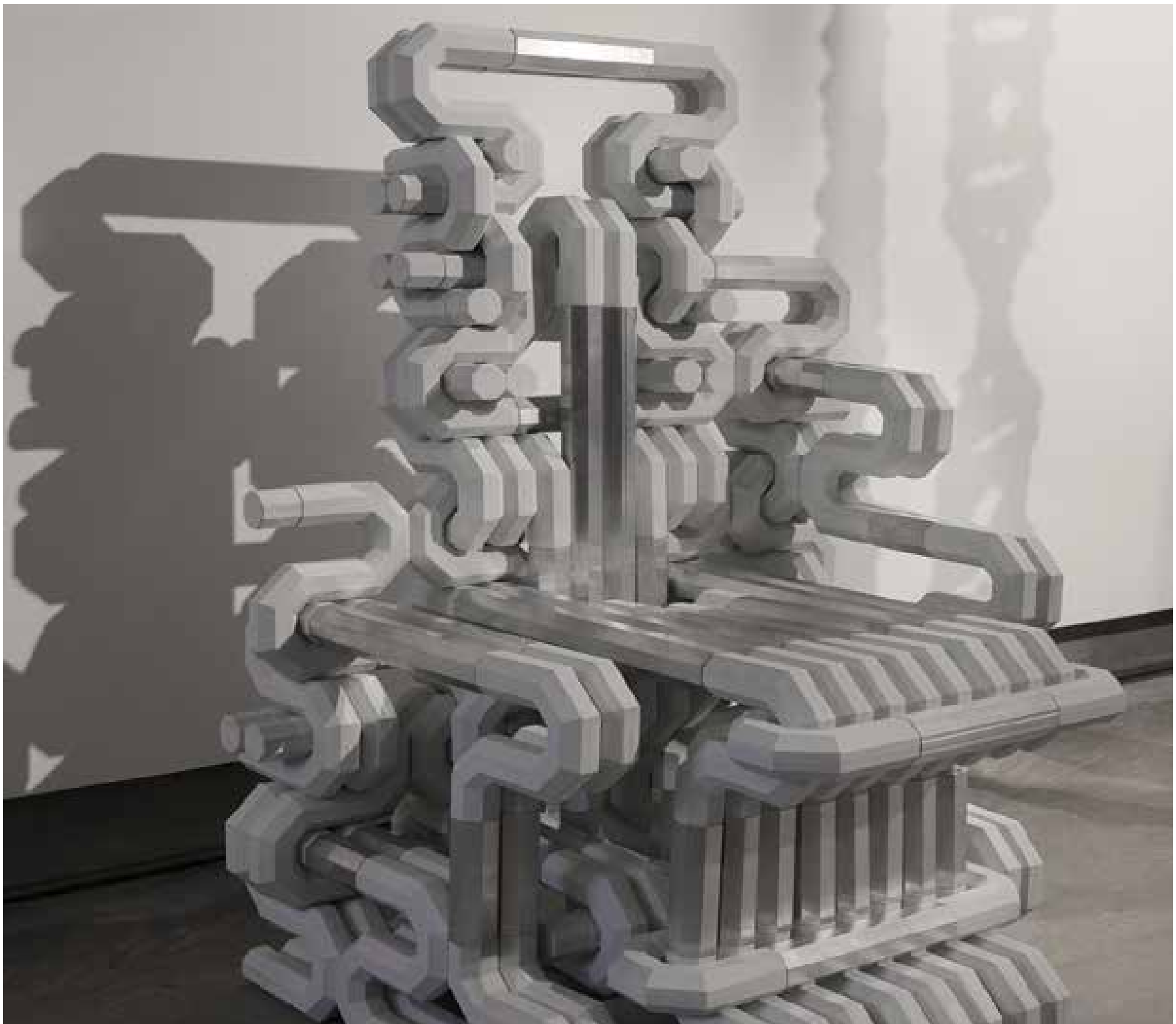
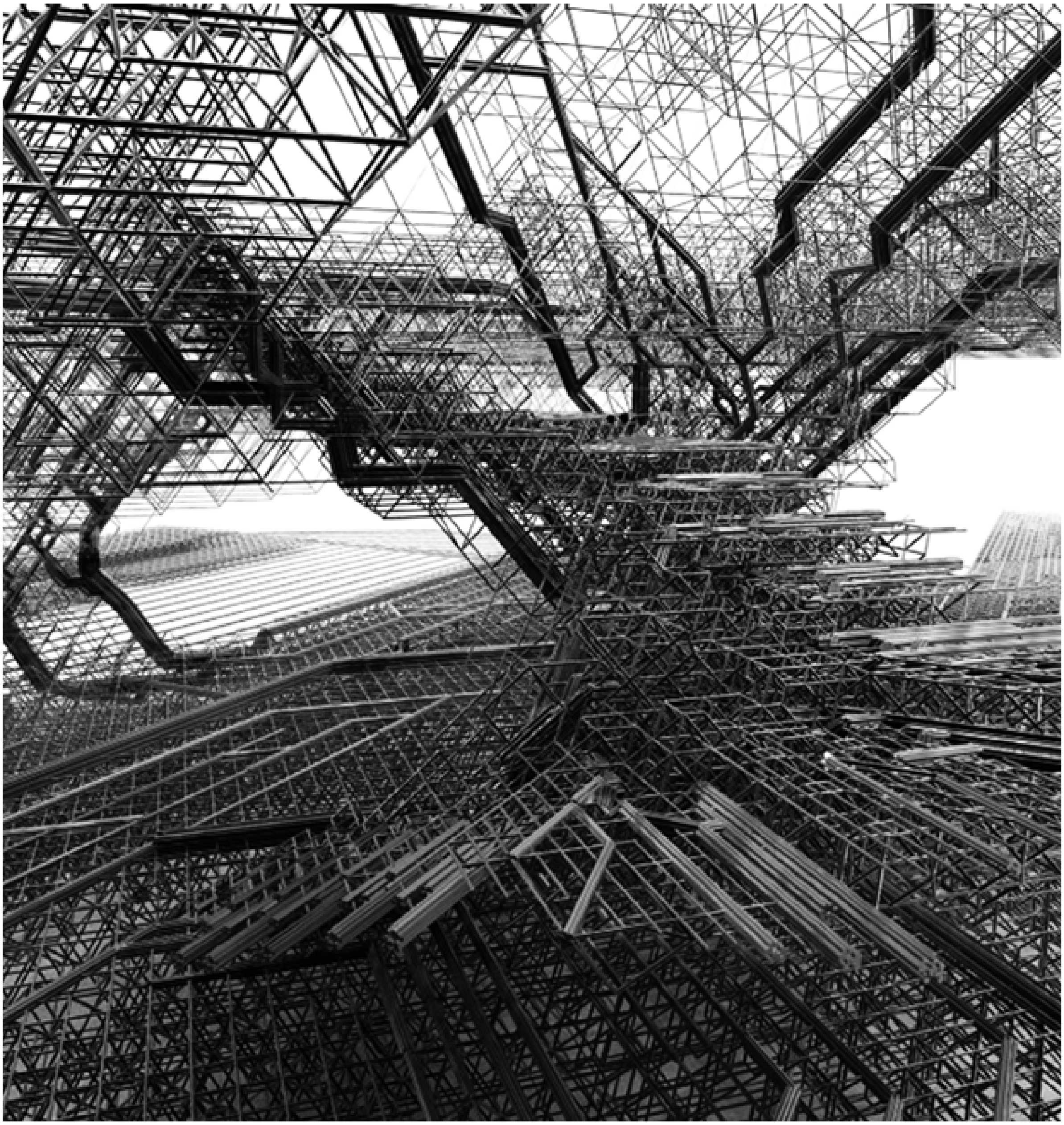


Figure 5–8 (page 84–87): SnP (2018). Recycled Nylon.
Design: *Daniel Widrig, Guan Lee, Igor Pantic.* Team*:*
Aikaterini Konstantinidou, Laura Lammar, Tatiana Teixeira.
Source: author.

Figure 9 (left): Structural Slip (2018). Ceramic. Design: *Daniel Widrig, Guan Lee, Adam Holloway*. Team*: Vittoria Fusco, Banni Liang, Dan Liang, Mingyu Wei. Source: author.*



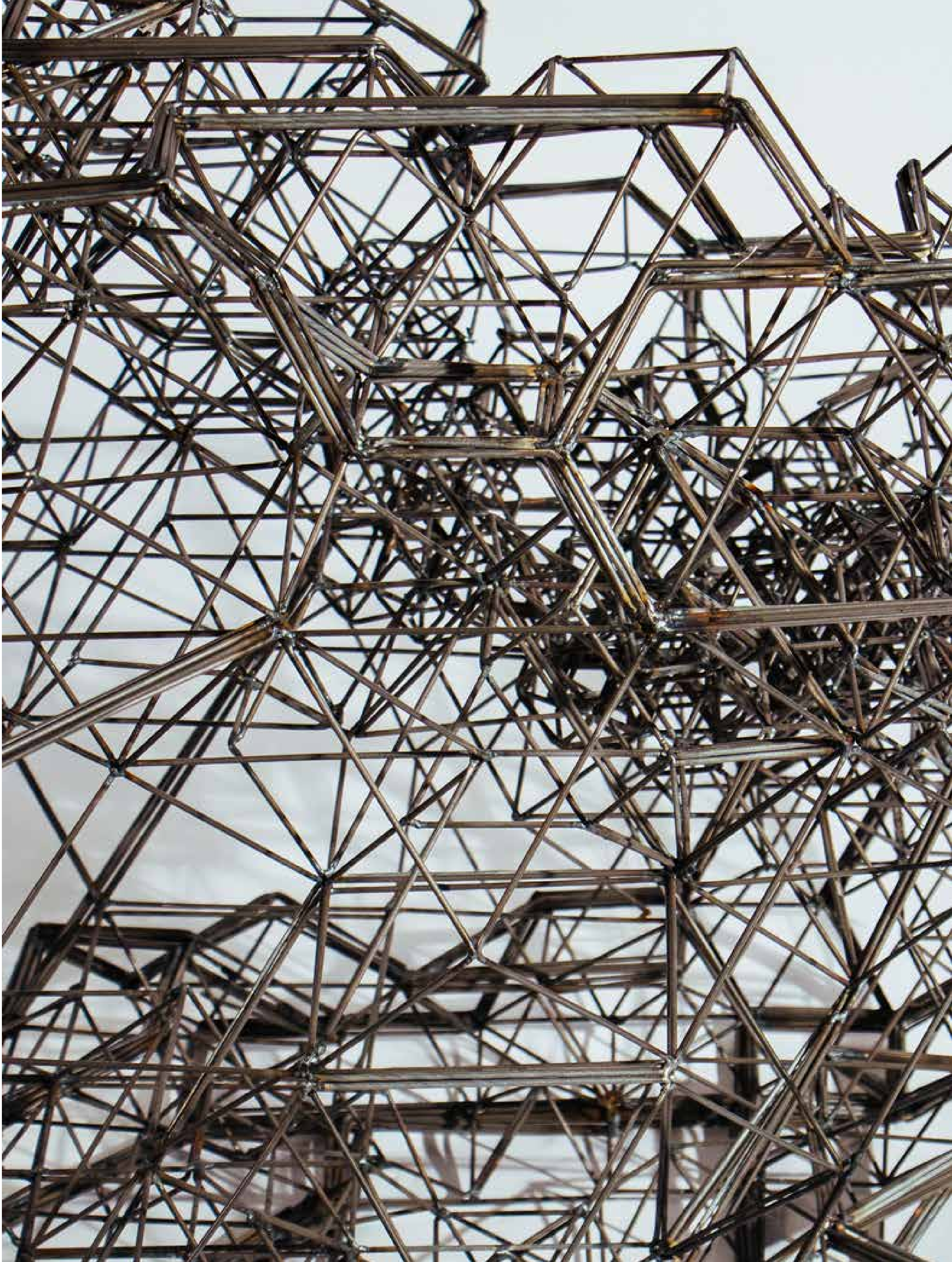
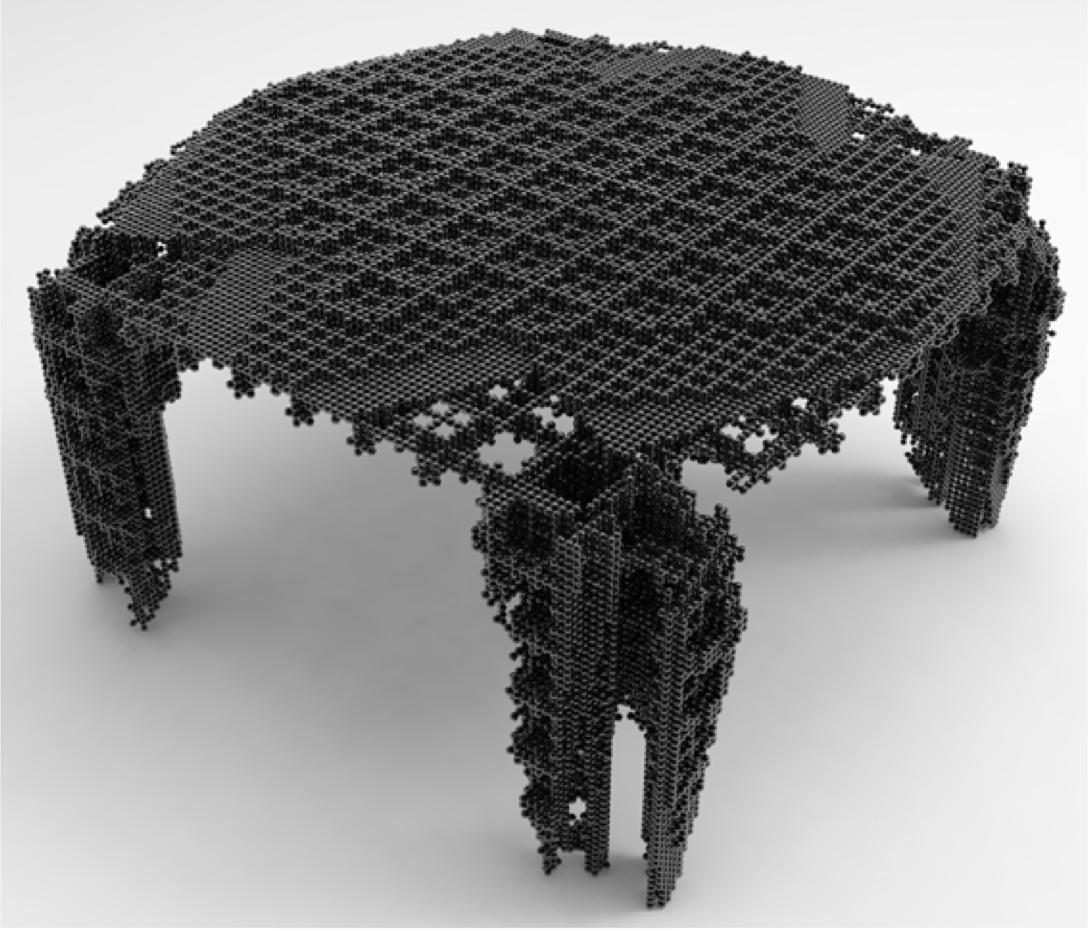


Figure 10–13 (page 89–92): Spacestream (2015). Steel. Design: *Daniel Widrig, Soomeen Hahm and Stefan Bassing.* Team*: Zhen Shan, Mengying Li, Wenjian Yang and Shaoru Wang. Source: author.*



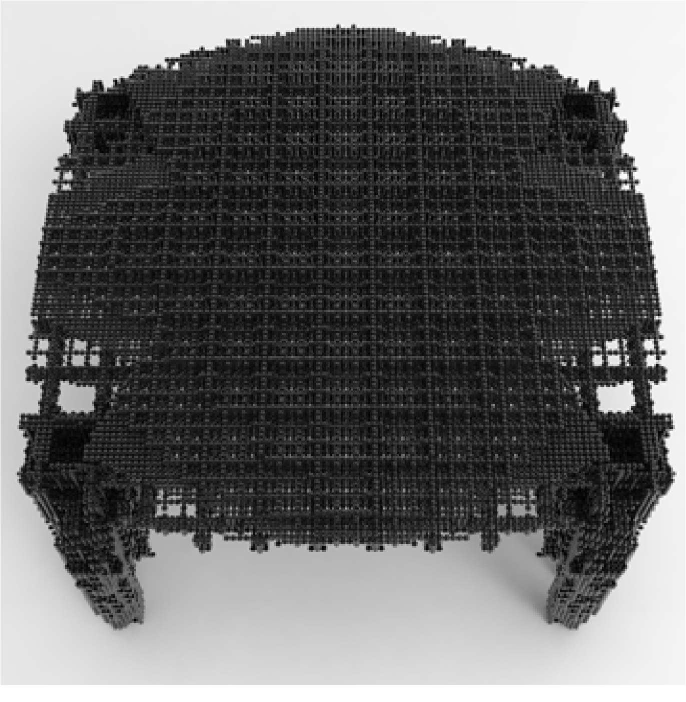


Figure 14 – 15 (top to bottom, page 93): Binary Table (2016). Stainless steel. 1.25m x 1.25m x 0.45m. Design: *Daniel Widrig Studio. Source: author.*

Figure 16 –20 (this page and opposite): Brillock (2016). 3D printed PLA plastic, Wood .1.25m x 1.25m x 0.45m. Design: *Daniel Widrig, Soomeen Hahm, Stefan Bassing, Igor Pantic.* Team: *Mayank Khemka, Huan Pu, Jianfeng Yin, Xiangyu Ren. Source: author.*

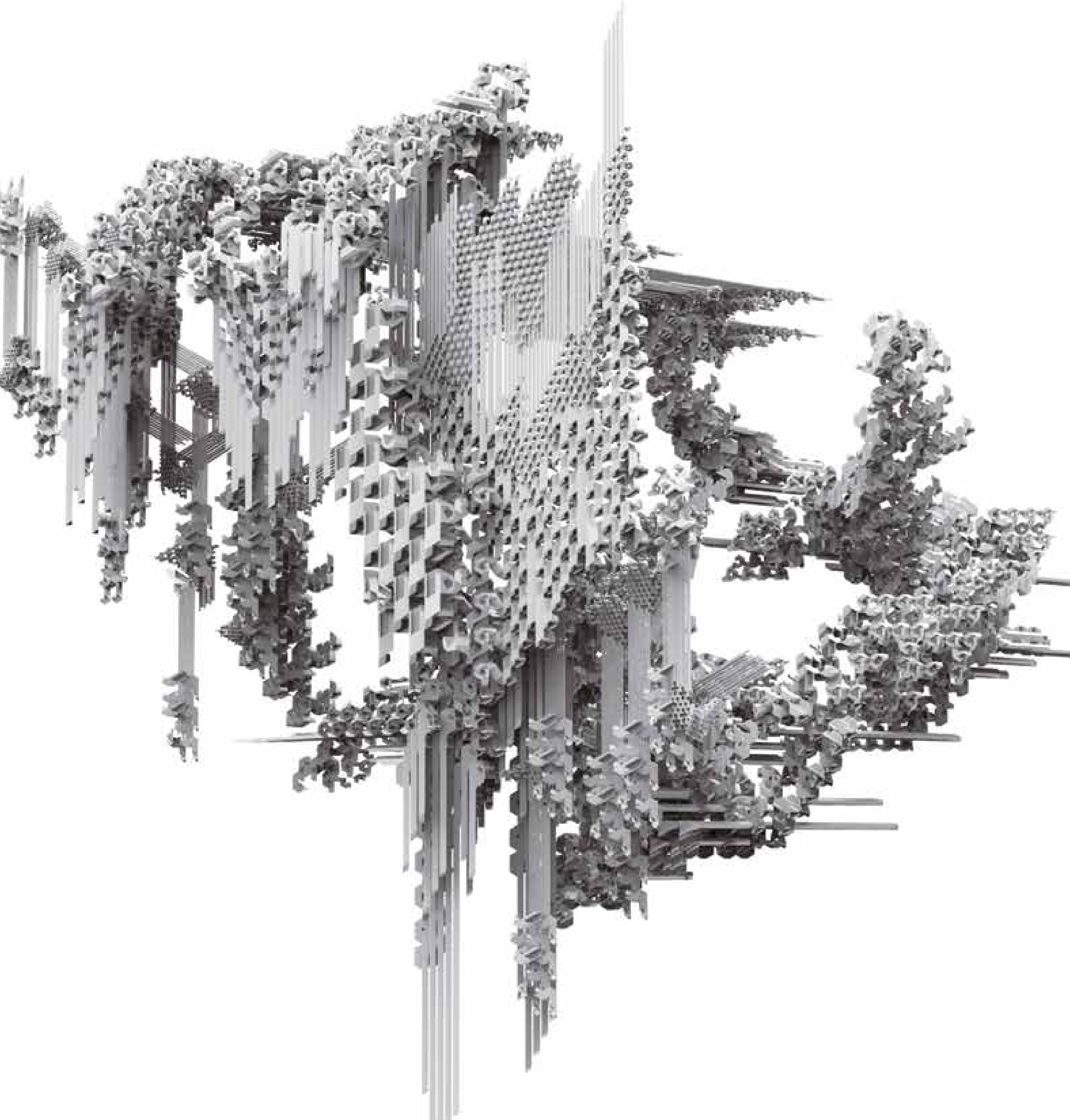


Figure 21: Increase (2015). Paper, Resin.Design: *Daniel Widrig, Soomeen Hahm, Stefan Bassing.* Team: *Chao Zheng, Chang Chen Wei, Chao-Fu Yeh, Jinlian Wang. Source: author.*

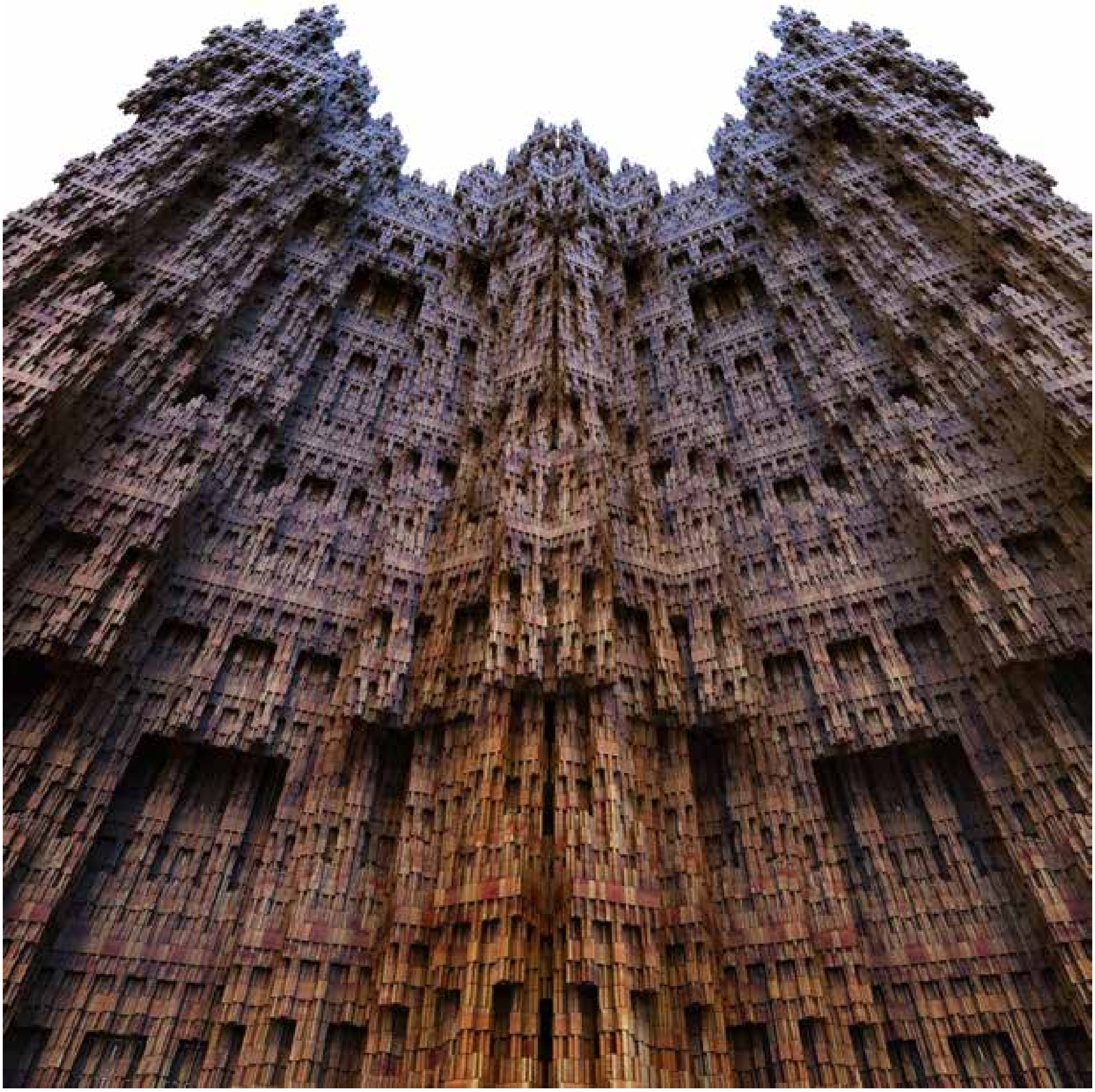


Figure 22: 5 minute architecture (2016). Digital Image.
Design: *Daniel Widrig Studio. Source: author.*

Figure 23 & 24 (top to bottom, opposite): Space-filler (2007). ABS Plastic. Design: *Daniel Widrig Studio. Source: author.*

Figure 25: Victoria & Albert (2018). Stainless steel. Design: *Daniel Widrig Studio. Source: author.*

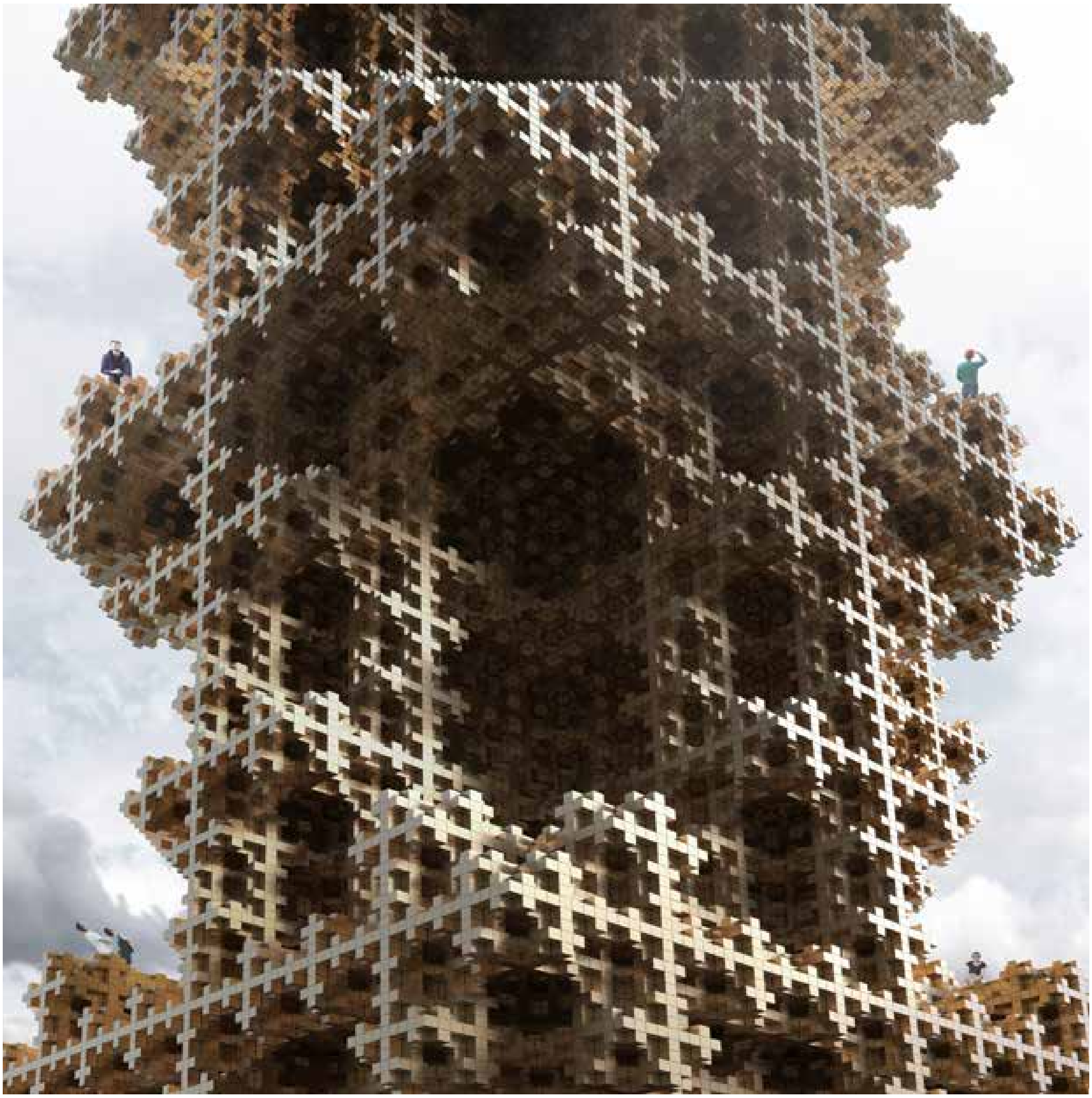


Figure 31 (opposite page): C. Tiles (2008). Ceramic. Design: *Daniel Widrig Studio. Source: author.*

Figure 32: The Wall (2017). Digital Image. Design: *Daniel Widrig Studio. Source: author.*

Notes

1. MAL is a research-based design, art and architecture practice based in University College London. MAL's design methodologies focus on materiality, craftsmanship, digital technology and sustainability. Research projects investigate modes of production through design, either at our lab, Grymsdyke Farm, or in collaboration with manufacturers at different scales.

2. A fractal is an object or quantity that displays self-similarity at all scales. The Vicsek fractal is three-dimensional, allowing our design to explore spatial configurations as well as patterns.

3. Safdie, Moshe on his iconic *Habitat '67*. In an interview with *Dezeen*, Safdie described the context for the design of *Habitat '67* and mused about how he had bought all the LEGO blocks in Montreal in order to model the scheme, Published on 19 Dec 2014, https://www.youtube.com/user/dezeenmagazine/search?query=habitat+7

4. Lynn used the words "ugly" and "misshapen" to refer to the nascent stages in translation between digital and realised digital architectures. The semi-naïve efforts of 1990s architects led to grotesque translations between ambitious form and construction industries not yet able to accommodate it.

5. Martin Bechtold's article "On Shells and Blobs" describes non-structural shells as one symptom of the transitional period of digitally fabricated architecture: digitally delineated forms rely on conventional construction techniques and commensurate, inefficient bending-stress structural design. Bechtold predicts design of membrane-stress bearing structural surfaces as a meaningful progression in digital architecture.

6. In Luciana Parisi's article "The Intelligence of Computational Design," she made a compelling summary of how discourses on digital design have shifted with time.

7. Centring is the temporary support framework typically made of timber to allow for the construction of masonry of concrete structure that is not stable until the lime-based cement or mortar sets. The process of removing this formwork is termed decentring.

8. Sanchez and Andresek described the operation of their output evaluation process less clearly than the premise. The digital analysis and feedback tools they described will likely become more commonplace for architects and engineers in the near future.

9. Mario Carpo is critical of how digital designs constrained by fabrication processes limit architects to making small objects with non-architectural consequences. Modular design system is a way we can provide a counterpoint to this concern.

10. The word textile is a reference to how the blocks would not only stack together but also interlock; as a surface, its construction logic is more like fabric than a typical brick wall.

11. Frank Lloyd Wright's Usonian Automatic Houses were not commercially significant as a system. However, his ambition to make spatially and expressively interesting designs affordable remains a relevant architectural concern.

12. *Yingzao Fashi*, as a historical, imperially-motivated, and non-Western example of construction standardisation demonstrates the reach and modularity's universality as design tool.

13. Here referring to the Microsoft augmented or "mixed" reality technology shown here: https://www.microsoft.com/en-IE/hololens

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Bio

Dr. **Guan Lee** is an Architecture lecturer and co-director of Material Architecture Lab at the Bartlett School of Architecture, UCL. He is also tutor in Architecture at the Royal College of Art, where he teaches a postgraduate studio, ADS6. His practice, Grymsdyke Farm, is set in the Chilterns in Buckinghamshire, approximately 35 miles northwest of London. The farmhouse remains residential but the other buildings are converted into workshops and studios. Grymsdyke Farm's motivating concept is to establish and explore the value of living/working arrangements that involve intimate engagement with materials and processes of making. Lee's practice engages in a wide range of design fabrication, digital and analogue. Guan Lee has a BSc. in Architecture from McGill University, Montreal, Canada (1997), an Architectural Association (AA) Diploma (1999) and an MSc. Landscape Urbanism (2003), also from the AA, and completed his PhD by Design (2013) at the Bartlett, UCL.

Daniel Widrig is Architecture lecturer and co-director of Material Architecture Lab at the Bartlett School of Architecture, UCL. Widrig's studio now works in a broad range of fields including sculpture, fashion, furniture design and architecture. He has received international critical acclaim and has been published and exhibited internationally. Widrig is also the recipient of numerous prestigious awards including the Swiss Arts Award, Feidad Merit Award and the Rome Prize. Prior to founding his studio Daniel was Artist in Residence at the German Academy Villa Massimo in Rome. In 2011 his 3D printed dresses, developed in collaboration with Dutch fashion designer Iris van Herpen were named one of 50 Best Innovations of the year by Time Magazine. Amongst others his work has been shown at the Centre Pompidou Paris, Pushkin State Museum of Fine Arts Moscow, Gropius Bau Berlin and the Victoria and Albert Museum in London.

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