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Design Making —
The Values Had, The Object Made, The Value Had —
Practice · Making · Praxis

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Daniel Keith Elkin
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INTRODUCTION

Design Making — The Values Had, The Object Made, The Value Had — Practice · Making · Praxis

Daniel Keith Elkin
James Stevens

04—11

#design making

#makers

#value

#design praxis

#design research

Design Making

This issue of *Cubic* Journal concerns *making*, and the value-structures connected to the premise, before and after execution. Fifteen authors and constituent research teams present their work in manifested design research here. In this work, physical, semi-physical, and transitionally physical embodiments of objects, spaces, and prototypical design conjectures are part and parcel of the researchers' progress. Embodiment neither preempts, nor follows their work, but is essentially the substance of research itself within these manuscripts. The editors collected this work as status-taking for a broad range of creative and scholarly enterprises in several regions of the world. European, Southeast Asian, and American authors in architectural and product design fields provide perspectives on making-centric design research, across manual, digital, post-digital, and post-consumer spectra of fabrication. But as an assemblage, these works are more than a catalogue. They prompt retrospective thought on the values held, and the value given, by these authors' conjectural experiments in material form.

In this issue's title, the word *value* pivots on a semiotic hinge between different uses of the word. *The values had*, including the plural, suggests *starting biases*,[1] research frameworks, and/or institutional foundations that underpin designers and researchers as both individuals and members of institutions, disciplines, or professions. As much as the authors are academics within a global disposition to create knowledge, their predispositions within their research and professional surroundings are, perhaps, what lead their work to this journal issue as *makers* rather than other types of researchers. With *the object made* in between, a second and decidedly material use of the word value implies that value itself *can be had*, grasped or made *objective* as well as an *object* after manifestation. This second usage is perhaps more familiar in the industrial, post-industrial, to generally capitalist contexts of all design and research presented here: for what is expended, what positive impact, benefit, or amortisation is gained? What *value*?

Implicitly or explicitly, each text presented takes a standpoint on the second premise of value. Making research carries an inherent optimism common to all design research, emphasised in practices where material manifestation, as a time-stamp, test, or milestone, must occur for the work to move forward. The optimism lies in the bravery, ambition, or hubris to employ resources to manifest objects. These authors fix material, labour, and thought *in place* through manifestation, such that they cannot be used for other purposes. Without value gained through subsequent time, users, and research, these resources are lost. Therefore, each body of work presented here requires a measure of courage to assert that value *will be had* if the larger environment beyond the researcher tolerates this resource concentration and fixing. These authors conduct work that they believe to be valuable; they do so at their own considerable opportunity cost and risk given the unknown and untested territory of the material research within this issue. In concert with the authors' self-confidence, the writing that accompanies these objects is partially a negotiation of the first definition of values against the second definition of *value*: some constructions of *value* are only appreciable when motivating *values* are shared, reconciled, or debated. Texts giving access to studio environments, connecting research product texts and literature review contexts, or providing insight to the mindset that precedes making, reveal the value structures that differentiate and connect design research with other productive fields.

David Schafer of StudioMake and Rangsit University in Thailand, provides granular insight into haptic feedback criteria during and after a bespoke door hardware fabrication project. Photographs of Schafer's work, conducted in the author's studio and with help from nearby fabricators, argue their own aesthetic value. Editors and readers can subjectively accept or reject this value, though viewing the brass, teak, and wax prototypes elicits broadly-appreciable gratification as imagery alone. In addition to these images, Schafer engages his colleagues in an intimate work discussion regarding his set of values-as-design-criteria. These criteria, which experience and professional interest drive and frame, relate to micro-experiences during spatial transitions and in fabrication. Concurring with Juhani Pallasmaa,[2] Schafer conceives of hands almost as a set of voices. Before fabrication, they discuss inter-scalar and cross-spatial uses for architectural components, converting architectural fragments like steel wide flange segments into a door pull as readily as they form raw material. After manifestation, hands communicate across the substance of doors themselves, seeking information through heat exchange, texture, and mechanical-operational response. With designers' value sets and starting biases, Schafer's research is immediately comprehensible within the discipline. Similar to Pallasmaa, Schafer articulates design values and constraints; values perhaps intuitively palpable, but insubstantively described in design discourse. Admittedly esoteric, some of these experience values benefit from Schafer's description as an experienced design voice as well as a researcher and maker. To demonstrate one possible range of the outcome's breadth, regarding *what design can do, and what can be made* through these rich haptic experiences, is a returnable value easily understood by designers and educators. As they communicate with sceptical clients, students, or stakeholders, the maker's resource-fixing through manifestation returns value, partially because the subtleties of the aesthetic experiences are so minute. As Schafer implies, *these objects must be touched to be proven*. Verbal discussion of such experiences is substantively idle. When the currency of value is *evidence*, rather than *truth*, physical manifestation bridges value gaps by pulling a small number of material experiences out of the infinite field of possibilities. Schafer's values driving his work return to core of the design discipline, with attention to infinitesimal aspects of lived experience embodied and gratefully communicated in his discussion of bespoke fabrication praxis.

Sara Codarin's work at the boundary of technological application adds value at the frontiers of knowledge, within a subset of architectural practice such technology touches less readily. Her work with the Lawrence Technological University College of Architecture and Design applies site robotics and automation with 3D scanning technologies to cultural heritage preservation. Codarin's work adopts architectural preservationists' widely-held values regarding deteriorating, abandoned structures in Detroit's metropolitan area. Seeking new and innovative ways to repair and preserve this architecture, Codarin's work approaches the problem as a maker interested in innovative tools and expressive problem-solving. The predominating question of *how* to apply the technology and truly make it viable in this unusual scenario leads to Codarin's innovative toolpath generation algorithms and new robotic material deposition workflows upon a test bed generated from a 3D scan. Drawing on an intervention tradition including Sverre Fehn and Peter Zumthor, Codarin's experiences with drone-propeller-blown dust and time-damaged eccentric geometries demonstrate persistence in service of straightforward, easily appreciable value-sets: *if the technology works, the deterioration will stop*. Sites for conflicting values to meet, doubtless encountered at Fehn's Hedmark and Zumthor's Kolumba Museums, occur between choices of technologies and materials: her work, like many of her fellow architects', does not blend into the material or tectonic context of the test-site, but interjects as a transitional statement. Woodward Avenue Presbyterian Church, which Codarin uses for testing, reflects craft and construction traditions different from the Kuka Kr6-arc robotic arm's diligent progress setting layers of aqueous clay into a stone masonry gap. The people who laid that original masonry, alive and present, would undoubtedly comprehend the dedication and problem-solving ambition driving Codarin's research as similar to their own space-making ambitions. Ten miles from the archive of industry and making in the Henry Ford Museum, Codarin's manuscript is a snapshot into twenty-first-century production, at the leading edge of technology where innovative workflows demonstrate value through application in new fields.

Brian Lee's research on design prototyping process directly argues for a value field in Hong Kong's social innovation industry context, which is suspicious of designers' abilities to add consensually-agreed worth. His writing, diagrams, and case study projects finely examine movement between mindsets and prototyping media to concretely answer the question, *what value is gained by making prototypes?*, particularly in projects where audiences are under-served and material risks to clients and publics are high. Lee explicitly expresses what many of the texts here imply: that designers add value to many innovation processes through their simple ability to make *thoughts into images, and images into objects*. His case studies at The Hong Kong Polytechnic University touch on urban infrastructure and aging populations: researchers refit an antique tram with transparent fairings to reveal its internal workings to users and passers-by. An elderly man uses a LEGO model to rearrange partitions and furniture in his apartment. Within these scenarios, doubt raised against designerly ways of thinking and working sits at every margin in the face of developmental inertia and safety-preoccupied constituencies. Prototype-making provides value by allowing retrospective reflection upon negative fears and, even more difficult to describe in the absence of a tangible, physical prototype, *positive, imaginative possibilities*. The transparent-sided tram not only functioned *normally* and *safely*, it was also *beautiful* and *revelatory*. The elderly apartment residents' livelihood was undamaged by designers' participation, and *they discovered spatial autonomy, which they believed unattainable*. Lee's writing clarifies the structure behind the value physical making as prototyping can provide, allowing access to design thinking's complex and laterally-moving depths within the social innovation enterprise.

Dr. Guan Lee and **Daniel Widrig**'s expressive modular design experiments privilege transgressive aesthetics and experimentation values, contrasting with normative tectonics through an algorithmic, digitally-driven vocabulary. Contemporary drawing and fabrication techniques allow modular and fractal geometries as holistic spatial expression systems, which Widrig and Lee explore through various media. Modules, for Lee and Widrig, act as the translational device to physicalise digital zoom-facility between the scale of the atom and the scale of the city. In a tradition of digital fabrication and design research, the authors embody an argument for modular aggregations collecting, like colonies of ants or termites, into constructions large enough to enclose bodies and human life. In the process, their preference for expressive geometry and novel aesthetics profoundly disturbs the hierarchy and tectonic separation underpinning normative construction: trabeation, frame and infill, and any structural rhythm as simplistic *bearing-span-bearing-span* can be discarded as aesthetic and organisational values underpinned by normative construction practices and their limitations. In their absence, fog-like fields of scalar and connective transitions underpinned by diffuse-but-ironclad logics take shape. The last of their digital collages project futures where digital fabrication equipment scaling broadly disseminates such logic. Will a displacement of twenty-first-century construction economies, and their constituent value preferences for industrial standardisation and scaling, accompany this aesthetic change, as some twentieth-century architects and designers contended?[3] Lee and Widrig make no such claims, confining the value given by their mathematical and formal experiments primarily to making-internal concerns; modularity allows their researchers a method of clarity within variety and expressiveness. Modular assemblies scale up easily for researchers who erect their own work into overhead spans, unlike trabeated structures which may require additional manpower or equipment. For them, modularity enables their radical aesthetics, and these radical aesthetics enable spatial discovery as its own revelatory condition.

Philippe Casens and **Nathalie Bruyère** offer a retrospective on their work at the Institut Superieur des arts de Toulouse, soon to be published in a larger manuscript. Their consumer and user engagement work is founded in the *Global Tools* post-Marxist philosophy and socio-economic theory. Perhaps the text most explicitly dealing with value constructs outside of design, Bruyere and Casens' article discusses post-consumerist economic and social structures related to co-production tools and workshops. Bruyere's research collaboration *Ultra Ordinaire* designed image conversion software, allowing consumers at Bonnefoy Social Center to convert their personal imagery into embroidery artefacts. Among other manuscripts here, their work connects *tool use* and *tool making* to the radical project of craft: to undermine, disturb, or provide alternatives to consumerist and industrialised *making* patterns and parallel *lifestyle* patterns. *The commons* and *commoning*[4] structures in their writing connect object making to object and intellectual property ownership, and the constituent values internet connectivity and digital fabrication both destabilised. Their writing suggests that peoples' values and objects they make are less cause and effect, and more chicken and the egg: *could a change in the way we jointly make things create a change in the way we live together?* The text Casens and Bruyère present in this issue provides the post-industrial, post-Marxist intellectual setting for the larger monograph due for forthcoming publication, a setting shared by a number of texts in this volume's investigation of innovative production initiatives.

In Sichuan Province, the People's Republic of China (PRC), **Kuo Sze Yi** and his partners' research *chuan dou* wooden framing and other carpentry techniques in changing rural contexts. Kuo's work progresses the carpentry vocabulary to new manifestations of communal development action, both in professional and student workshop projects. Their making depends upon craft traditions adapted over time to demographic and geographic change as villagers move house, recover from earthquakes, and negotiate the PRC's changing economic structure. Ritual and symbolic values of the chuan dou system reflect complex relationships among the villagers, and among villages. Against this richness, Kuo works to help villagers cope with *hollowing out:* the aging and displacement of villages' able-bodied population groups as younger generations leave for work in Chengdu and other nearby cities. Small gestures, simultaneously novel and antique, such as village wayfinding projects and adaptable outdoor gathering pavilions, suggest new purposes and new everyday experiences for villagers whose place in society has changed. The design research here combines formal pursuit of new vocabulary, and humanistic re-assertion of experiential values, in environments where neither old nor new praxis can predict the future. Kuo's work demonstrates a pragmatic inventiveness interested in returning concrete value through available means, concretely sympathetic to the carpenters and villagers with whom he works.

The lead editor's own work in a village context near Hong Kong deals with *construction technology improvement*, a betterment construct driven by seemingly consensual values, but in fact fraught with power imbalances, unsuitable practices, and implementation failure. John F.C. Turner and his colleagues' extensive research provides a foundation for Elkin's technical research implementation methodology, testing *tooling provision* within construction technology networks. The value added by the metalworking tooling concerned – an improved *pressure forming* setup for doubly-curved shell production – seeks an implementation niche within small to medium enterprise contractors' complex constraints. Elkin argues that aspects of the construction technology network members' fabrication practices partially explain the failures of industrial technology implementation within housing and autonomous development markets. Industry and technology research, pushed forward at the *state of the art*, struggle for a firm footing in development markets that do not operate at the state of the art, *and may be harmed in their basic operation if forced to do so*, oftentimes through resource concentration and authority centralisation. Elkin attests that within this framework the values driving new technology development are arguably different from industrial optimisation practices. Furthermore, *maker researchers* may be uniquely equipped to develop that technology. From examination of his own work, Elkin hypothesizes construction technology improvement that uses the maker-researchers' unique knowledge subsets to disentangle new construction technology implementation.

Working closer to the state of the art, **James Stevens**' manuscript frames the future for post-humanist making and fabrication, an increasingly relevant body of practice in the future of a Fourth Industrial Revolution. Stevens' gently projective and encouraging text suggests that within the coming artificial intelligence (AI) enabled production contexts, craft and the maker as the *liberal subject* of fabrication polemics is likely to have a more complex future than the dire predictions of some postmodern criticism. Stevens works with his *MakeLab* colleagues to develop a material deposition workflow allowing intimate, co-robotic interfaces between computer-numerical controllers and a craftsperson, developing a series of posthuman maker objects. Through 3D scanning and analysis, Stevens' projects a method to develop AI fabrication workflows extending the agency and reach of the posthuman fabricator, propagating his, her, or its material intelligence to greater lengths. Stevens' literature review questions values as deep as the definition of humanity within its ecosystem and productive culture. He adopts Katherine Hayles' contention that posthuman ontology will likely animate the human person with new priorities and potentials. With humanist values such as humanity's supremacy and uniqueness suspended, what inter-humanistic objects and ecologies may emerge? Stevens humbly offers a window into this posthuman future, in which Homo sapiens and other actors' blended intelligences and values assemble entirely new premises for object-making. In the immediate term, his progressive tool-making research manifests a stimulating series of artefacts and workflows, fully animating the present while projecting the future.

Strongly rooted in present-day practice, **Eddie Chan** offers a pedagogical framework for object-making in the Hong Kong Design Institute's (HKDI's) Department of Architecture, Interior, and Product Design. Chan deals broadly with preconceptions and misconceptions of a changing design education market in Hong Kong and South China. Where drawing production factories and digital renderings predominate students' early professional experiences and expectations, where does design pedagogy insisting on physical manifestation, modelling, and exploration fit? Many professionals share Chan's experience in the rapid development economy throughout South China and the Greater Bay Region: development, and by extension, design production cycles, that are hyper-dense and hyper-fast. Chan argues the layered value that making gives to students through a number of public installation projects, and demonstrates through students' learning experiences and professional growth the value they can gain by extending themselves into increasingly uncommon design education territory. Chan presents his students' work as design experiments with accompanying hypotheses, testing, and feedback. Students' scale-naïve assumptions about digital fabrication and rendering's capabilities, prefabrication limitations, and the reality of atmospheric effect become real to them as making-centric pedagogy affords them a true testing ground. Value is returned in these students' abilities to closely comprehend some of the most essential components of spatial competency, ironically only partially rendered by spatial design disciplines' primary representation media.

Arch 002 emerges from the post-consumer processing research which **Elise DeChard** and **Fernando Bales** conducted in their fabrication facilities. Their work repurposing polyethylene drainage piping into concrete formwork subverts tacitly-included values of *single purpose* embraced throughout Home Depot home improvement outlets and their supply chains. Bales and DeChard's work, compared to Antoni Gaudí's catenary model making illustrates one line of progression in the construction industry, from a semi-primordial condition of forces, material, and discovery to a late-stage capitalist society with corporate production as mediator. In this setting which potentially fosters banality, DeChard and Bales borrow Kennedy & Violich Architecture's *material misuse* premise to develop a series of expressive spatial possibilities, encountered by crossing between catalogue aisles in home improvement stores. This cross-pollination is latent in the experience of nearly every home-builder or home-owner in North America, but not fully appreciated without the transgressive value sets driving formal and structural provocation through *Arch 002*. Accepting their mediated position, Bales and Dechard work to re-process and re-see the formal and spatial value given through transgressive reuse, to develop an expressive formal and spatial vocabulary.

Lastly this issue offers **Daniel Echeverri**'s ongoing dissertation work on hybrid digital/physical narrative construction. These semi-embodied experiments explore discursive possibilities between storyteller and listener afforded by emergent digital technology. Echeverri's work remains tactile, exploring boundaries between older manifestation media for narrative, and the new frontiers of experience, thus encompassing objects and experiences that have otherwise never *physically* existed. Perhaps fittingly, this last manuscript stands firmly with one foot in a current bodily experience understanding, and the other in fully-binary experiences soon to become commonplace. As an exercise elemental to experience, Echeverri's storytelling returns to this Cubic Journal issue to the topics prompting us to question the value and values after and before making. The objects and experiences we make are part of us, as humans, post-humans, or trans-humans. As such, they speak to our core concerns and our ongoing exercise of understanding our experience. From the universal to the particular, artefacts generating knowledge, or objets de art serving *peculiar times*, places, and needs, these objects made, the values had, and the value had, reflect the ongoing narratives of making as research and societal enterprise.

Notes

1. Philip Plowright uses the term "starting bias" to describe designers' and architects' pre-conditional experience, moral, and ethno-cultural preferences distinct from their design work briefs. Refer to: Plowright, Philip D. *Revealing Architectural Design: Methods, Frameworks & Tools*. New York: Routledge, 2014.

2. The specific Pallasmaa text Schafer, and other authors in this issue, refer to is: Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester, UK: Wiley, 2014.

3. Perhaps the strongest claims made related to novel spatial and construction aesthetics came via deconstructivist linguistic theory applied to architecture. Jacques Derrida correlated social and semiotic destabilisation to new architectural form-making by Peter Eisenmann and other authors, connections which have recently borne intense critical scrutiny. Refer to: Derrida, Jacques, Joana Masó, and Cosmin Popovici-Toma. *Les Arts De Lespace: Écrits Et Interventions Sur Larchitecture.* Paris: Éditions De La Différence, 2015.

4. Editors and authors similarly addressed commoning and the creative commons in *Cubic issue #1 vol. 1 – Design Social, Technology – Activism – Anti-Social*. As participants in material culture, design-researchers' work necessarily crosses between physical manifestation and its consequences, such that while this issue concerns Making, its content transacts with the previous issue's concern with the Social Refer to: *Cubic Journal Issue #1 Vol. 1 - Design Social. Technology - Activism - Anti-Social*, no. 1 (2018). doi: http://10.31182/cubic.

Bio

Daniel Elkin is a designer and builder working in Hong Kong. Elkin is an assistant professor of Environmental Design and Technical Coordinator for the Department of Environment and Interior Design at The Hong Kong Polytechnic University. His work focuses on spatial agency and its relationships with material practice, tooling, and construction technology. His work has been published in the journal *Architectural Research Quarterly*, at the College Art Association Annual Conference, and in a number of popular publications. His recent research studies stilt house communities in Hong Kong and Southeast Asia, studying intersections between community development, individual development decisions, and owner-builder construction technology. He has masters of architecture degrees from Cranbrook Academy of Art, and the University of Cincinnati.

James Stevens is an associate professor and Chair of the Department of Architecture at Lawrence Technological University, where he is the founding director of makeLab, the University's digital fabrication lab. James is coauthor of the book *Digital Vernacular*, *Architectural Principles, Tools and Processes* (Routledge 2015). He is a licensed architect in the State of Michigan, USA and certified by the National Council of Architecture Registration Boards (NCARB). He is the recipient of the AIA Henry Adams Medal for Excellence in the Study of Architecture and was the 2016 Fulbright Scholar in Albania. He holds a master of architecture degree from North Carolina State University and a bachelor in fine arts degree from The Savannah College of Art and Design. He is currently a PhD candidate at the University of Ferrara, Italy at the Polis University campus in Tirana, Albania were his research focuses on digital fabrication and digital craft.

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In Hand: Touch as a Critical Act in Creating and Experiencing the Built Environment

David Schafer

012–031

This photo essay depicts the design and fabrication research that David Schafer and his team conducted through a grant from the Association of Siamese Architects (Thailand). His architecture and design practice crafted bespoke objects which investigate the value that hands-on making gives to an intuitive and embodied design. Seeking intimate relationships with the hand, skin, eyes, and body both before, during, and after manifestation, this work describes a material practice intimately familiar with making's feedback mechanisms and constituent benefits to the design studio. They study ergonomic relationships with familiar object typologies and segue into the creation of experientially sensitive door handles in wood, leather, steel, brass, and other materials. The palpable haptic richness of these objects, through a responsive and fertile design process, reveals opportunities amicably distant from standardised, functionalist design methods.

#architecture

#craft

#design

#digital fabrication

#hardware

Introduction: The Future of the Past

The authors maintain that there is no distinct boundary between the act of design and the act of construction. They are inseparable parts of the same spectrum. The authors prefer to think with their hands and find empirical knowledge to be a critical aspect of our design process.

In our roles as teachers in the classroom and mentors in the studio we see the growing disconnect from architecture as a craft, a separation of thinking from doing, and an increasing abstraction of the Thai designer's education. Architecture schools have no workshops. Designers and students develop ideas solely in digital worlds absent of the texture of material, the vitality of sunlight, and the warmth of a body. Their projects' ambitions are limited to glossy prints. The strong socioeconomic division, and cultural aversion, between the mental and the manual is a particular disservice to the architect whose work is ultimately manifest in unfamiliar techniques and materials known only by name. Increasingly isolated from the act of building, the stifled results are simply retinal exercises. In response, the present research is more concerned with how buildings feel rather than how they look.

We understand the increasing need for specialisation and the growing freedom technology grants. We don't seek to end critical discourse or emphasise practice in the educational environment, but find it necessary to present an alternative form of conception, one that positions the architect as an emphatic maker.

It is perhaps ironic that the digital revolution originated with the fingers on our hands, i.e., counting using our ten digits. The term *digital fabrication* implies futuristic technologies where the maker is edited out, a utopian design experience where ideas effortlessly come to fruition as the perfect objects designers want them to be. It exalts the absence of the hand, intimating that computer-controlled machines are virtuous and faultless. Designers are simply users and operators, with their role increasingly minimised and mediated. The author and project team believe that fabrication can balance digital processes with the idiosyncratic beauty, sensibilities and temperament of the human. This work does not reject technology. It works to humanise it.

By working with enduring techniques—casting, carving, forming—the project team engage the masters of craft that have preceded them and acknowledge the immaturity of digital fabrication in comparison. In our research, digital fabrication acts similarly to the primitive, and the future reveals itself through actively engaging the past; a synergy between old modes of craft and new modes of production. As digital languages translate to physical machines and actual materials, errors and idiosyncrasies are inevitable. There is a grey area within these glitches. *Failure* lies at one end and *personality* lies at the other. Ruskin (1853) saw humanity in the irregularities and errors of Gothic architecture. The work presented identifies and fosters digital glitches in CNC (computer numerical control) processes as humanizing aspects. The project team considers the ghost in the machine to be the ancient soul of the craftsman.

The authors want to immerse their hands back into architecture; to actually touch the structure and details. They want to deeply consider architectural elements of touch, components of a building which directly engage their bodies—door handles, latches, push plates, drawer pulls, handrails, light switches, faucet valves, and toilet levers. They also want to consider their experiences as active participants—pushing, pulling, resting, holding, leaning, and nudging architecture. Furthermore they want to consider the role that these specific points of contact play—enhancing, diminishing, refining, or magnifying their experiences.

In *The Eyes of the Skin*, Juhani Pallasmaa writes

> *the skin reads the texture, weight, density and temperature of matter. The surface of an old object, polished to perfection by the tool of the craftsman and the assiduous hands of its users, seduces the stroking of the hand. It is pleasurable to press a door handle shining from the thousands of hands that have entered the door before us; the clean shimmer of ageless wear has turned into an image of hospitality. The door handle is the handshake of the building. The tactile sense connects us with time and tradition: through impressions of touch we shake the hands of countless generations (Pallasmaa 2005, 56).*

Research Methods: Process, Premises, Precepts

The door can be considered a unifier between spaces. The handle serves as both punctuation to the current space and as an introduction to another, distinct space. Inside to outside. Hallway to bathroom. Bedroom to closet. Street to garden. Crossing the threshold is a physically complex and conceptually rich moment within architecture. We chose to focus on the moment in which passage is initiated, and the micro-site of contact for that act.

This work envisages a door handle engaged in two stages:

The point when one *grasps material*, we physically understand the *form* of the handle and subsequently evaluate the *feel* of the material.

The moment one *initiates movement* of the handle or latch mechanism we verify our *expectations* based on our understanding of the discernible design semantics and we *experience* the physical operation of the instrument.

In addition to readings and photographic surveys, physical prototypes served as the primary modes of investigation for the research shown. The work hybridised analogue and digital processes of making and was conducted within our studio's workshop. We experimented with our own large-scale CNC tooling, and collaborated with Bangkok's network of fabricators and craftsmen.

The work anticipated a concurrent process between fabrication and contextual interpretation. We expected site to inform fabrication, and fabrication to affect our understanding of site. We knew that all forms were derived in the flesh. The computer, through projective digital reality, played a supportive role. All designs were material driven. The work acknowledged and embraced history, use, and wear. We amplified the moment of contact and active engagement of the door handle. The authors encouraged complexity and contradiction. We anticipated that our prototypes would coalesce into a collection of pieces which emphasise process, technique, and material. Read as a whole, these pieces ideally provoke discussion about the friction between the character of the hand and myths of technology.

Research Conclusions: Materials, Methods, Prototypes

Over several months patterns developed within our ideas and physical sketches. Themes of engagement were organised and refined, sometimes absorbing multiple investigations into a single design. We developed a series of door handles, pulls, and latches that magnify and draw focus to particular physical or experiential moments within the simple act of engaging a door. Four separate approaches, shown through collections, precipitated from the work.

A. Traces of Wear

Close contact with the living, breathing, and secreting human body leaves marks and residue that accumulate over time. The touch of the human hand degrades the designer's or manufacturer's vision of finality. We sought materials and finishes that continue to improve over time, aging into graceful weathered patinas, and benefit from the gentle polishing of a repeated touch. The project team derived the form of each handle from hand-lathed wax prototypes. We completed shop drawings digitally.

B. Conduits of Space

The door handle moves a select portion of wall and connects to the space on the other side. To pre-visualise or pre-engage the other side leads us to reconsider our own space. A peephole allows discreet visual access, helping us to feel secure. Our hand placed on a glass pane helps us brace for the change in weather. The door handle allows for select information to pass through as is appropriate for the relationship of the spaces it connects. We can tune accessories to enrich this complexity. We can reduce a window to the size of a finger, or enlarge a keyhole to the size of a wall.

C. Expectations of Operation

An eccentric gear-based mangle rack turns continuous rotational movements into back and forth linear movements. The counterweighted spinning handles intuitively inform the position of the deadbolt throughout the motion, and allude to the tools that were used to manufacture the object itself. Laser cut aluminium plates with hand-turned brass and teak counterweighted knobs add weight to the operation and patina throughout wear.

D. Fragments of Architecture

Architecture is an additive process using standard and modular materials. We conceived of door pulls that share the same origins as the building. Working at a small scale with typically large-scale materials we established a vocabulary that maintained a faint familiarity, quietly hinting at its origins for those who would listen.

In all cases we desired to add complexity. This initial point of engagement is ripe for opportunity. The door handle as a regulator and interface yearns for intensification. A deeper contemplated object can set the tone or introduce a perspective from which the rest of the space and structure can be understood, like an *amuse-bouche*. By making strange the typically banal door handle we awaken those who engage in a new sense of what lies beyond (Cadwell 2007). The importance of intimate scale and the tactile engagement places the hand at the origin of this understanding and to the heart of the architecture.

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Figure 1: Opening doors and crossing thresholds. Observing old, well-preserved, perfectly neglected architecture, the patterns of wear from both intended and incidental use are conspicuous. The sun, the rains, hands, and movements all leave their marks. Source: *author.*

Figure 2: Holding things to see how they feel. In an early exercise we instinctively grasped objects to understand and detect the textures we best respond to, as well as to engage in the visual clues of industrial design semantics, and lastly to allow our hands to settle and discover what we could not see. Source: *author.*

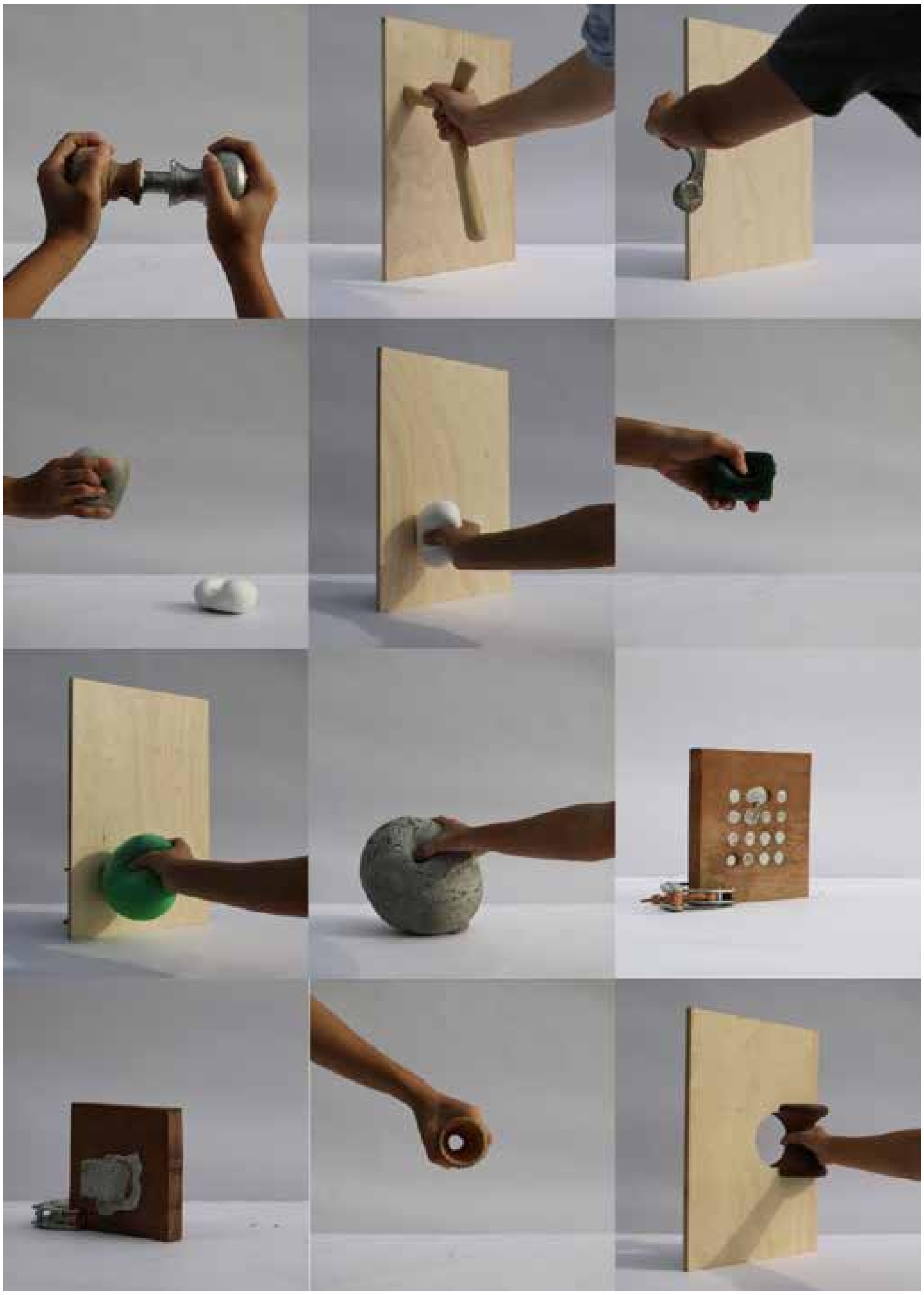

Figure 3: Making sketches that we can touch. Investigations into the use of metals as a conductor, which pre-emptively inform a user of interior conditions. These works use both intuitive forms, and found objects which break from known conventions. As fragments of thresholds, these objects explore engagement of door edges and the penetration of the door surface. Source: *author.*

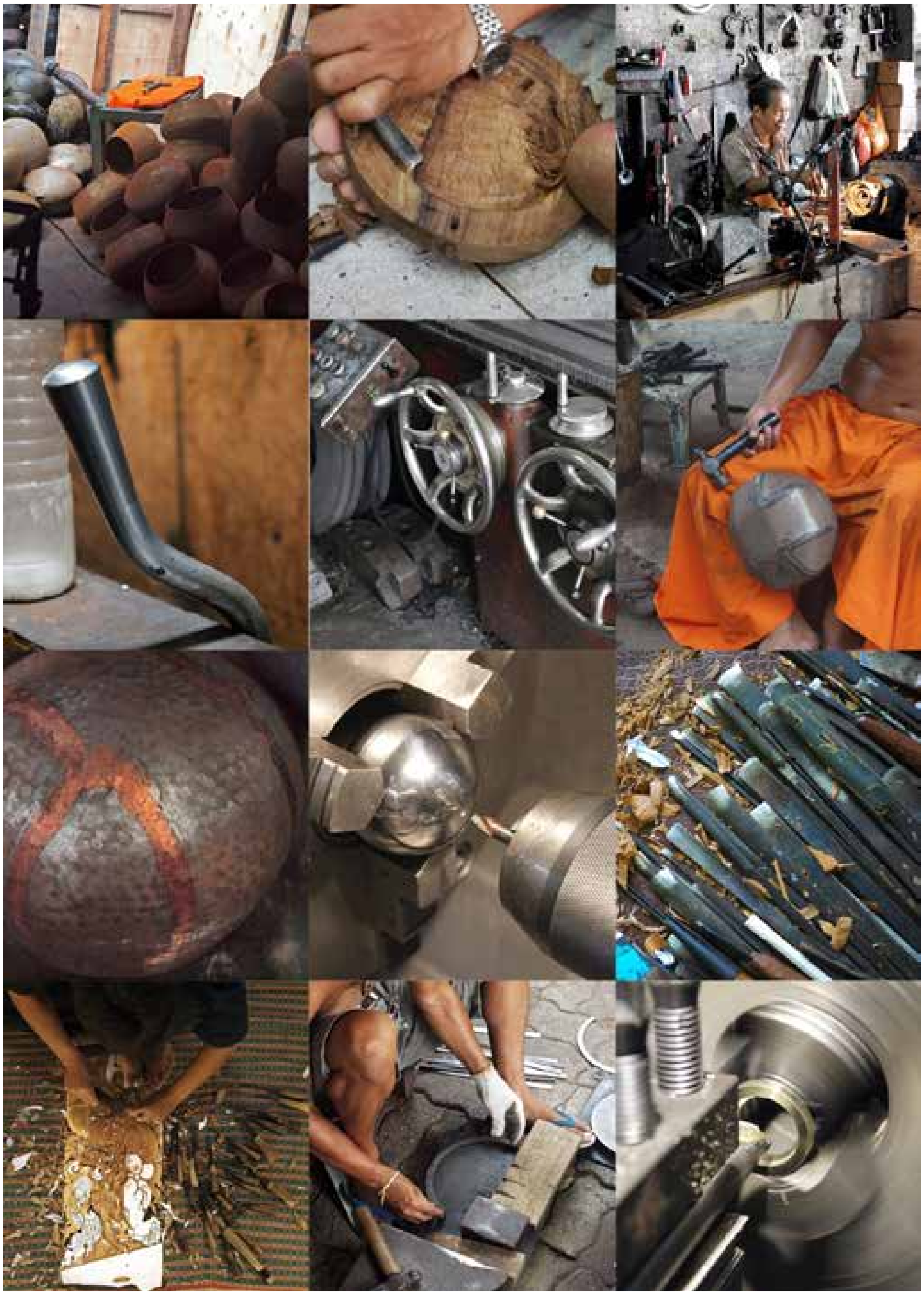

Figure 4: Observing craftsmanship. Workshops and craftsmen help launch our design explorations and material understanding. Our relationship with the makers is as important and complex as our relationship with the materials and techniques. Source: *author*.

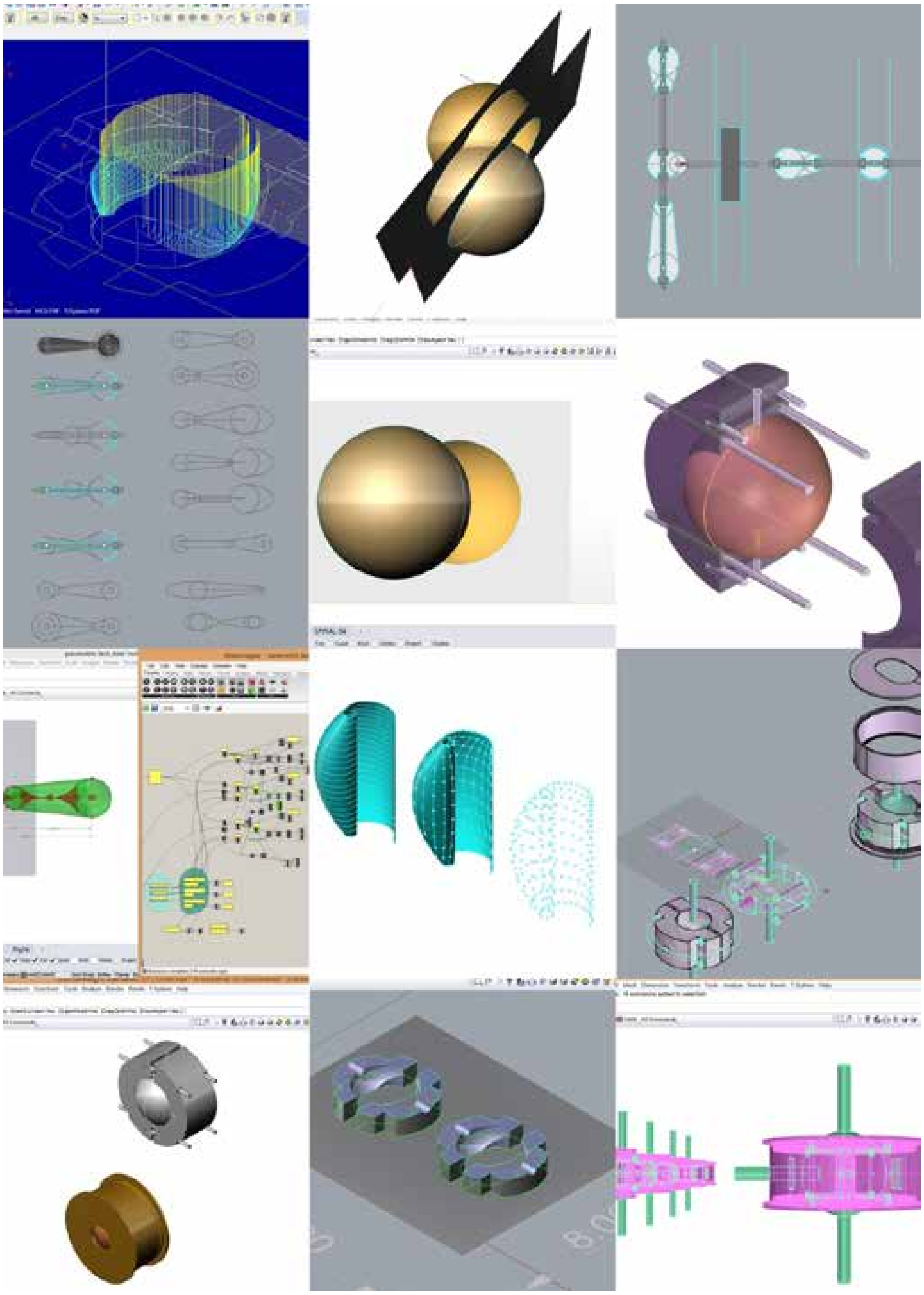

Figure 5: A moment without gravity for the sake of clarity. Numerous investigations progressed from physical material into digital development, often for increased precision and translation for machine language. Some ideas were digitally shaped, and material translations proved more poetic. Source: *author.*

Figure 6: Thinking in steel. A study working with materials for simple manual tools: heat, hammer, anvil, and saw. Some sketches sought to transform recognisable architectural elements into discrete objects. Further steps are needed to address the completion and operational uses. Ideally their familiarity stays intact, with accustomed origins obscured. Source: *author.*

Figure 7: Letting the machines handle the material. We expanded our studio's CNC capabilities to allow uninhibited experimentations. Moving fluidly from studio to workshop allows failure and discovery to overlap and materialise quicker. We machine directly into wax to create prototypes that can either be cast in metal, or cast aside. Source: *author.*

Figure 8: Sharpening tools and working materials. We complete as much work as possible in our facilities. We collaborate when our skills or tools have reached capacity. Having an intimate relationship with the successes and failures of our ideas tunes our ears to the desires and fears of the material we work with. Source: *author.*

Figure 9: Traces of wear. Texture detail of hand chiselled back lip and hand polished front surface of a teak door handle. Source: *author.*

Figure 10: Traces of wear. A backside lip for fingers on a brass door handle. Source: *author.*

Figure 11: Traces of wear. Brass and acetal thermoplastic details on a crystal potassium alum door handle. Subjected to use, the crystal erodes over time revealing the pattern of use whilst fulfilling a simple sanitation role in the process. Source: *author.*

Figure 12: Fragments of architecture. Extensively milled wide flange beams result in delicate forms, belying their industrial origins. Discolouration shows heat-bending boundaries. Source: *author.*

Figure 13: Operational expectations. Interior details of the *spherical handshake* and the *mangle-rack latch*, mechanisms which facilitate a multifaceted engagement while granting passage. Source: *author.*

Figure 14 (right): A single table for diverse ideas. Moving forward with multiple, concurrent designs allows parallel ideas to influence each other during the act of making. Source: *author.*

Figure 15: Coaxing together a brass stretcher plate and a buffalo leather diaphragm. Both pieces are strategically laser cut to allow certain areas to exhibit weakness, facilitating assembly, and other areas cut to gain strength from changes in geometry. With time the entire assembly will slowly settle into a graceful form derived from repetitive use as the leather stretches against the brass. Both items can be seen in their assembled state in the upper right side of Figure 14. Source: *author.*

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Bio

David Schafer is an architect and fabricator based in Bangkok, Thailand since 2009. Originally from California, he first explored architecture at the University of Arizona. He earned his architecture license from the State of California, and then returned to academics to study a more intimate scale of making. At Cranbrook Academy of Art, he formulated the approach that would lead him and his late partner, Im Sarasalin Schafer, to establish Studiomake. This practice maintains that innate understanding of our environment is rooted in intimate scales of interaction. In their studio these tactile moments develop from fluid, recurrent shifts between the act of design and the performance of construction. Working in full scale and real time the team of architects and craftsmen explore the overlapping realms of architecture, interiors, furniture, and object design.

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Additive Manufacturing Technologies in Restoration: An Innovative Workflow for Interventions on Cultural Heritage

Sara Codarin

032—055

The current advancement of this research within the construction sector is the missing link for bridging the gap between the digitisation of building processes and the fabrication of architectural components. Renewed market needs and contemporary design languages require increasingly in-depth digital proficiency for the management of representation and production. The primary challenge of turning digital data into matter in the building design field must be overcome in order to demonstrate a possible transfer of benefits for new constructions, or interventions on existing buildings. The scientific community unanimously states the importance of deepening the most updated digital fabrication systems. With the aim of elaborating a methodological approach that prevents the technique from prevailing over the cultural assets a project requires, the present study proposes an innovative workflow for restoration projects on culturally relevant architecture in a state of degradation.

#additive layer manufacturing

#digital fabrication

#second digital turn

#digital architecture

#cultural heritage

Introduction

Digitisation of design processes enables architects and engineers to interface with a common language, reduce uncertainties, and ensure greater awareness in decision-making phases.

In parallel, unceasing development of construction technologies aimed at processing digital data, and subsequently reproducing their spatial characteristics (Rocker 2006; Gershenfeld 2012), opened up new and unexplored design possibilities. This challenges and fundamentally transforms well-practised design traditions (Keating et al. 2014).

Indeed, when the first digital revolution came into play (Carpo 2013), the formal elaboration of architectural projects remained confined within the digital environment, represented through two- and three-dimensional simulations. The transition to the second digital era, theorised over the last decade as the second digital turn, determined the development of automated tools. These tools are programmable to materialise the digital space with great flexibility, without limitations imposed by standardised production methods (Carpo 2017). Digital manufacturing technologies, such as robotic arms, 3D printers, smart-assembly or combined tools, to name a few, laid the foundations for the customisation of performative architecture, spanning the technological unit and the architectural organism. This ongoing cultural breakthrough, which falls into the definition of post-digital (Figliola 2017), aims to make the digital space tangible and perceivable (Gramazio and Kohler 2008). This fills the gap left by the first digital switchover, which failed to develop an aesthetic and material sense in architectural production (Picon 2014).

Consequently, the design output is no longer just a link between the conceptual phase and the built result, as in the past. We are witnessing a substantial change to the typical architectural professional process, in which design is not separated from construction, and the transition between one and the other is almost instantaneous. This change reiterates processes and optimises methods leading to pioneering conceptual and aesthetic paradigms by allowing simultaneous work within digital and virtual environments.

Advancements in CAD/CAM (Computer-Aided Design and Computer-Aided Manufacturing) interplay allow evaluation of successful digital architecture production experiments (Mostafavi and Bier 2016). Such experiments entail using secondary technological structures to articulate new constructions or existing volumes. Similar sequences comprising off-site technological units in factories or research laboratories, and on-site assembly of more complex architectural systems unite this applied research.

On-site automation is widely under study as the uncertainties of construction environments are still crucial features to be faced in order to change previously known building site settings.

Given these premises, it is of particular interest to explore the advancement of scientific knowledge within the restoration field. This requires case-by-case design solutions based on unpredictable variables such as lack of information regarding the buildings' geometry, assembly materials, and possible structural instabilities (Brandi 1963).

The present contribution investigates digital technologies and the role of manufacturing tools to support decision-making phases for innovative interventions on cultural heritage. In turn, it requires knowledge of traditional construction systems and craft methods as a metaphorical boundary in which design outcomes should be tailored.

Methodology

Today, valorisation and restoration projects on existing architectural heritage refer to established techniques used by artisans. Making decisions directly on site is a common task, although not always supported by adequate tools to ensure the digital documentation, repeatability, and measurability of the performance.

European approaches developed in the 1970s aimed at industrialising the construction process shifting from the serial prefabrication of building elements to the mass production of standardised housing estates and building systems (Zaffagnini 1981). Current methodologies are instead more oriented to customisation and personalisation (Bock and Langenberg 2014). This change opens new possibilities for industrialisation in sectors that require bespoke solutions, such as restoration.

The immediate consequences could be cost reduction and more reliable results over time, especially when the production of non-standardised components is required and serial production for their realisation is not viable.

Industrialisation within the building industry mostly refers to the off-site production of materials, products, and technologies subjected to quality supervision in a controlled environment. So far, in the European framework, on-site industrialisation is not widespread. It could particularly help to optimise the rate of time and quality for the production of discretised elements, that are not realisable through mass production.

The present study analyses projects on existing buildings realised through traditional procedures and, in parallel, deepens relevant experimentations on building site automation. For each set of case study projects, it draws attention to the main technical complexities that architects and researchers encounter and still requires in-depth analysis and applicability evaluations. Therefore, the paper classifies these technical complexities based on the priority in which they should be solved.

These considerations laid the basis for the definition of a first-hand experimental activity to explore a digital workflow for restoration processes, from design to construction.

Such methodology encourages dialogue between craft and information technology (IT) integration within interventions on cultural heritage.

Case studies: large-scale digital construction

Large-scale digital technologies generate complex geometries in a short time frame compared to non-automated implementations. In this analysis, depending on the construction process, they are categorised as subtractive technologies, additive assembly systems, additive layer manufacturing, and combined processes.

For each technology, design, production, or assembly processes are to some extent digitally controlled. Below are some examples in support of this research.

Researchers have explored subtractive processes primarily using computer numerical control (CNC) machines or hot wire cutters.

In 2015, the company D-shape[1], in collaboration with the Institute of Digital Archaeology[2] realised a scaled-down prototype of the Monumental Arch of Palmyra using a CNC machine on marble blocks. The arch was severely damaged after conflictual events and, for a long time, Palmyra's site was inaccessible. During that period, the scientific community promoted a campaign to create a database of photos of the area to produce a digital model using a photogrammetry technique. The following step was to display a symbolic reconstruction to raise awareness of the arch's cultural importance and continue encouraging documentation. Robotics, in this context, allow for an immediate reaction to a cultural loss and to address resources for effective reconstruction once local socio-political instability is over.

Research projects have mainly used robotic hot wire cutting (RHWC) to investigate design processes. Significant examples are the RDM Vault at Hyper-body's robotics workshop in Rotterdam (Feringa and Søndergaard 2014), and the REVAULT project at the University of Michigan.[3] An example is the realisation of study prototypes for the continuing construction of Gaudí's Sagrada Familia Church (Sheil 2012). Researchers previously investigated digitally-assisted stoneworking for columns and masonry components through scale models to learn the geometrical intricacies for each piece. This allowed professionals to deeply engage with the understanding of the geometry relations that Gaudì himself could not in his time understand because of the computational difficulties that contemporary digital design methods can resolve with higher success.

The realisation, in 2006, of the façade of the Gantenbein cantine[4] set the beginning of a series of process iterations led by Gramazio and Kohler Research (Wangler et al. 2016). Their approach is described as "the process of joining materials to create constructions from 3D model data" (Labonnote et al. 2016). The In-Situ Robotic Fabrication project specifically provides a significant step forward in the study of building automation regarding the future deployment of robots directly on site. In order to do that, the robot must recognise its position, the geometry of building elements nearby, and material tolerances (Gramazio, Kohler, and Willmann 2014). Current research enabling interactions with human workers can expand these capabilities. For the *Endless Wall* installation, for instance, a human drew a curve on the ground, and a robot correspondingly shaped a brick wall. This real-time update is a crucial point to support a robotic breakthrough in the construction sector (Keating and Oxman 2013).

Additive layer manufacturing (ALM) is a research area that requires technical optimisation for full-scale building applications. ALM's promising potentials lie in safety, limitation of raw material waste, cost-efficiency, control of material storage, and experimentation with innovative materials. Speed and geometrical freedom are not fully resolved aspects. Although advanced building construction companies are integrating additive processes on site, these tools lack the level of development of industrial robots. The "process of joining materials to make objects from 3D model data, usually layer upon layer"[5] is achievable through two foremost tested systems, based on different methods for the generation of the machines' toolpaths: powder-bed deposition and bulk-material plotting. These terms are often approximated to 3D printing, which is instead a subset of these techniques.

Researchers applied the first process additive construction using a powdered sand mixture cured through hydration with an inorganic binder. *Radiolaria*, a prototype realised in 2007 by D-shape, is generally considered to be the first large-scale freeform additively manufactured structure.

Material plotting is the most used in academic research. It is usually clay based. Among the most effective experimentations we can find are Woven Clay (Friedman, Kim, and Mesa 2014), Pylos (Dubor, Cabay, and Chronis 2018), and InFormed Ceramics (Ko et al. 2018) projects.

This study, from the technical perspective, refers to ALM as:

1. An end effector installed on a robotic tool;
2. A means of fabricating objects from the

digital environment;
3. Through material deposition;
4. Using a print head.

Scaling up the ALM process to the architectural scale requires awareness of the interplay between equipment objects. Large extruders limit robot behaviour during fabrication, and the overall efficiency of work may decrease every time workers must fill the container with new material. This can also affect the object's drying process and deformation.

The present research is interested in the analysis of additive manufacturing procedures. It will address a laboratory experience, based on this approach, to collect data and find critical solutions for some technical complexities that occur during implementation.

Cases of restoration making

The digitalisation of building sites under restoration is an opportunity to link digital design and digital building processes. At the time of writing, digitisation has revolutionised design, thanks to dedicated architectural software. By merging digital production and assembly, digital construction can simplify the process from digital design to digital production of finished structures and buildings (Labonnote et al. 2016).

As previously mentioned, it is essential to remember that restoration processes require a case-by-case approach. Although a long construction tradition codifies possible decisions, they cannot always be evaluated in advance or processed through digital means.

The traditional construction site is structured with a sequence of events following a linear scheme (National Heritage Training Group 2005). Each occurs when the previous action is concluded (Zaffagnini 1981). *In situ* procedures can be completed with off-site integrations or with architectural discretised components installed directly on site.

To date, definition of the digital building site is underway. Construction phases do not necessarily have to follow a deterministic scheme. Innovative construction tools may include robotic arms to lay building materials, customise on-site standard components, and build volumetric additions if required.

The tools currently available on the market need enhancements to develop a complete construction cycle *in situ*. Evidence of this can be found in case studies disseminated at an international level, which hybridise on-site and off-site production (Gramazio and Kohler 2014).

Notably, additive manufacturing can be considered an attempt to replace wet construction systems, because it does not require extended drying time or formwork for casting and curing.

This study primarily focuses on damage to buildings' geometries, such as the collapse of building elements, gaps in the building envelope or decorations, and the loss of elements of the volume.

Given this limitation, this paper examines several projects of volumetric additions or fragment replacement on historical architecture (*Fig. 1*).

The same decision-making approach unifies such projects. For each building, architects consolidate the existing surfaces and design the missing parts by choosing a recognisable language, in contrast with historical patterns. A brief description of selected restoration cases follows.

The first analysed project is the Hedmark Museum in Hamar, Norway, it is Scandinavian vernacular architecture restored by Sverre Fehn in 1971. The building holds three layers of history:

1. The thirteenth-century Bishops' fortress ruins of the Ancient Diocese of Hamar;
2. The eighteenth-century barn built using the ruins of the ancient medieval palace as parts of the walls;
3. The twentieth-century intervention bringing the building to its contemporary state.

The present temporal layer lies atop the ruins. The architect emphasised openings and gaps in the building envelope, covering them with plate glass, touching the structure with metal pins on each corner, and providing an ephemeral contrast to the massiveness of the pre-existent structure.

Architects applied a similar approach to the Monastery of San Juan in Burgos, in the north of Spain. The parish built the historical volume in the eleventh century. It suffered damage due to two successive fires in the fifteenth and sixteenth centuries. At present the structure is mainly in ruins, though exterior sidewalls survive. Conservation efforts led in 2015 for the construction of a roof which floats above the ruins. This roof preserves the ruins as an independent structure, keeping the perception of the original architecture unaltered. It is shaped like a large folded plane that evokes the ecclesiastical three-nave temple that initially existed. All volumetric integrations were designed by BSA studio using different materials, colours, and textures from the pre-existent masonry.

Another notable example in the European context is the Kolumba Museum in Cologne, Germany. Designed by Peter Zumthor, it was built between 2003 and 2007. Previously, the site was occupied by the Romanesque Church of St. Columba, destroyed in World War Two and replaced by a chapel in 1950. The new structure combines existing fragments of the Gothic church and the 1950s chapel into one complete building. The museum shares its site with the ruins, wrapping a perforated grey brick facade around them. The new work adopts the original plan of the ruins to become part of the architectural continuum.

Finally, the eleventh-century Cathedral of Bagrati in Kutaisi, Georgia, is a restoration case of reintegration. It focused on the substitution of damaged elements with modern materials, inside a valuable example of eleventh-century Georgian architecture. The building has been heavily damaged throughout the centuries and was reconstructed to its present state through a gradual process starting in the 1950s, with significant conservation works conducted in 2012 by Andrea Bruno. The contemporary volume is adjacent to the historic walls, and it is recognisable by differences in geometry and colour from the ancient masonry.

As for digital constructions, research extrapolates technical complexities that a traditional restoration construction site requires. Among these:

1. Production of customised elements to be installed within geometrical constraints;
2. Structural enhancement; and
3. A formal language to resolve the interface between the pre-existing and the new intervention.

Researchers transferred these variants in a hypothetical digital restoration site, which is considered a consistent option once the advancement of technology solves some key aspects in order of priority. Among these:

1. The space required for automated systems to be installed near ruins;
2. The possibility to produce non-standardised elements in touch with irregular vertical or horizontal surfaces;
3. Development of engineered materials with load-bearing properties;
4. Systems to control the colour scheme of ALM outputs.

A simulation of a possible digital construction site for restoration projects follows.

Test-bed: the Woodward Avenue Presbyterian Church

The innovative contribution of the present research is underway at the College of Architecture and Design (CoAD) of the Lawrence Technological University (LTU) in Southfield, Michigan in collaboration with the Department of Architecture of Ferrara, Italy.

The common goal is to address the use of digital fabrication in restoration, as an opportunity to update cultural heritage conservation processes. In this field, digital tools are rarely implemented owing to a lack of studies that assess their applicability and benefit.

Researchers at CoAD are mapping historical architecture in the Detroit area under degradation, resulting from the collapse of the local economic system in the 1970s.[6] Most of these buildings are included in the Federal National Register of Historic Places.[7]

Survey activity has produced a dataset used to classify architecture of cultural relevance that is partially or entirely damaged, starting with those that are already labelled to be preserved.

Researchers use this cataloguing process to find a consistent test-bed. The test-bed chosen is an abandoned building characterised by several critical geometric conditions analysed using digital tools. Researchers decided to examine the Woodward Avenue Presbyterian Church, a neo-gothic building constructed in 1911, which has been a national landmark since 1982.[8] The last religious service in 2005 marked the beginning of its abandonment (*Fig.* 2).

A preliminary photographic analysis identified the main critical aspects. They specifically concern the structure and the external envelope. Cracks in windows have allowed rain to wet stones and wooden elements over the years. Thus, several architectural components have experienced repeated freeze-thaw cycles, exacerbated by Michigan's harsh continental climate. Moreover, gaps exist in the perimetric walls, and the layers of the internal vaulted systems are no longer cohesive.

Survey activity integrated data obtained from complementary tools. An *imaging 360-degree laser scanner* collected point clouds of overall building geometry.[9] A *structure-sensor* operating through a photogrammetric technique created meshes of decorations or structural details that are out of range for the scanner's visual cone (*Fig.* 3). In addition, a *lidar sensor* connected to a drone integrated geometric data for inaccessible areas (*Fig.* 4).[10]

The aforementioned analysis of restoration making cases helped categorise damage within the building system. In fact, this phase of the research consisted of mapping areas of the building united by certain characteristics. These include loss of portions of materials and presence of uneven vertical and horizontal surfaces. The wall gap was used as an investigation field (*Fig.* 5).

Experimentation: filling the gap through additive manufacturing

The quantitative data collected during the survey of the Woodward Avenue Church were turned into matter through the full-scale realisation of a wall's portion.[11] This wall prototype is a test-bed to simulate possible on-site operations of additive manufacturing for the production of large-scale architectural elements on complex geometrical constraints as wall gaps (*Fig.* 6).

Researchers employed specific equipment for testing the digital manufacturing process. A six-axis robot executed kinematic sequences. Installed on the robot head is an end effector, or a nozzle connected to a flexible hose, for extrusion of printing material. A pipe pushed the printing material into the end effector under compressed air power.

Researchers modelled the volume of the wall gap and linked this model to a parametric digital environment,[13] to ease iterations and possible variations of the process. Researchers then sliced the model into horizontal layers that were filled with an internal support geometry. The project team broke resulting polylines into a list of targets for the robot to reach. Researchers offset each layer multiple times to generate the required wall thickness.

Thereafter, researchers generated the robot toolpath over the model. To do so, they employed a plug-in[14] that extends the software's capabilities and allows the remote programming of the robot axis. The project team used this component to design a script, or toolpath generation algorithm, that converts target points into robot code and simultaneously detects collisions, reachability issues, and singularities (*Fig. 7*). Before uploading the code in the robot controller, researchers validated axis kinematics by visualising the robot at each of the targets and checking for targets out of reach, joints out of range, singularity issues, self-collisions, and collisions with surrounding objects (*Fig. 8*). The virtual simulation provided an early opportunity to correct possible issues that may have occurred. This was followed by a simulation of the robot kinematics in the physical world. Before interacting with the wall prototype, researchers wrote a basic script to analyse whether the robot could operate effectively within a simple geometrical constraint. The wall crack was approximated to a rectangular gap (*Fig. 9*). This allowed the project team to check the positioning and the rotations of the nozzle at every target point.

Currently, extrusion testing is under study. Clay was chosen as a base material for the experimentation because it is easily recyclable, comparatively inexpensive, and workable to achieve a high-quality finish (*Fig. 10*).

During experimental phases, certain aspects will be monitored. Researchers will evaluate the precision, replicability, and measurability of the process performance.

The responsiveness of the material, in terms of viscosity, hardening rapidity, and compressive strength limitation, is critical in relation to the different surfaces slopes deposited through the end effector (*Fig. 11*). The accuracy of the robot in the physical world, following the software simulations, determines whether the end effector is just touching, or colliding with the wall surface. Moreover, linear and rotation limits of the robot axes set up the most suitable toolpath speed for the realisation of the wall gap volume.

The achievement of the expected research results is a tangible opportunity to merge the design processes and construction, or making, procedures (Stevens and Nelson 2015). They contribute to defining the characters of the future digital craftsman, within which "the automatic feedback between the machine and the material is the next step of digital craftsmanship" (Carpo 2013).

Speculation on additive manufacturing

The output of this research includes the algorithm design, based on overcoming the concept of standardisation. This premise is commonly used for the elaboration of generative volumes. In this context, the research took advantage of these potentials to deepen new design paradigms in restoration for volumetric integration of complex shapes in building envelopes (Codarin and Medici 2018).

This project's outcome is an algorithm that guides a robot to reach target points and make clay extrusion possible. It allows for the management of ALM processes in all aspects.

The script is composed of a sequence of information:

1. Input geometry;
2. ALM geometry;
3. Robot toolpath;
4. Axis kinematics;
5. End effector installed,
6. Analysis data; and
7. Output.

Every component can be modified to explore different iterations and proofs of concepts.

On the one hand, ALM use shortens the production process of customised components and reduces on-site storage of building materials. In this research context, layers are the architectural units to measure a building process. They are basic components, a new statement to describe a future holistic concept of tectonic construction.

Restoration practices could benefit from this approach. Digitisation of the restoration site opens the door to replicability, prediction of architectural systems' performance, use of new building techniques, or elaboration of traditional craft.

Additionally, the use of on-site robotics could help operations in inaccessible areas, especially in post-emergency conditions where fast measures are required. Moreover, it could enhance the quality of results, thanks to the programmable level of detail. Robots read and turn digital algorithms into restorative actions. The elaboration of a wide database of program scripts could help address digital documentation on Cultural Heritage and encourage further studies or application testing.

In this shift of design paradigms, the architects have the role of the professional who achieves several complex tasks. They produce the idea and develop the concepts through the project. They then have the knowledge and the tools to simulate the three-dimensional result in the digital environment. Finally, they can realise the physical model using large-scale tools associated with end effectors that link digital data to the tangible world in a continuous, uninterrupted flow.

The process takes place in a digital continuum (Leach 2002), which is the operative expression of the digital infrastructure we live in (Levitt and Dubner 2014), where skills and professional competencies meet.

Digital tools expand the designer's workspace, introduce the possibility of customising production, and extend the digital designer-craftsman arm (Sennett 2008), simultaneously linking design and fabrication.

The designer must define an innovative system of man-machine relations through a conscious approach that draws on traditional craftsmanship.

Acknowledgements

The experimentation is made possible thanks to the College of Architecture and Design of Lawrence Technological University – Southfield – Michigan - USA.

Notes

1. For further information, see: https://d-shape.com/(online: 10 March, 2019).

2. For further information, see: http://digitalarchaeology.org.uk/ (online: 10 March, 2019).

3. For further information, see: https://taubmancollege.umich.edu/research/research-through-making/2011/revault (online: 10 March, 2019).

4. For further information, see: http://www.gramaziokohler.com/web/d/bauten/52.html (online: 10 March, 2019).

5. See the ASTM definition of additive manufacturing: https://www.astm.org/ (online: 10 March, 2019).

6. Significant abandonment of Detroit's built heritage began during the oil crisis, which affected the United States of America from 1973 to 1979 and significantly affected Detroit's auto industry-dependent economy.

7. For further information, see: https://catalog.archives.gov/ (online: 10 March, 2019).

8. The documentation about the Woodward Avenue Presbyterian Church is available at: https://catalog.archives.gov/id/25338557 (online: 10 March, 2019).

9. The point cloud of the Woodward Avenue Church is available at: http://webmodel.space/ (online: 10 March, 2019).

10. The present analysis addresses some deductions: 1) the most accurate geometric digital output (point cloud) is given by the laser scanner; 2) the structure-sensor is a useful complementary tool that can be used for quick surveys; 3) drones have the potential to collect data in inaccessible areas, but are not necessarily easy to use. Drone-supported scanners are not static tools, and the downdraft generated by the propellers raises dust and sediments from architectural components.

11. The experimentation is underway at the makeLab of the Lawrence Technological University. For further information, see: http://make-lab.org/ (online: 10 March, 2019).

12. The robot arm employed is a Kuka Kr6-arc, used for research and academic purposes at CoAD of Lawrence Technological University.

13. See: https://www.grasshopper3d.com/ (online: 10 March, 2019).

14. See: https://www.robotsinarchitecture.org/kuka-prc (online: 10 March, 2019).

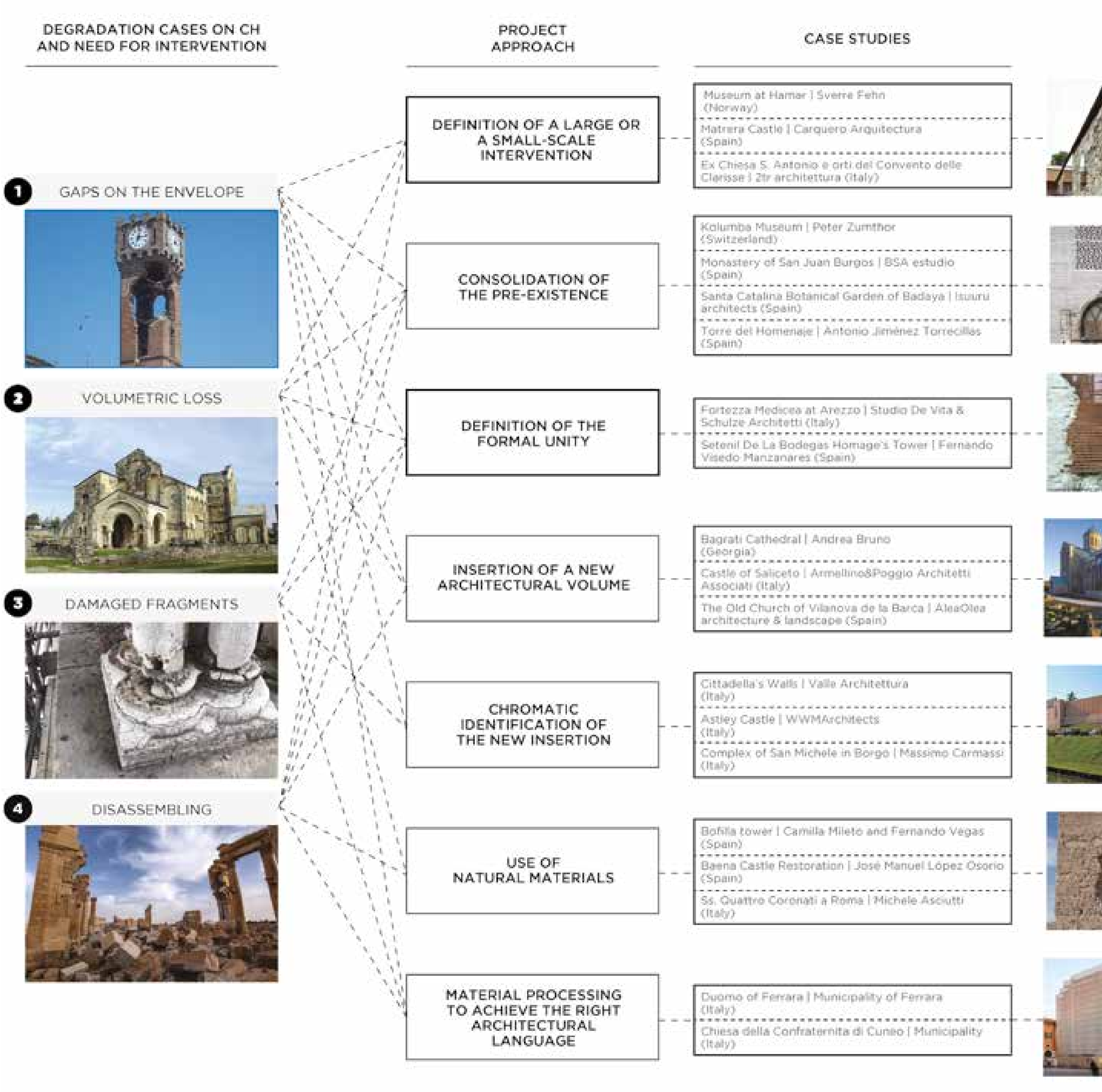

Figure 1: Cases of restoration of architectural heritage in the international framework. The selected projects are characterised by a similar design approach, using a contemporary language. Source: *author.*

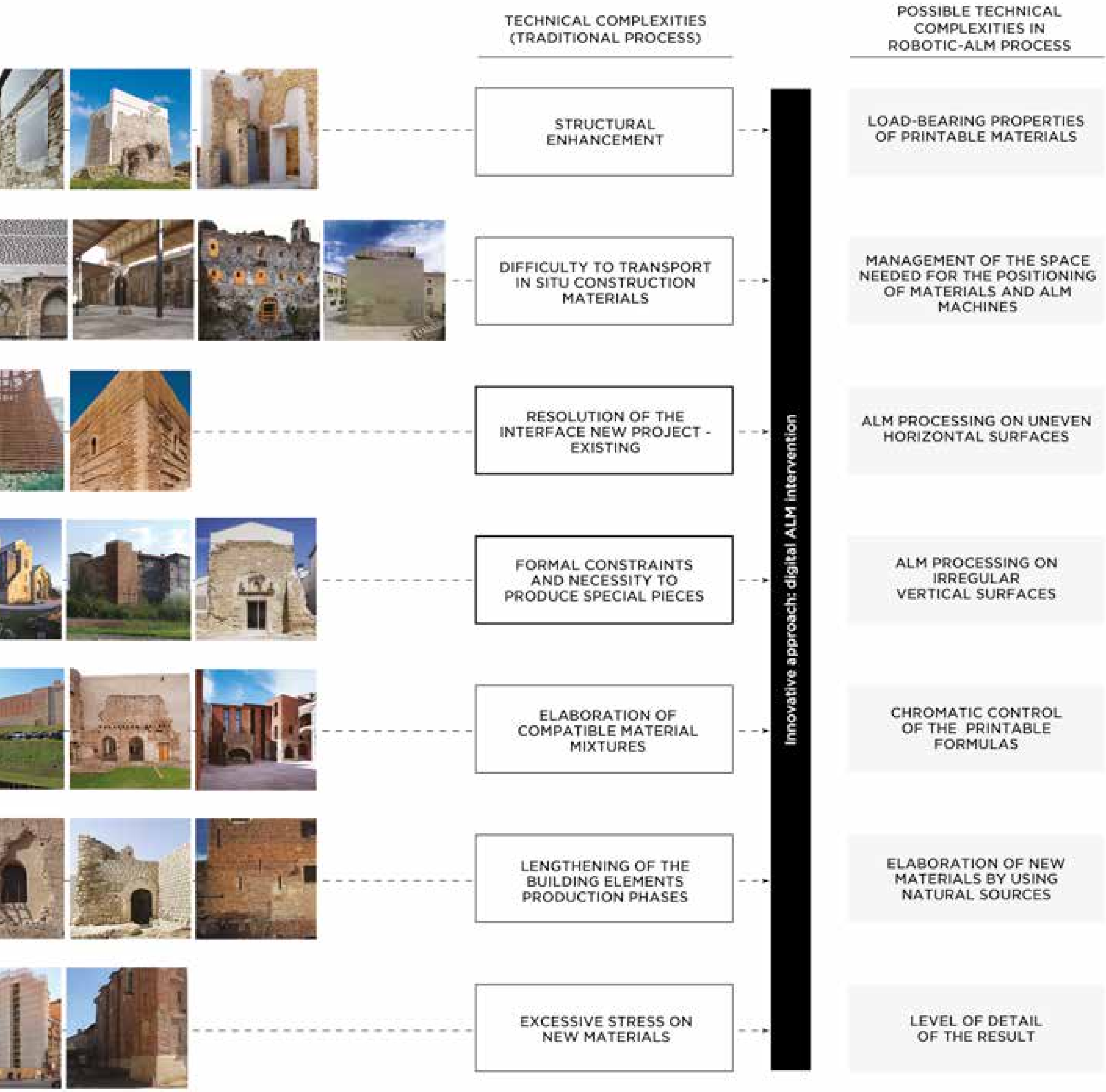
TECHNICAL COMPLEXITIES (TRADITIONAL PROCESS)
POSSIBLE TECHNICAL COMPLEXITIES IN ROBOTIC-ALM PROCESS
STRUCTURAL ENHANCEMENT
LOAD-BEARING PROPERTIES OF PRINTABLE MATERIALS
DIFFICULTY TO TRANSPORT IN SITU CONSTRUCTION MATERIALS
MANAGEMENT OF THE SPACE NEEDED FOR THE POSITIONING OF MATERIALS AND ALM MACHINES
RESOLUTION OF THE INTERFACE NEW PROJECT - EXISTING
ALM PROCESSING ON UNEVEN HORIZONTAL SURFACES
FORMAL CONSTRAINTS AND NECESSITY TO PRODUCE SPECIAL PIECES
ALM PROCESSING ON IRREGULAR VERTICAL SURFACES
ELABORATION OF COMPATIBLE MATERIAL MIXTURES
CHROMATIC CONTROL OF THE PRINTABLE FORMULAS
LENGTHENING OF THE BUILDING ELEMENTS PRODUCTION PHASES
ELABORATION OF NEW MATERIALS BY USING NATURAL SOURCES
EXCESSIVE STRESS ON NEW MATERIALS
LEVEL OF DETAIL OF THE RESULT
Innovative approach: digital ALM intervention

Figure 2 (top, opposite page): Interior of Woodward Avenue Presbyterian Church. Students and researchers at the College of Architecture and Design of Lawrence Technological University conducted a geometric survey for research purposes. Source: *author.*

Figure 3 (bottom, opposite page): Digital mapping achieved by using a Lidar sensor. It provides real-time geometric and photogrammetric information. This tool is used in quick assessment surveys. The outcome is useful in the preliminary phases of a project. Source: *author.*

Figure 4 (top): Experimental survey conducted with a drone connected to a structure sensor for collecting data in inaccessible areas. Use of this tool highlighted some critical aspects, including impact of the drone's kinematics on dust and stone debris, and flight time division into regular intervals to increase data accuracy and approximation. Source: *author.*

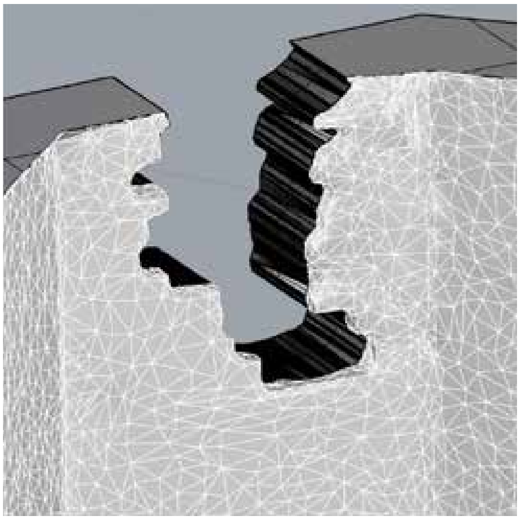

Figure 5 (opposite page; top to bottom, this page): Elaboration of the test bed. 3D modelling of the building's wall crack and overlapping of the geometry with photogrammetric information. Lidar sensor scans supported the proposed workflow for quick decision-making in urgent response scenarios. Source: *author.*

Figure 6 (top, page 48): Experimental settings for the simulation of an on-site digital robotic process. Operating in the physical world allows us to analyse all possible interactions between the robotic arm and the static geometries surrounding it. Source: *author.*

Figure 7 (top, page 49): The algorithm developed to guide the robot through the ALM process. Every cluster of inputs is strictly related to the mathematical rules underlying geometry. Therefore, geometry in space related to an action's execution time determines the robot's kinematics. Source: *author.*

Figure 8 (middle, page 49): Definition of the ALM toolpath and robot's movements within a geometric constraint in the digital environment. This procedure detects errors, such as collisions or positioning of unreachable target points, in an early stage of the design process. In the event of such mistakes, the virtual robot turns red. The script generates a graph describing which robot axis has issues and when. Source: *author.*

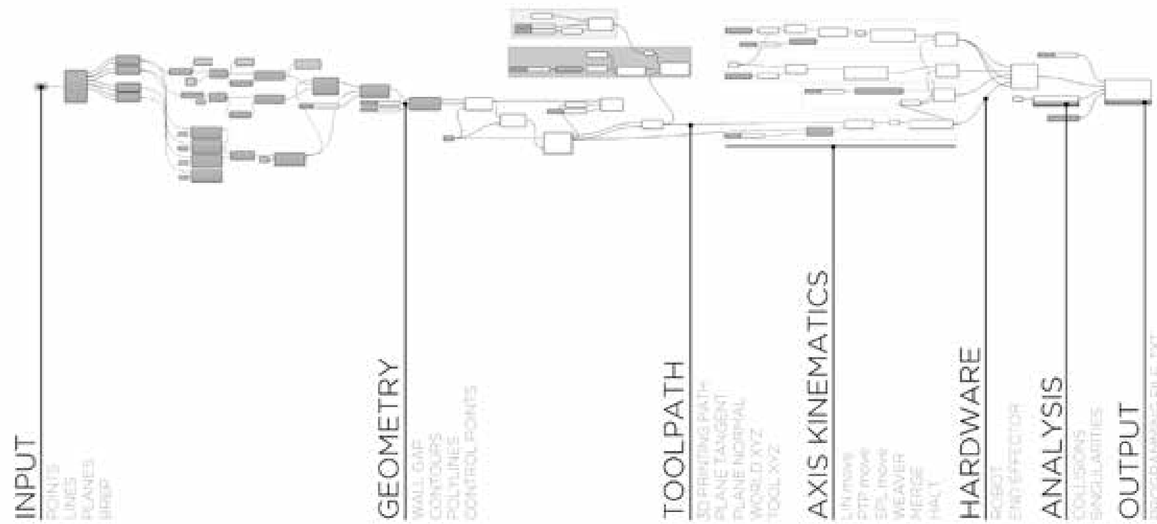

Figure 9 (below): Video frame images of the robot interacting with simple geometrical constraints generated by two vertical surfaces. This was an early stage before adding levels of complexity to the experiment. Source: *author*.

Figure 10 (opposite page): First extrusion of the toolpath. It is composed of the outlines and the internal supporting geometry. Initial testing was made on a flat surface to analyse the material's response to the robot's speed and to the nozzle's orientation relative to gravity. Source: *author.*

Figure 11: Iterative testing of the additive manufacturing process, using the end effector installed on the robot's head. Source: *author.*

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Bio

Sara Codarin is a PhD student at the Department of Architecture, University of Ferrara, Italy. She is fascinated by technological innovation within design processes. Her doctoral research investigates design and fabrication workflows in architecture with promising applications for the conservation of cultural heritage. She spent an academic year in America as a visiting scholar at the College of Architecture and Design of Lawrence Technological University, Michigan to develop an experimental application of her research. She studied large-scale robotic additive manufacturing by simulating on-site fabrication processes to produce construction units for the recovery of damaged buildings. Her work is tied to this broader knowledge base about substantial economic, technological, and social changes that will have repercussions in the architectural practice of future generations.

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Prototyping: The Dual Actions

Lee Y.H. Brian

054—073

Reflecting upon the constructionist model "learning-by-making," prototyping (prototype making) as a product design and research approach is well recognised for assured development of innovative concepts in individual or collaborative working environments. A prototype is typically used as a tool to support experiments or interventions and to evaluate research goals. It also facilitates participatory design and user-centred design. However, it carries both coded and tacit knowledge that we, design educators and practitioners, find problematic to explain and instruct, particularly to non-designers. This paper amalgamates and argues the characteristics of prototyping including types, formats, and principles through literature review. Reflecting upon the designer's intentions and the dual coding cognitive learning process, the author proposes a descriptive model that illustrates the dual actions experienced by the designer which can enable study on the improvement of the prototyping process.

#prototyping

#constructionism

#dual coding theory

#analytical-synthetic action

Introduction

A prototype is a simplification of a product concept meant to resolve issues in product development (Otto et al. 2001). It can be considered as an ideation technique in which a physical object is built to encourage new ideas-"we build to think" (Rikke and Teo 2019). Designers and non-design practitioners recognise prototyping, or prototype making, as an essential activity for innovation, collaboration, and creativity in design (Hartmann et al. 2006). Described by Murray et al. (2010), prototyping is the design of a working model of a product or service to test out reactions of potential clients and providers. It is an informal evaluation or testing approach to test ideas in an incomplete form and move quickly into practice. Operating principles of prototyping include:

1. Speedy production processes;
2. Low cost;
3. Providing tangible experience;
4. Iterative design; and
5. Feedback from users and specialists.

Prototyping became a buzzword during the design thinking movement, elaborated by 3D printing and maker culture's emergence in the last decade (Halverson and Sheridan 2014). More people recognise that physical models support the transformation of intangible concepts or two-dimensional experiences into physical or three-dimensional objects that users can effectively understand, such as perceiving form factors or ergonomic responses (Rikke and Teo 2019). In Hong Kong, there are numerous non-academic organisations, such as the Hong Kong Design Centre and some professional societies, promoting design thinking and offering participants a glimpse into designer-ly ways of thinking or working. Target audiences include non-design professionals, such as business community leaders and civil servants. The design thinking process of the "the five-stage Design Thinking model by The Hasso Plattner Institute of Design at Stanford University" and the "double diamond model" of the British Design Council are favourable guiding principles, through which exercises numerous people have learned about the prototyping methodology.

For social innovation projects, Hillgren et al. (2011) elaborated the advantages of incorporating prototyping as a method for establishing long-term engagement with stakeholders. Prototyping can facilitate open discussion, conflict realisation, empathy development, consensus development, and conflict resolution through visualisation and collective experience. As prototyping is prior to *final* implementation, which conceptually limits freedom for further interpretation, modification, and negotiation, prototyping increases stakeholder buy-in and reduces conflict.

This approach follows the principle, "Fail earlier to succeed sooner" in the context of use (Burns et al. 2006; Brown and Wyatt 2010). Prototyping is an informal evaluation or testing approach for an idea to emerge in an incomplete form and swiftly move into practice. For bottom-up social innovation initiatives, prototypes act as catalysts and binders which help stakeholders, especially non-professionals who take part, build ownership. Prototypes allow collective involvement through iterative development: a prototype is understandable as part of an ongoing process, open to user contribution. As such, it not only supports conventional design processes, but also extends into the social economy by connecting users to professionals, resolving conflicts, and creating an agreement amongst the stakeholders with entrenched personal interests (Murray et al. 2010). Social service providers in Hong Kong have recently shown great interest in prototyping, and approached design researchers and professionals to offer training and support on the prototyping technique. A noteworthy fact is that most stakeholders perceive prototyping as a design professional skill set.

The author held discussions with stakeholders, such as design workshop facilitators and participants, to articulate what prototyping is, and how this skillset can transfer more effectively. In particular, knowledge transfer must address the time constraint of short-term design thinking workshops, lasting the duration of a few hours or days. Innovation training emphasising early prototype making, such as sketching, scenario design, mock-up or model making, is well accepted as a strategy that ensures quality design concepts and market fit. Unfortunately, the author witnessed failure cases and difficulties pushing forward effective prototyping practices with different workshop participants, particularly those without art or design training. To understand this, design educators must clarify what prototyping is, and how it may benefit the promotion of design thinking to other disciplines, as well as pedagogical development in design school.

Scope

In design education, prototyping involves material processing techniques, from hand tools to mass production methods, hand-eye coordination training through sketching and modelling, and visual-spatial thinking techniques through two- and three-dimensional visualisation practice. It is a time-consuming investment. Prototyping is discipline-specific know-how and is therefore difficult to facilitate in a short-term course. What are the factors that contribute to effective instruction of the prototyping methods other than time? To answer this, we must firstly have a detailed understanding of the prototyping experience.

Rikke and Teo (2019) provide eight common prototyping methods or types as a holistic overview of the process. They state that there are endless ways to build a prototype, but Rikke and Teo's methods include:

1. Sketches and diagrams, for visualisation of concepts;
2. Paper interfaces, such as a draft mechanism design to gain user feedback on the user experience;
3. Storyboards, like a storyline sketch to explain the user's journey;
4. LEGO prototypes, or more broadly a set of modular toys or components to facilitate quick modelling;
5. Role-playing, such as the imitation of a scene whereby potential users can anticipate experience for reflection;
6. Physical models, like a three-dimensional mock-up of a chair design for ergonomic evaluation;
7. "Wizard of Oz" prototypes, which are partial demonstrations of automated systems triggered by humans rather than by computation; and
8. User-driven prototypes, developed in forms according to users' intuition and preferences.

These methods demonstrate tangible experiences, such as ergonomic or mechanical characteristics, and intangible experiences, such as aesthetics or symbolic characteristics, using low-fidelity or high-fidelity creations. These range from proofs-of-concept to functional manifestations. The forms of eight prototype methods are distinctive, but interplay of their functions in the design process can cause confusion.

To clarify the problem, the author differentiates these methods in the accompanying matrix (*Fig. 1*). According to a review of various design and design research projects, prototype methods present two dominant spectra of characteristics:

1. The detail level of their prototyping contexts, between low and high fidelity;
2. Dimensions of perceived user experience, for example from two-dimen-

sional visual information to animation, including the symbolic meaning and cultural practices.

Two of the prototype types, “Wizard of Oz" prototypes and “user-driven" prototypes, are not included in this matrix because they refer to the prototyping engagement strategy instead of the form of the work. The superimposed characteristics of these methods explain the reason why identification of a right or precise choice of prototyping method during design development is challenging to both designers and non-designers. The novice designer may encounter uncertainty, which hinders the effectiveness of product development or design collaboration due to ambiguity. There is no absolute prototyping method. On the contrary, an experienced designer employs prototyping methods depending on which are most handy. For instance, prototyping methods may depend on the availability of relevant materials, tools, and objects.

Dual coding in the prototyping process

Application of the matrix showing the distribution of prototyping methods supports the prototyping process. For instance, the red arrow indicates that a designer can develop a concept from a sketch to a role play prototype at the level of dimensions of representation to address the concreteness or richness of information at different levels of fidelity simultaneously. During this process, the designer makes sense of the design concept through the dialogue between the verbal concept and the visual concept.

This sense-making mechanism can be understood through *dual-coding theory* as described by Allan Paivio (1971, 1986). The theory explains dynamic associative processes in cognitive actions, a subsystem of holistic sensory cognition that connects verbal and visual stimuli and representations (Clark and Paivio 1991). The stimuli include newly experienced materials through the sensory systems, such as visual, auditory, and kinaesthetic information, and previously learned materials stored in the memory as knowledge. The theory supports students’ learning experiences through adopting verbal and visual means together, and also ensures better memory and depth of the learning contexts. Paivio postulates that “visual and verbal information is encoded and decoded by separate, specialised perceptual and cognitive channels in the brain.” The visual channel simultaneously manipulates mental images or non-verbal entities, called *imagens*. Verbal entities such as spoken or written words, called *logogens*, in the linguistics channel function linearly and sequentially (*Fig. 2*).

When the same information is presented to the brain in different forms, for instance verbally through written notes of a design concept, and visually through a sketch or model, this is a form of “dual coding.” The use of visuals and text together can increase comprehension. This helps explain why designers apply visual means to carry out research and brainstorming with the input of verbal contexts, such as historical information, symbols, and abstract verbal theories. Visual information enhances the understanding, development, and memorisation of abstract verbal information. In design practice, this theory explains how designers articulate verbal and visual coding materials to develop purposive design artefacts, which communicate better with their audiences or users. Shifting in-between actions, the designer explores the most sensible prototyping approach, and critically reflects the constraints of a product’s form development. The process can simultaneously occur in the designer’s brain, on paper, and with hands-on making with physical materials and tools. The author argues that the immediate cognitive action of the prototyping process is the learning experience the designer perceives while he or she recognises and associates logogens and imagens together. This explains why there are many types of prototyping methods, and usually multiple methods are used in one design project: during the design process, the designer articulates design opportunities or appropriation, and justification/reflection.

The connections that pair logogens and imagens, called referential connections, are mechanisms that link words to images, or images to words. The movement inter-crossing different pairs can be considered an articulation process whereby designers adopt different prototyping methods and carry out the iterative process. For instance, if the designer explores an outdoor seating platform to enable intergenerational interactions amongst elderly and younger generations, at least physical models to probe appropriate ergonomics, and storyboard methods to demonstrate users' experiential sequences, should be applied to support the design hypothesis for further development.

Here follows further explanation about the implicit relationship between this cognitive movement between logogens and imagens, and the motivation of the designer which shapes and moves forward the idea generation and prototyping process. The discussion below will elaborate the situation through the distinction of science and design study, and the constructionist's perspective on the designer's experience. If we build a model to explain the cognitive experience of the designer in the prototyping process, researchers must explore the forces driving the designer to shape visual form.

Prototyping builds dialogue between analysis and synthesis

In product design practice, a prototype is a representation of an innovative concept, but it enhances understanding and enables communication at both personal and collaborative levels. One essential characteristic of prototyping is that it interweaves making and reflection, as research, iteratively. Thus, prototyping takes different forms, and their flexibilities are the reasons why those unfamiliar with prototyping practice cannot adequately describe it. Cross (2001, 2006), Rittel and Webber (1973), Simon (1969) and Alexander (1964) elaborated on the distinct characteristics of general design activities through differentiation against science/analytical and design/synthesis perspectives. We can further implement these two distinctions to discuss the differences in prototyping processes: analytical-prototyping and synthesis-prototyping.

Analytical activity in science concerns *how things are*, how to solve science problems, also called *tamed problems*, and how to identify the components of existing structures or products. Moreover, results or practices must be repeatable. Analytical-prototyping concerns recognition or understanding of the pattern or structure of the prototype through visual means. It focuses on the study of a part or a specific component through visualisation. It also clarifies the relationship of design features, and dimensions or measurement confirmation.

Synthesis activity in design concerns *how things ought to be* and how to solve design problems, sometimes called *wicked problems*, and to identify the shape of the components of new structures. Design practices may not need to be repeatable, and usually perform as a unique solution. In synthesis-prototyping, the approach emphasises pattern synthesis or hypothesis making through visualisation, such as association or combination of images, or physical construction. Synthesis-prototyping focuses on the materialisation of abstract concepts to concrete concepts. For example, prototyping converts comparatively abstract wording describing *a comfortable seat* to a concrete image of a chair with a cushion. It also enables the exploration and evaluation of unique forms.

Through prototyping, aligned with Cross' design process concepts, a designer proposes additions and changes to the artificial world which require knowledge, skills, and values entailing the techniques of the artificial. Design knowledge is inherent in the artefacts of the artificial world, and is gained through three design-related activities:

1. Designing of artefacts;
2. Usage of artefacts; and
3. Manufacturing of artefacts.

For instance, in using artefacts, designers gain knowledge connecting forms and configurations by copying from, re-using, or varying aspects of existing artefacts. In manufacturing artefacts, designers gain knowledge through making and reflecting either upon the making process or instruction. Prototyping, or designing through prototyping, is a knowledge-acquiring process in which the designer experiences both making, through shaping and pattern synthesis, and reflecting, through analysis and pattern identification.

Design involves substantial learning experiences which can be understood in the perspective of Papert's constructionism[1]–learning by making (Ackermann 2001). Thus, the designer's action of making, such as the analytical-prototyping and synthesis-prototyping, is also a learning process. The analytical process and synthesis process happen iteratively until the final prototype is settled. What aspect drives the movement back and forth between these two distinctive cognitive processes? This can be further understood through the perspective of knowledge creation.

Urging design's establishment of a stance on knowledge creation, the discussion of differences between design and research activities has emerged more formally and explicitly since the 2010s. Stappers and Giaccardi (2017) summarised various thoughts on this matter. Design activity usually connotes the production of creative work that is specific and concrete or situated. Research activity connotes the output of knowledge that is generalisable and abstract. Stappers and Giaccardi quoted Liz Sanders' identification (2005) of the similarities and differences between the traditional design research approach, which is called information-based design research such as usability test and ethnography, and the designer-ly approach to study, which is called inspiration-based design research, such as cultural probes and generative techniques. Similar concepts include both the aim to create something new, or *prospective perspective*, and building on previously known matters, through *retrospective perspective*. Hence, different prototyping methods and the intentional perspective of the designer are needed.

Making is an effective learning approach in constructionist research practice (Halverson and Sheridan 2014). Theorists can understand the design-researcher's making process as building connections back and forth from abstract to concrete. This practice immerses the design-researcher into the wicked problem space, filled with various uncertainties, to emerge with a concrete experience or prototype demonstrating distinct design functions or features.

Through a review of the prototyping cases below, the author identifies *two implicit actions* in which designers employ prototyping activities iteratively between *two zones*. At one end is the zone of retrospective action, imitating, reviewing, measuring, or correlating. At the other end is the zone of prospective action, outputting innovative or hypothetical artefacts which in turn researchers can evaluate in the retrospective zone for proof against hypotheses or theory. The analytical-synthesis action happening in the two zones is highly connected. The prospective action is a high-level cognitive activity aligned with the *constructive forethought* Sutton and Williams (2010) described. They quote the statement from Gregory (2004) who said: "design generally implies the action of intentional intelligence." Thus, this sense-making intention drives the momentum of the cognitive changes from one end in retrospective and analytical actions, to the other end in prospective and synthesis actions. The designer simultaneously develops prototypes back and forth from the abstract world to the concrete world. This momentum is illustrated in *Fig. 3*.

Typically, the designer's cognitive experience swings between the analytical and synthesis modes, indicated in *Fig. 3* as swinging to the left when the designer processes the analytical/retrospective concerns, and to the right the synthesis/prospective concerns. This movement can operate as a dialogue between the designer and the artefact, at the intrapersonal level, or in the group discussion or collaborative working environment, at the interpersonal level. Designers perceive an iterative process during the development of a prototype from abstract and uncertain concepts to concrete concepts or vice-versa.

A proposed cognitive framework for the product prototyping process

Understanding the initial stage of prototyping is useful for connecting prototyping itself with its potential outcomes. At the beginning, the designer should acquire specific design criteria, either verbal and/or visual concepts, before entering the early prototyping stage, even if the criteria are unclear or uncertain. Designers commence prototyping from a goal, whether or not clear, which could be in words and/or visual form. They map different possible factors and elements comprehensively from partial to holistic consideration.

Mapping is constructed through three primary considerations: the constraints of the product, form development, and prototyping format. Conceptual clarity itself is a relative concept, and one of designers' major intentions regardless of specific project criteria. Prototyping typically articulates this clarity later in the materialisation stage. If there is no concrete concept or image in the brain of the designer, he or she may explore, through rough sketching, a stage before prototyping. Thus, prototyping only happens when the designer is ready to engage in making or has already envisioned a potential concept in the form of a mental image, sketch, or physical artefact.

To realise the relationships between the actions, conditions, and considerations, *Fig. 4* explains the designer's cognitive processes while perceiving the verbal and visual stimuli during early prototyping stages with the dual coding system as the first action, shown as vertical movement on the diagram. During the stage when logogens and imagens connect, the second action, shown as horizontal movement on the diagram, happens in two distinctive mindsets. The six constraints on product form development drive analytical/retrospective processes. The five prototyping principles and eight appropriated prototyping formats drive the synthesis/prospective processes. To initiate the dual actions mechanism, one of three common conditions for a product's form development steps in. Lastly, the prototype or test deliverable induces iterative development.

Knowing the requirements and constraints of product form development cannot explain a designer's motivation during the appropriation process, while the designer chooses prototyping methods. The driving force for prototyping method selection is the availability of actionable resources to the maker. Camburn et al. (2015) proposed five design oriented and actionable principles which aid designers to meet the objectives of a prototyping task. Designers incorporate the five principles below into the prototyping process to develop specific prototyping methods. Appropriateness to the project brief and the designers' situation motivates choice between one or more of these five principles. These work as subsets to the eight prototyping methods, and consideration of the six constraints:

1. Hack commercial products;
2. Employ basic crafting;
3. Prepare fabrication blueprints;
4. Repeat fabrication processes; and
5. Include structural voids.

The author proposes a framework to explain the considerations of the designer's experience in prototyping approach selection and development of prototypes driven by the proposed dual actions. In this framework, vertical movement demonstrates the dual coding path, and horizontal movement the ambivalent intentions of the designer shifting between analysis and synthesis processes. The processes involve iterative consideration of constraints and opportunities through various prototype methods.

Prototyping is a learning process across retrospective and prospective zones

Through learning by making, the author identified several characteristics of prototyping in its role to further substantiate the above-proposed framework of prototyping process through the elaboration of five first-hand cases. Sketching case studies describe the significance of cognitive movement back and forth between the analytical/retrospective zone and the synthesis/prospective zone during the prototyping process.

As mentioned earlier, the designer conducts analytical activities to imitate, review, measure, and correlate concepts through prototyping in the retrospective zone. The first case researched indigenous handicrafts and sought ways for prototyping and design thinking to support revitalisation. This paper selects a sketch-prototype (*Fig.* 5) from this project for discussion. It is a common practice to sketch to explore new ideas. However, sketching to facilitate learning or enhance memory plays a vital role in design, such as solving complicated assembly problems.

This sketch helped the author to build a mental model, describing the relationships of different components of the wooden cart and fabrication method in the mind's eye. This example illustrates that design researchers can adopt sketching to investigate the form of an artefact, as it can be directly carried out by visual or physical examination, and by reverse engineering the fabrication process. This kind of reverse engineering is indirect learning through a dry run in the brain, at a lower risk of resources. Designers can also review the constraints of form development such as functional, aesthetic and production considerations for their impact on product effectiveness (Bloch 1995 as cited in Crilly et al. 2009).

Sketches accompany verbal descriptions of visual thinking, during which designers can memorise and manipulate visual images (Reed 2013). Thus, sketching is a common tool used at the early concept and other phases of the development process. Sketching as a type of prototyping works not only for envisioning the hypothetical design but also applies to the analysis of the artefacts or scenarios whereby the design researcher can explore the contexts in detail through visual means.
Visual contexts usually refer to affective responses that users experience in human-product interaction, in which sense stimulation can be triggered. A recognised framework to

elicit the experiential impact of new designs is the three components or levels of product experience proposed by Desmet and Hekkert (2007). As defined by Hekkert (2006, 160), product experience is:

> *…the entire set of effects that is elicited by the interaction between a user and a product, including the degree to which all our senses are gratified (Level I: aesthetic experience - visual aesthetics, and tactile and kinaesthetic), the meanings we attach to the product (Level II: experience of meaning – semantic interpretation, symbolic association, linguistic expressions, and figurative expressions) and the feelings and emotions that are elicited (Level III: emotional experience – personal evaluation (appraisal) of an event or situation with beneficial or harmful impact).*

In practice, designers and researchers can use this framework to explain phenomena of iterative processes based on the evaluation of the three types of product experience induced while sketching or making a prototype.

Compared to written concepts, sketching or prototyping can provide visual information to the creator or interpreter. The designer can then associate aesthetic experiences and the experiences of meaning, and also tacit or intangible product experiences that verbal tools cannot support. For instance, aesthetic experiences, such as line quality of a sketch, help the creator to experience the abstract qualities of a sketch/prototype such as softness/hardness or gentleness/robustness in a design. The creator can also perceive additional information, such as emotional experience induced by touching the material, while fabricating an artefact. Furthermore, people can understand implicit know-how either by fabricating a design or drawing it on paper. This experience involves visual and spatial relationships correlating with various design components which cannot be communicated easily through words. Thus, sketching or drawing is a popular method to collect people's perceptions or express individual understanding.

On the other hand, if articulation in oral language of a participant or informant is an issue, for instance when researchers interview people who are deficient in verbal communication, verbal thinking and expression is less successful compared to a sketch-prototype. Building a physical model to make a direct copy of an existing design can also support the builder or maker to learn the unique structure and production method, which cannot be explicitly and comprehensively described through a verbal description alone.

Case two demonstrates prototyping as a synthesis process in a prospective manner. In this case, the author carried out an ergonomic chair design proposing an adjustable backrest. Before exploring a new backrest, the author examined several backrest designs of different ergonomic chairs through desktop research and sketching. Using a quick paper mock-up (*Fig. 6*) helped the visualisation of the three-dimensional structure and mechanical movement that cannot be quickly evaluated and shared by sketching alone.

Hands-on work and manipulation of tools support the proving of a design hypothesis, such as the identification of novel design pattern. Case three is another example that showcases the back and forth between retrospective learning and prospective learning. The project is an upcycling lampshade design and production project which the author and a project team facilitated for a group of secondary school students. The students learned about the properties of polyethylene terephthalate (PET) bottles by exploring their physical patterns and structural performance, cutting, bending, and punching the material. They experienced and identified material characteristics during the making process. After identifying a potential module or unit, the student integrated the components or units into a bigger piece of meaningful structure that functioned as a lampshade (*Fig. 7*).

Case four illustrates a fully functional prototype (*Fig. 8*). A revamp of an old tram for the event called deTour 2013 funded by CreateHK provided a chance to develop a full-scale, functioning design prototype. The project created an alternative urban experience by transforming a street tram, and the project team proposed a transparent envelope to allow people to understand the internal structure of daily transportation design. Researchers studied the workings of the tram windows, the linkage system that opens and closes the window, and the traditional wooden structures of the tram's framework, which became the primary feature. Transforming the tram to be entirely transparent was the experimental goal of the prototype.

This working prototype generated a new transportation experience for real users and demonstrated an innovative, feasible approach to the management of the tram company, and the Electrical and Mechanical Services Department of the Hong Kong Government, which took on the project risk. As mentioned above (Murray et al. 2010), prototypes help build coalitions amongst stakeholders, and in this case may assist future policy development. This example portrays how a functional prototype can benefit evaluation at the community level. Synthesis is essential in the prototyping process but evaluation and feedback through public engagement could be a more important project goal.

The final case is a qualitative research project about elderly people's' perceptions of home furniture and spatial needs through scale modelling (*Fig. 9*). The author's team developed the model to facilitate a participatory design activity for engaging elderly residents. The preparation of the models, including the selection, measurement, and making of the proper apartment and furniture, provided plenty of background information and encouraged project team reflection. The team implemented a two-step prospective and retrospective prototyping approach, with a model prototype allowing retrospection on the apartment's current state. Users guided most of the prospective phase as experts of their own experience (Sanders and Stappers 2008). The team visited the home of local elders who were instructed to build their current home furniture layouts. The team asked questions about relevant living problems such as, "does the bed meet your current needs?" Afterward, prospective questions like, "how does this arrangement meet your foreseeable future needs?" were easier to ask using the prototype. Elders designed and made their preferable furniture layout, and told the team reasons for changes or an unchanged design. This sample illustrates that a modular-type prototyping tool can engage non-professionals to express creative ideas and needs with more accuracy and accessibility than a questionnaire alone. It also supports a designer who can collect more genuine user needs through interaction between informants and prototypes. Especially, since participants know their personal needs well, prototyping with the two-step approach is more effective.

Conclusion

The above integration of various theories maps the designer's overall cognitive experience in the product design prototyping process. The core cognitive activity is the recognition of verbal and visual stimuli whereby analytical, constructive, and creative associations between verbal and visual materials can lead to comprehensive learning as well as the development of new meaning or knowledge. It is illustrated as the vertical axis in *Fig. 4* and represents the first dimension of cognitive action.

The five design-oriented, actionable principles, the six constraints of product form development, and the eight prototyping formats are the major elements that guide the prototyping process. Designers employ all of these factors in the second dimension amongst two distinct zones– a retrospective/analytical and prospective/ synthesis at the horizontal axis. The description of this dual-action prototyping process framework and the correlated cognitive learning activities are expected to shed light on the future studies of prototyping strategy and pedagogy in design education.

Acknowledgements

Special thanks go to Professor Siu, Kin Wai Michael for his intellectual input that inspired the research direction of the study and the editorial support from assistant professor Daniel Elkin.

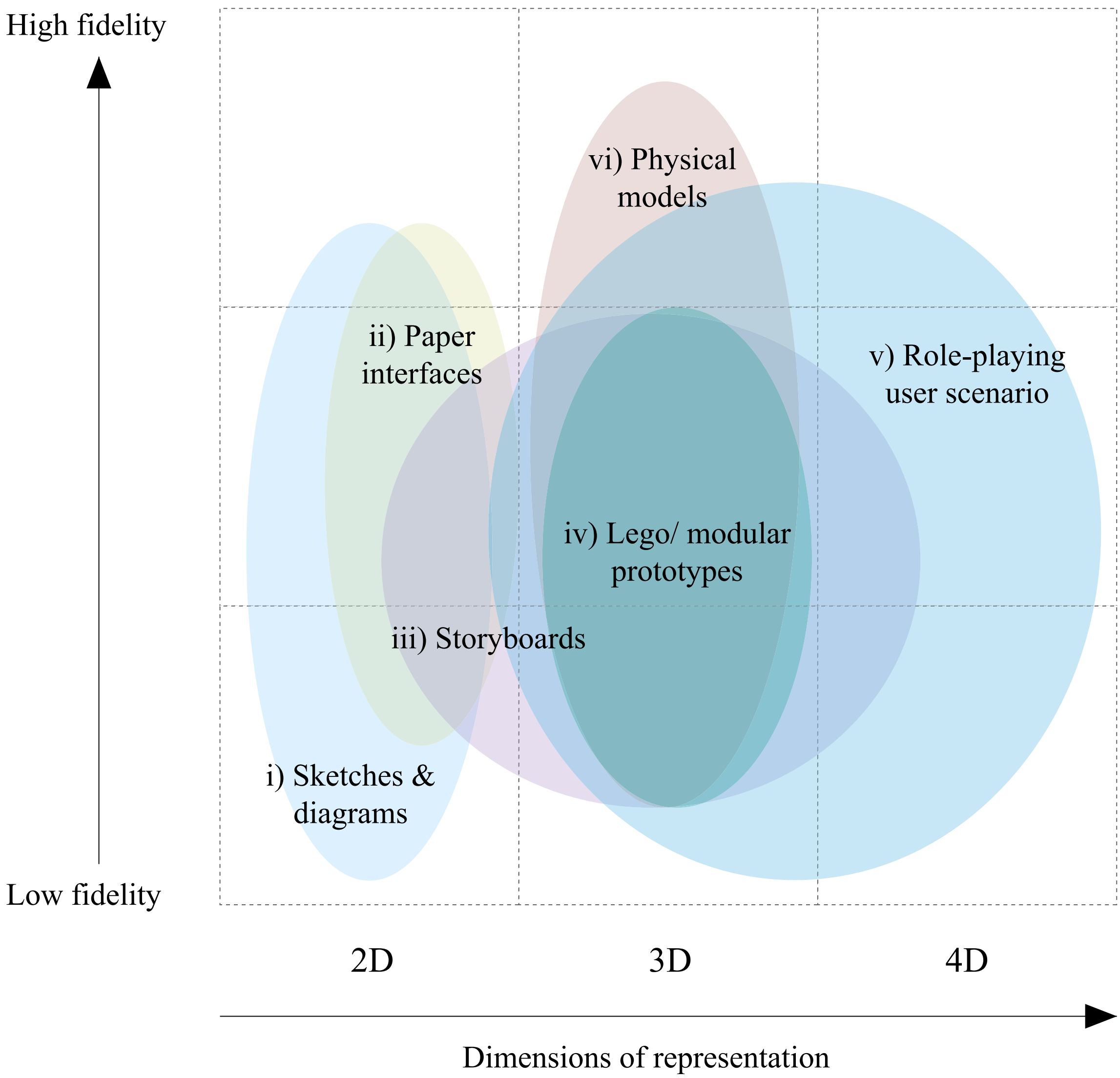


Figure 1: A matrix of prototyping methods illustrates two significant spectra of a prototype's characteristics. Designers may quickly visualise the most appropriate method according to current resources on hand during the prototype planning process. The paths of red arrows illustrate the designer's identification of the most reasonable type of prototype across different characteristics as shown in the two dimensions. Source: *author.*

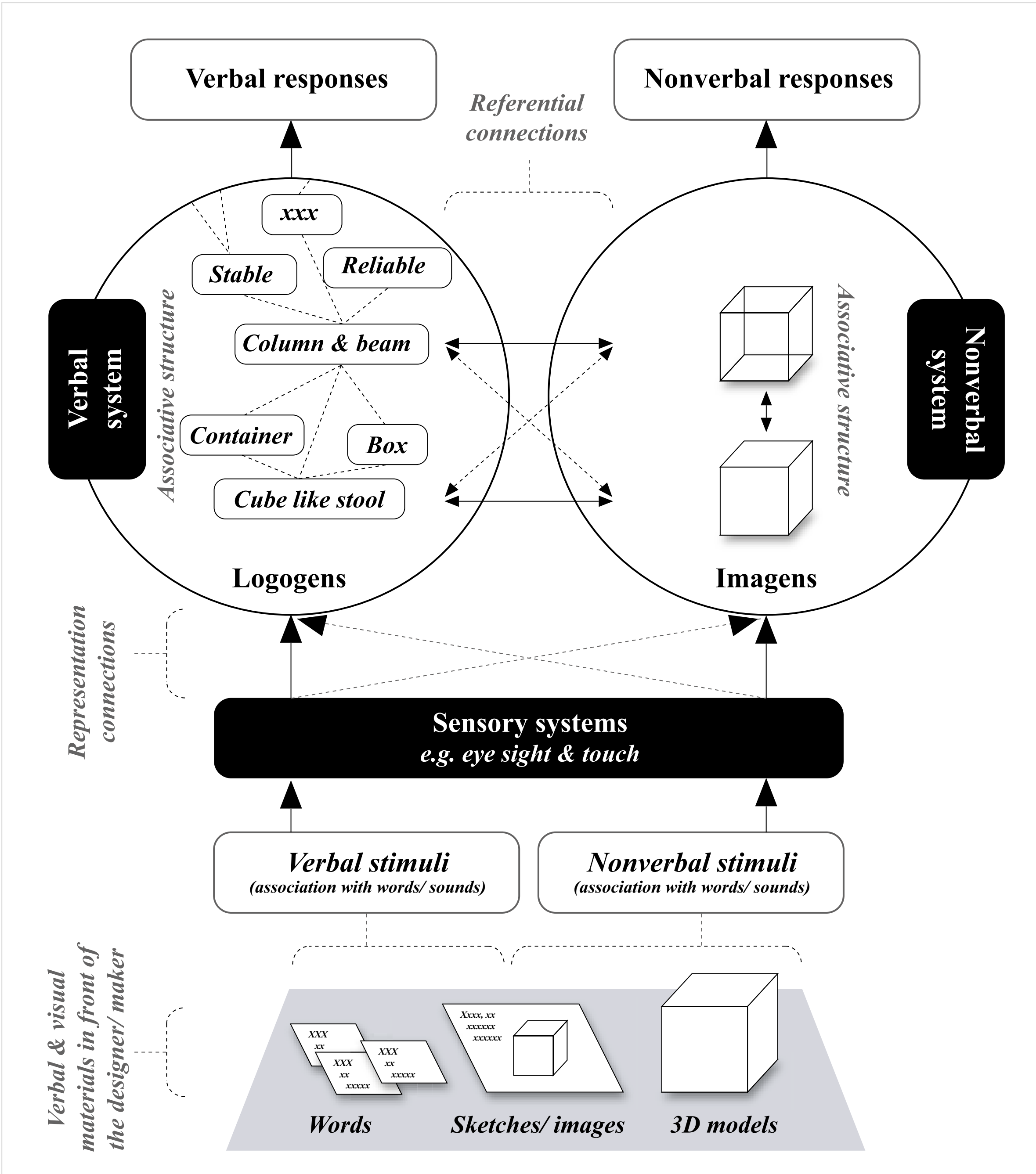
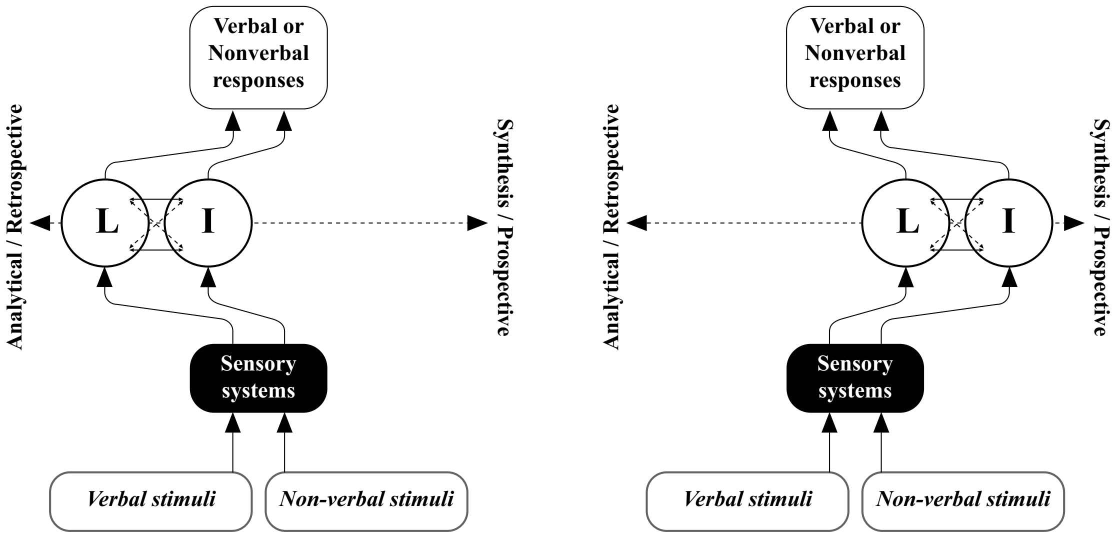


Figure 2 : This diagram illustrates the dual coding mechanism modified from Allan Paivio's theory (Paivio 1986). This indicates two cognitive subsystems sensing verbal and visual materials respectively. Verbal coding interprets lologens associations and hierarchies. Visual coding interprets part-to-whole relationships within imagens. Source: *author.*



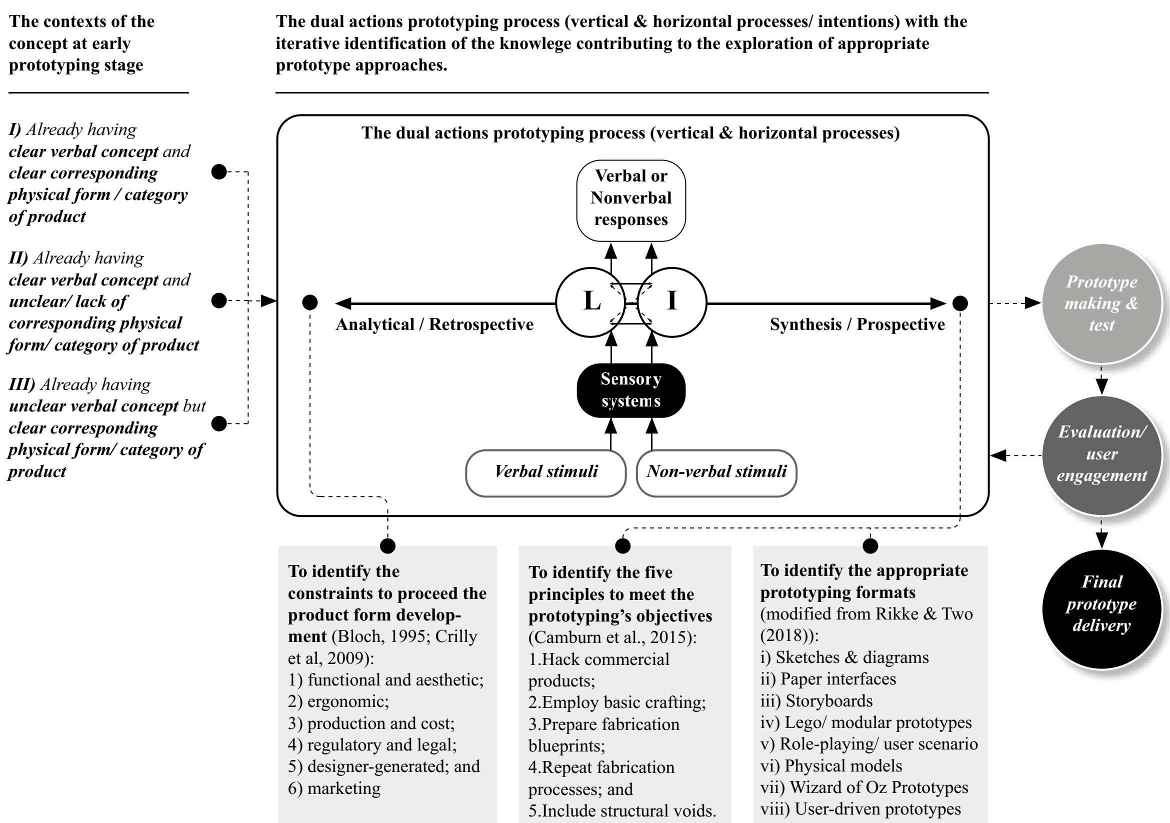


Figure 3 (top): The analytical/retrospective and synthesis/prospective swinging action diagram. The vertical path indicates the dual coding system from sensory stimulus to the responses of a designer. The horizontal dimension with two ends indicates the intentions of the designer who either operates the analytical-prototyping or synthesis-prototyping. Source: *author.*

Figure 4 (bottom): The dual actions prototyping processes framework. It demonstrates how consideration of constraints and opportunities of product form development, and various prototyping objectives and formats are connected and driven by the dual actions. Source: *author.*

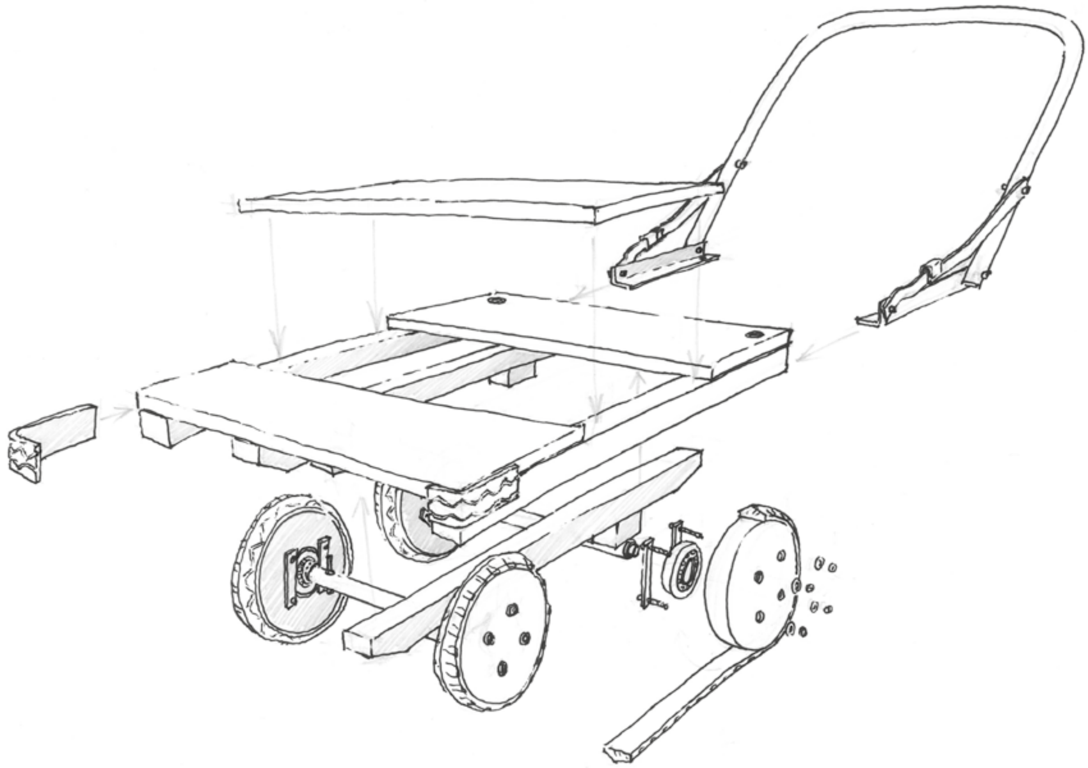


Figure 5 (top): Sketch as a visualisation tool to facilitate visual thinking that enables investigation of, in this case, craftsmanship techniques including the logic of structural form, selection criteria of materials, and fabrication methods. The drawing also facilitates visual driven communication amongst researcher, designer and the producer. Source: *author.*

Figure 6 (bottom): The paper model demonstrates the relationship of movable parts of the design hypothesis. The animated structural feature of the design supports simulation and evaluation through sequential movement and tactile experience. Source: *author.*

Figure 7 (page 69): Searching design patterns, or meaningful visual structure, is a significant learning experience and creative outcome of prototyping. This image is the result of a group of secondary school students after they explored PET bottles' material properties through trial and error, and explored pattern recognition by organising the material. Source: *author.*

Figure 8 (opposite page): The tram with a transparent envelope run on Hong Kong Island served people for more than a week during the end of 2013. LED lighting was installed to highlight the internal mechanism of the tram. Source: *author.*

Figure 9: The participatory design activity conducted during a home visit of a local elder who was asked to prototype his preferable home furniture layout with the modular components and models. Source: *author.*

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Bio

Brian Lee, faculty member of School of Design and co-leader of Asian Lifestyle Design Lab of The Hong Kong Polytechnic University, teaches and carries out research in product design and social design disciplines. His specific expertise is in ageing & healthcare product and service design, sustainable lifestyle and consumption analysis, and co-creation with multidisciplinary approach. His current work explores the intersection between socio-materiality and design practice, and research to address prototyping process development. He examines design hypotheses in the context of social, economic, and technological matters, artisanal practice, new production methods, and consumption practices. He demonstrates significant participation in understanding the role of artefacts and systems in response to the betterment of quality of life, empowerment of communities, and the promotion of sustainable living through prototyping and other creative engagement tools with stakeholders.

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Making a Case for Modularity

Dr. Guan Lee
Daniel Widrig

074—103

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

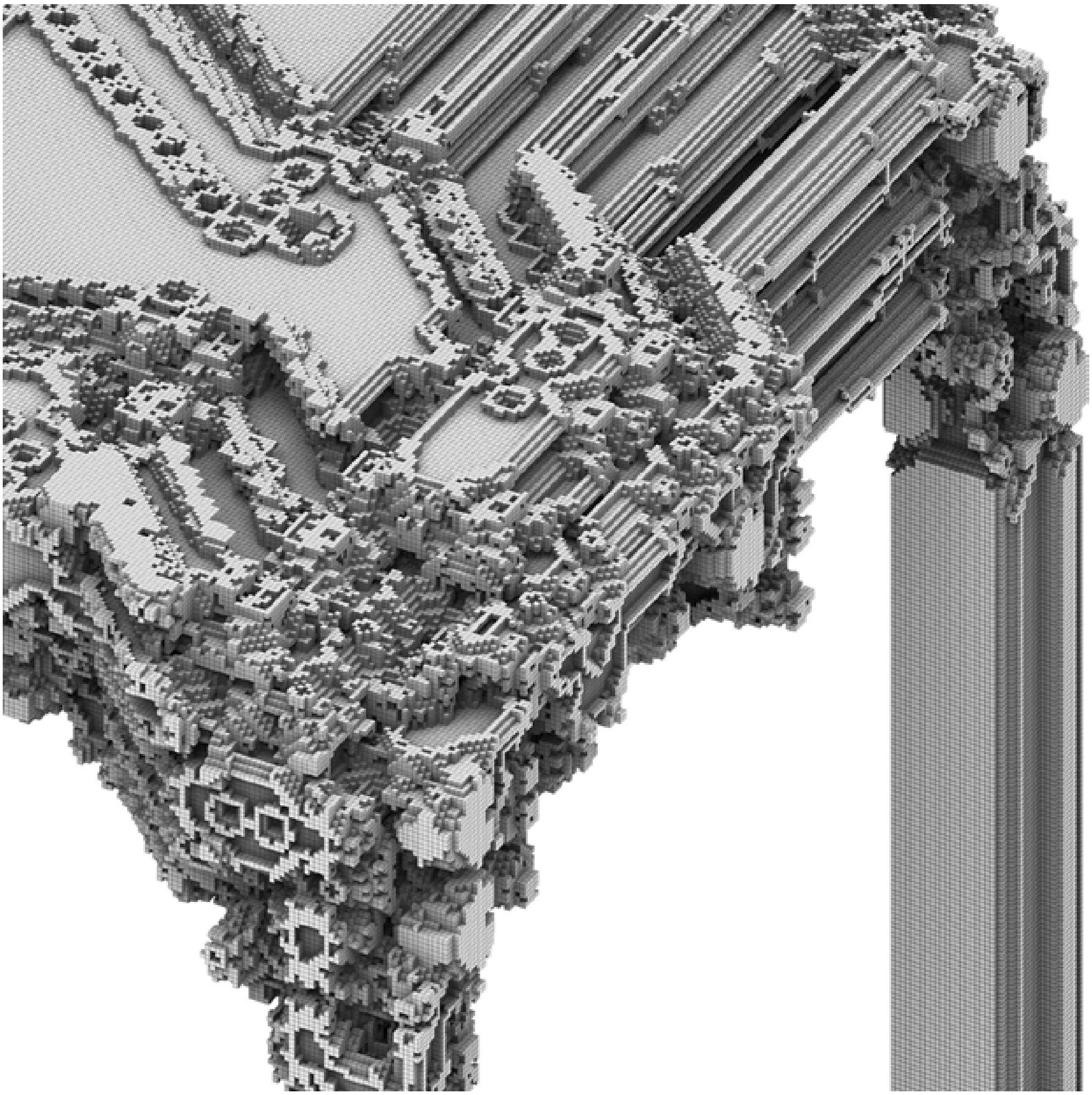
Design accomplished through self-same modules has a unique aesthetic quality as its constituent parts tangibly read in its overall fabric. Patterns and rhythm can be read locally, but when experienced from further away, additional design motives become apparent. Because of modular dimensions, the area 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.

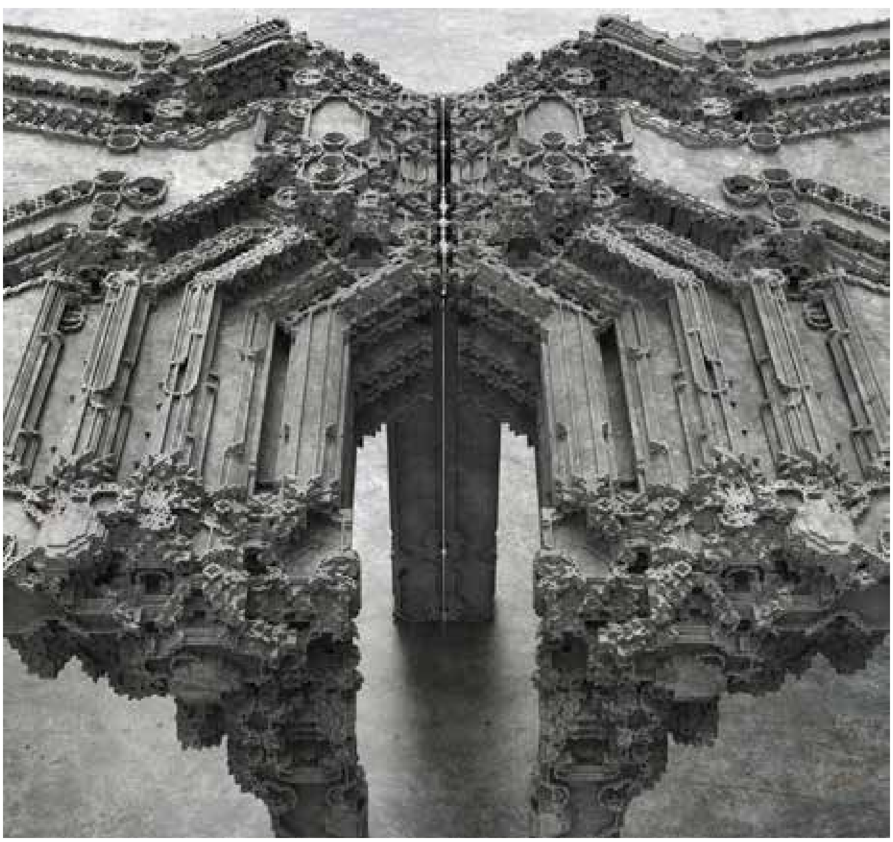
Modular designs are subservient to their parent geometry. The design of a modular system is a geometric exercise. A cube is a versatile module: it is the only platonic solid that is space filling, and has translational and rotational symmetry. If we subdivide space into a grid of cubic volumes, this 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.





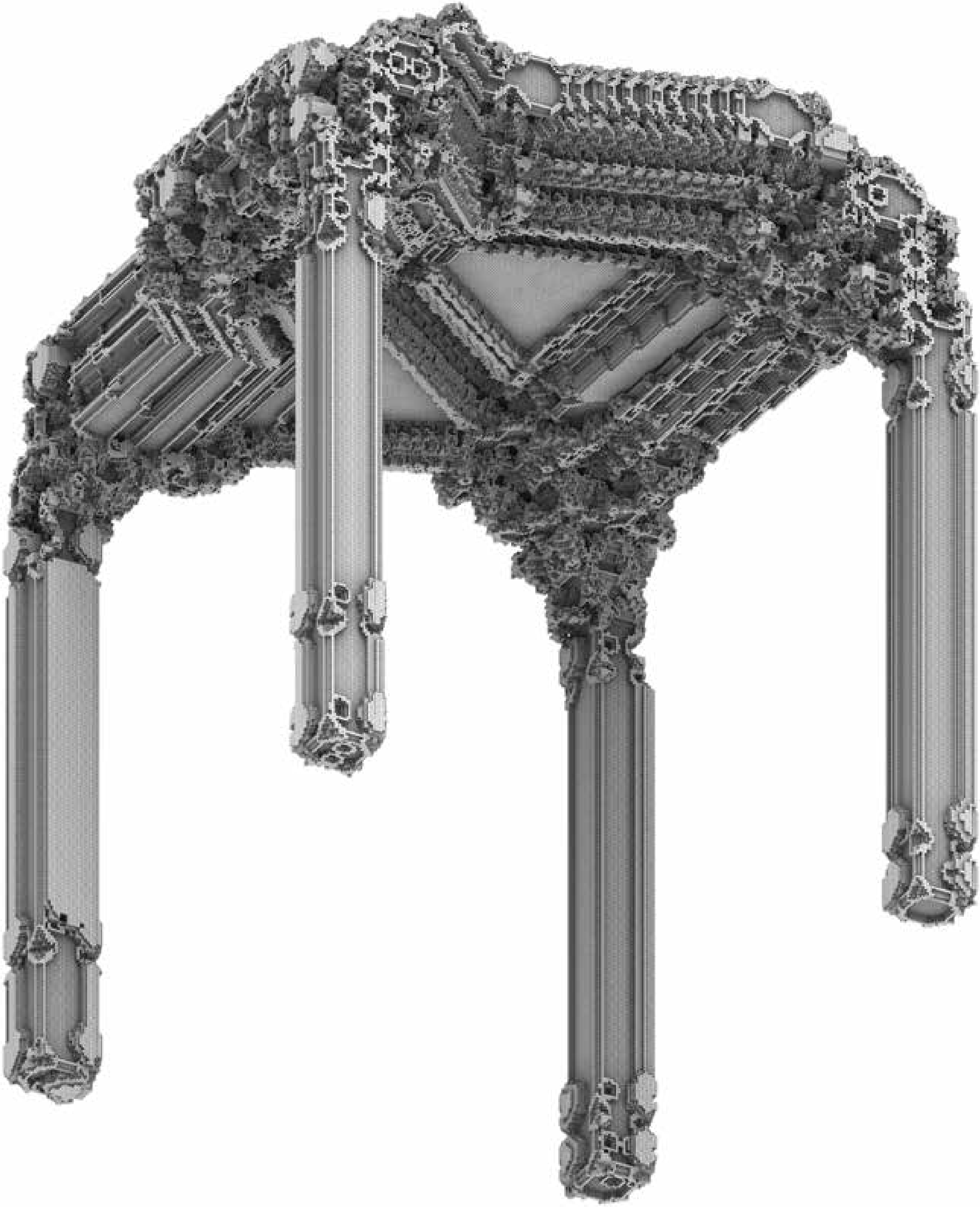
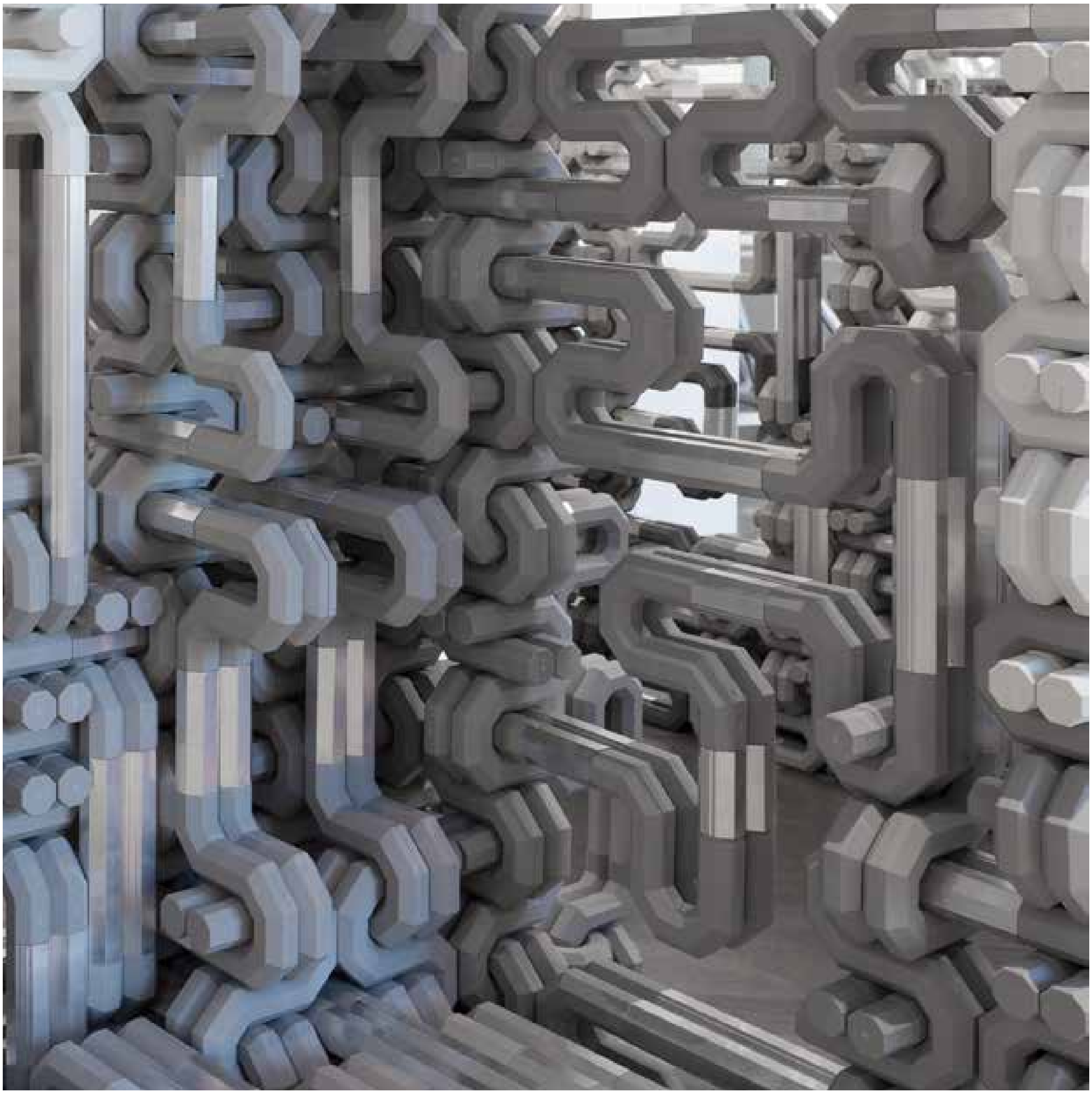


Figure 1–4 (page 81–83): Little Bit Chair (2016),
3D printed Cement. Design: Daniel Widrig Studio.
Source: *author.*



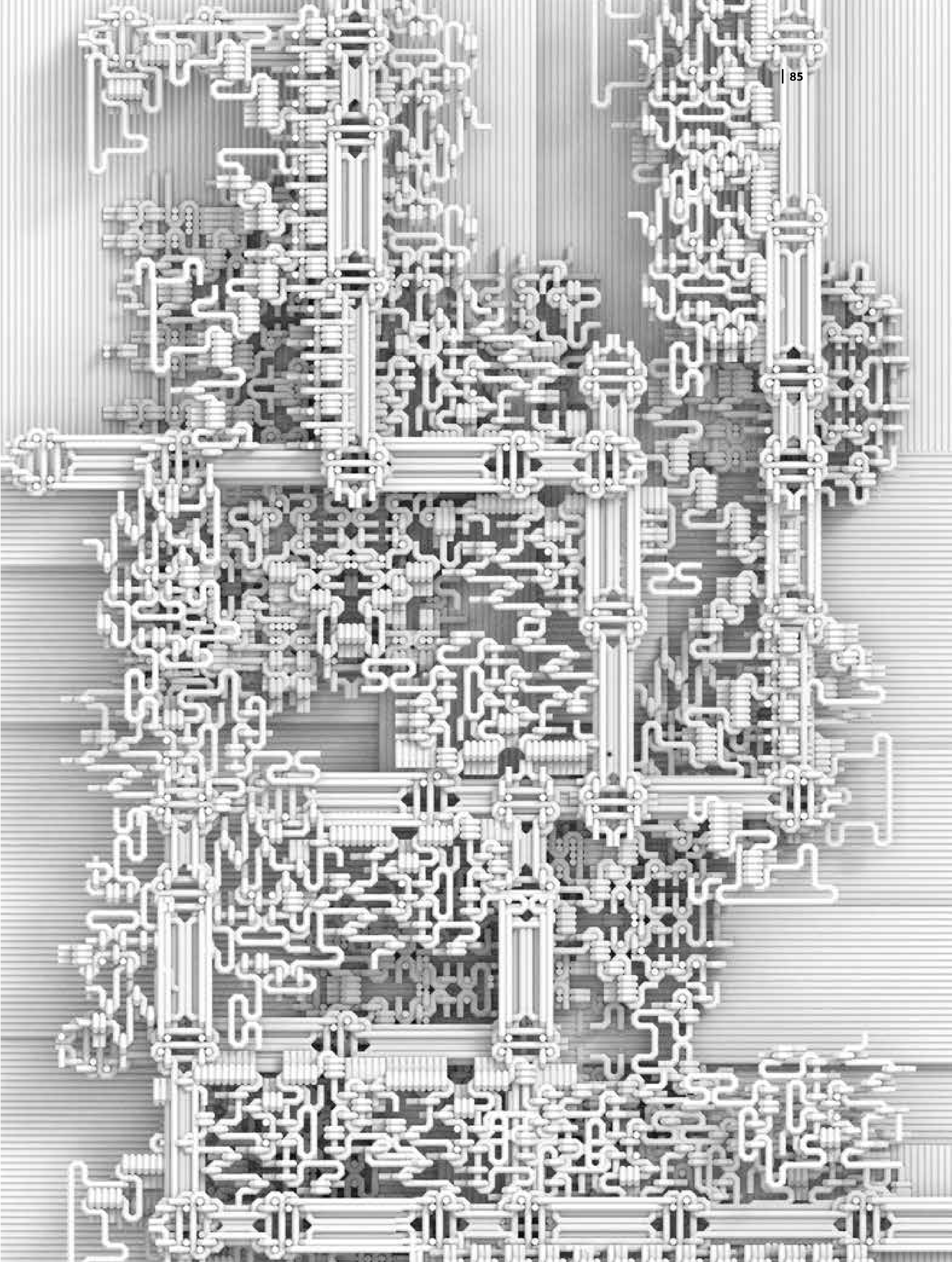
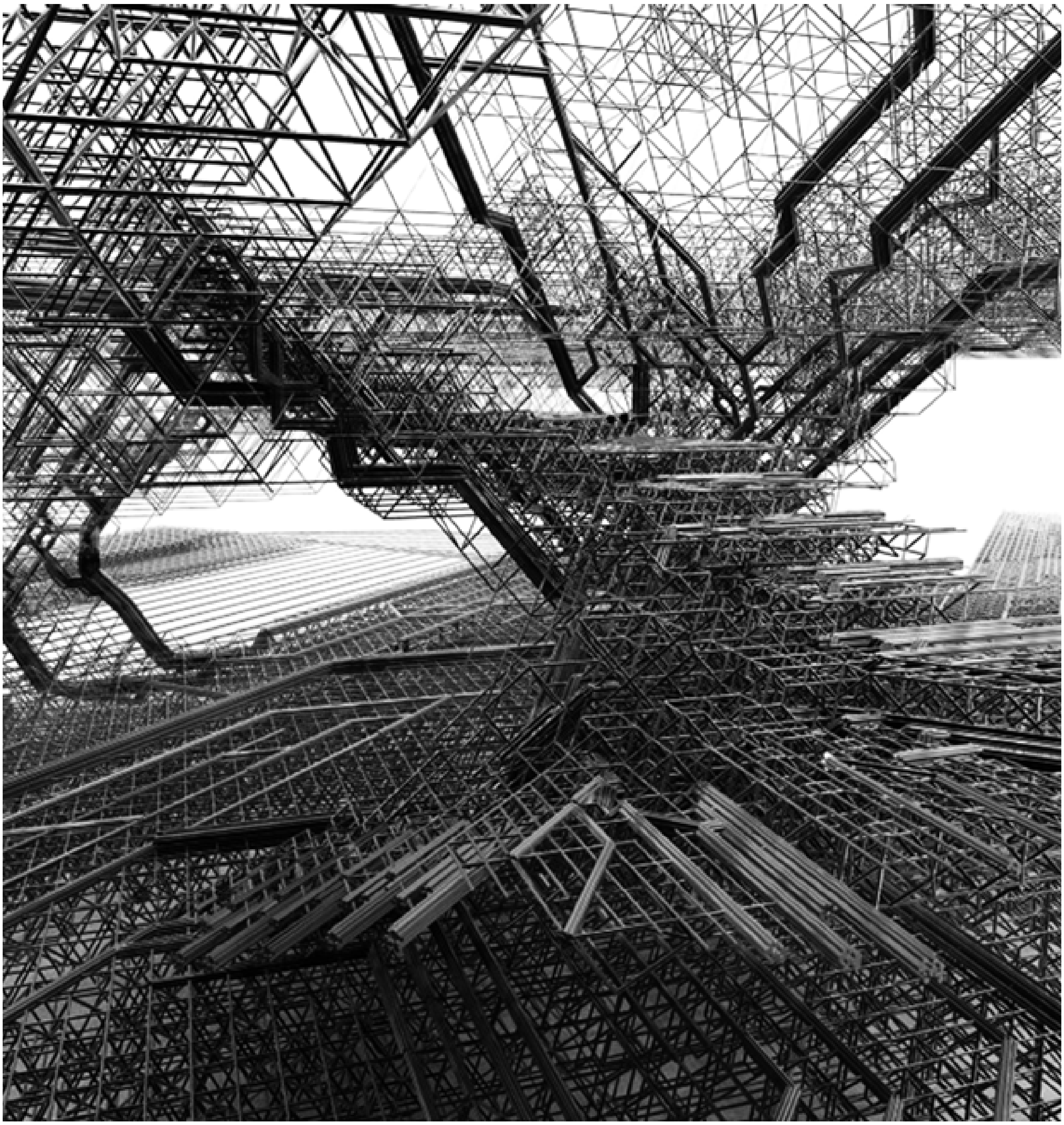


Figure 5–8 (page 84–87): SnP (2018). Recycled Nylon.
Design: *Daniel Widrig, Guan Lee, Igor Pantic.* Team*:*
Aikaterini Konstantinidou, Laura Lammar, Tatiana Teixeira.
Source: author.

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.*



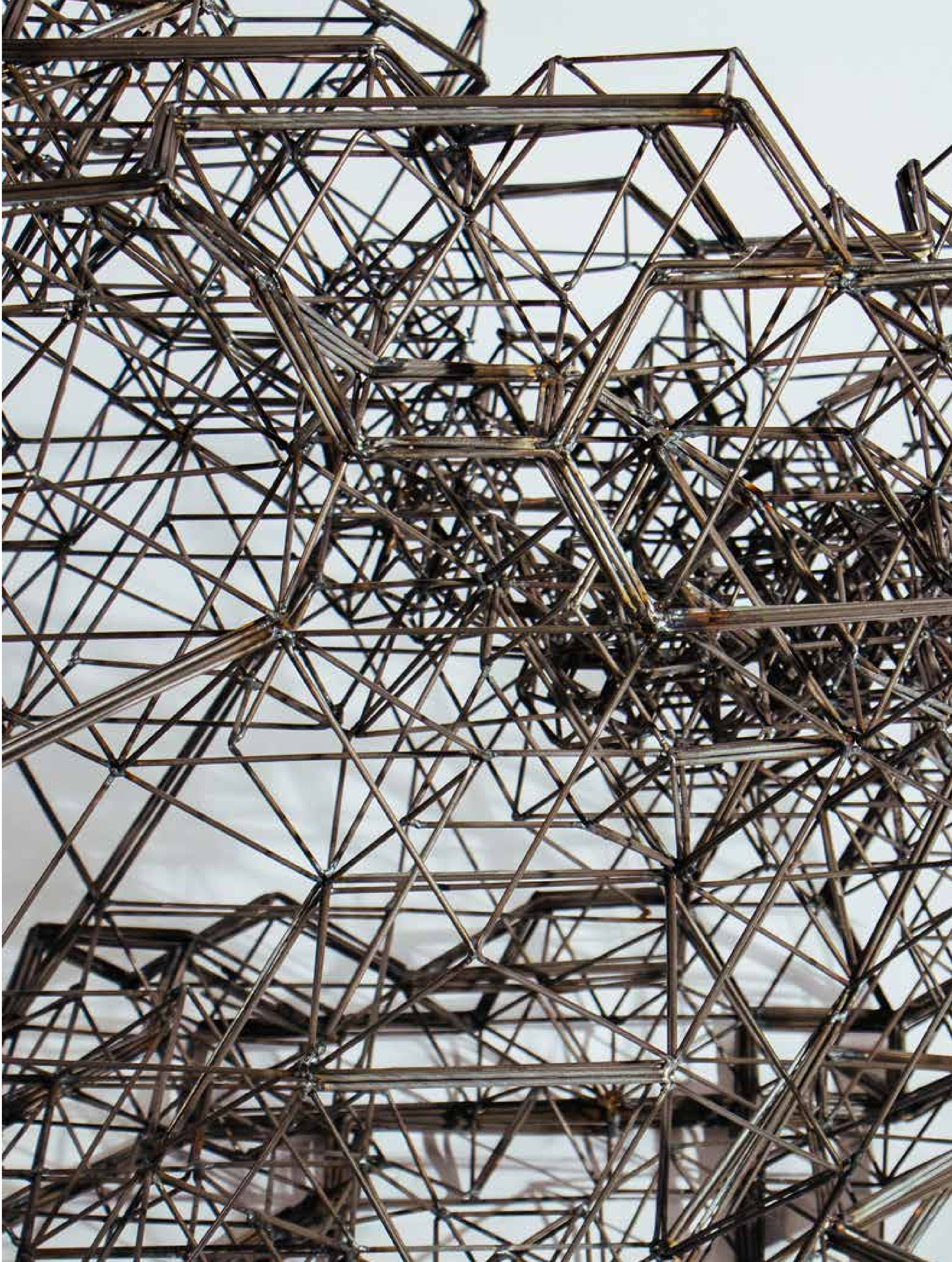
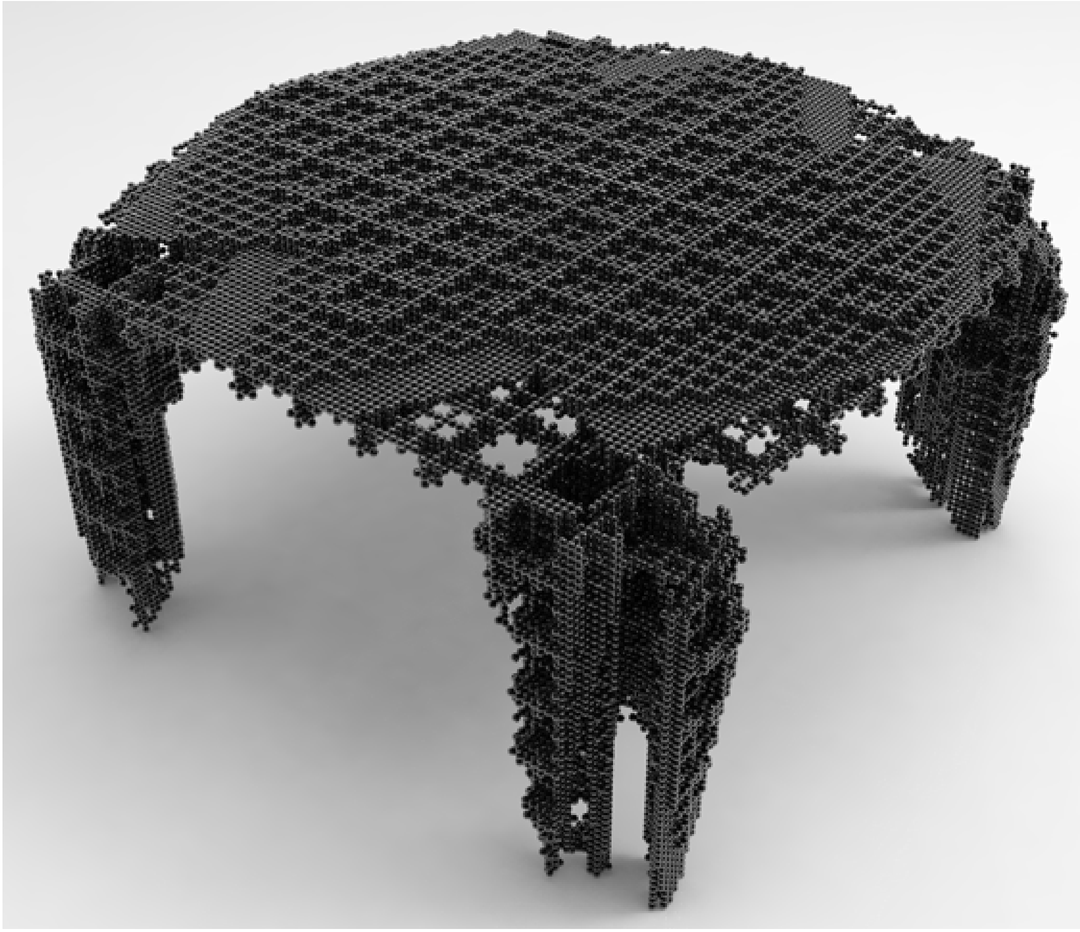


Figure 10–13 (page 89–92): Spacestream (2015). Steel. Design: *Daniel Widrig, Soomeen Hahm and Stefan Bassing.* Team*: Zhen Shan, Mengying Li, Wenjian Yang and Shaoru Wang. Source: author.*



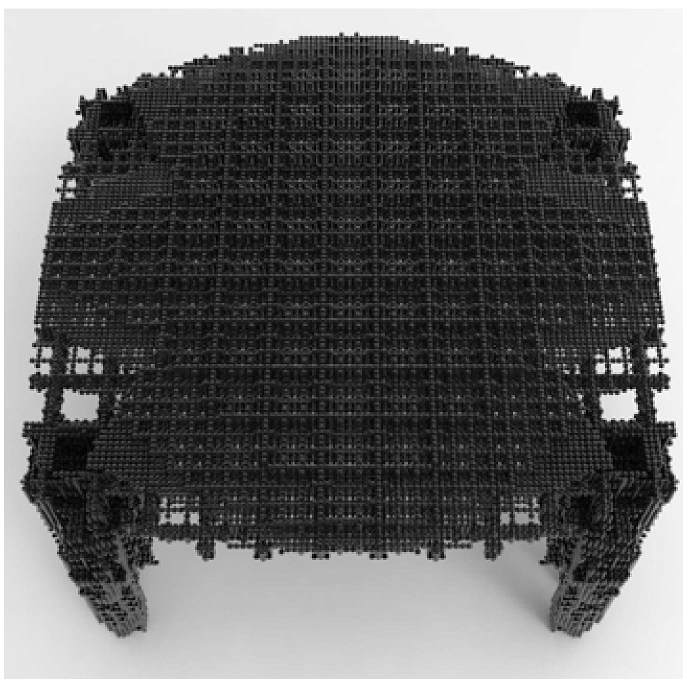


Figure 14 – 15 (top to bottom, page 93): Binary Table (2016). Stainless steel. 1.25m x 1.25m x 0.45m. Design: *Daniel Widrig Studio. Source: author.*

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.*

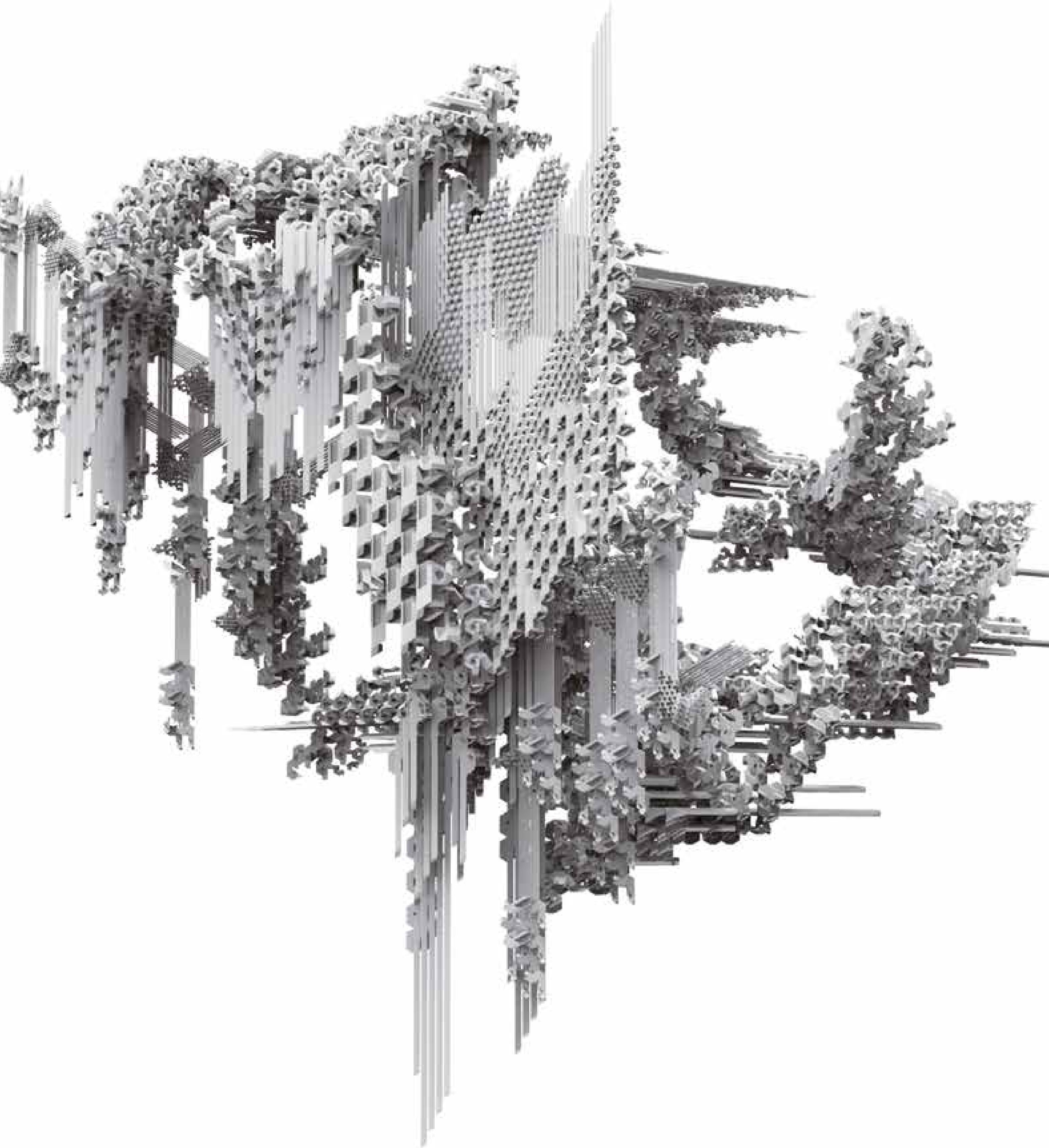


Figure 21: Increase (2015). Paper, Resin.Design: *Daniel Widrig, Soomeen Hahm, Stefan Bassing.* Team: *Chao Zheng, Chang Chen Wei, Chao-Fu Yeh, Jinlian Wang. Source: author.*

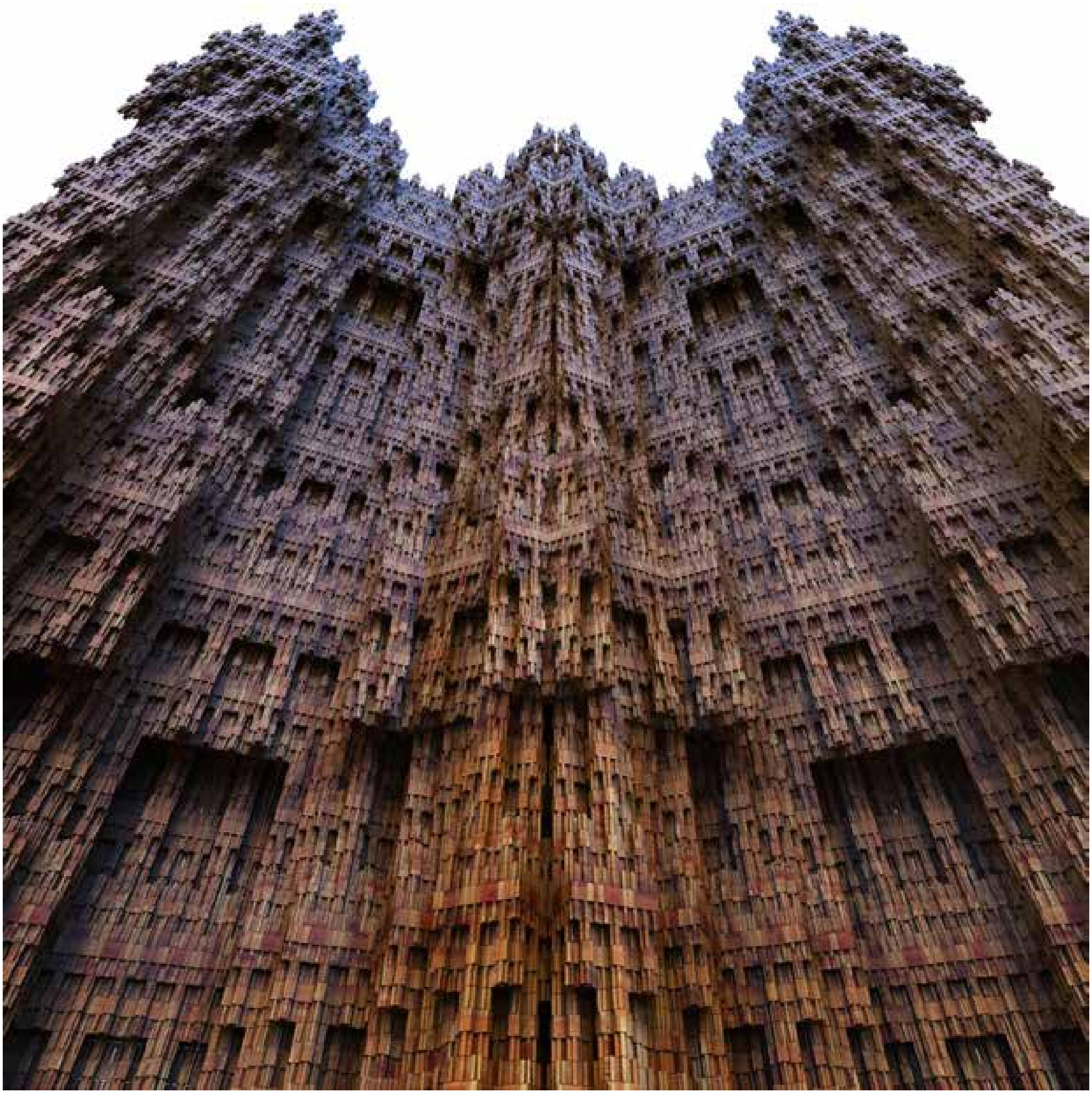


Figure 22: 5 minute architecture (2016). Digital Image.
Design: *Daniel Widrig Studio. Source: author.*

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.*

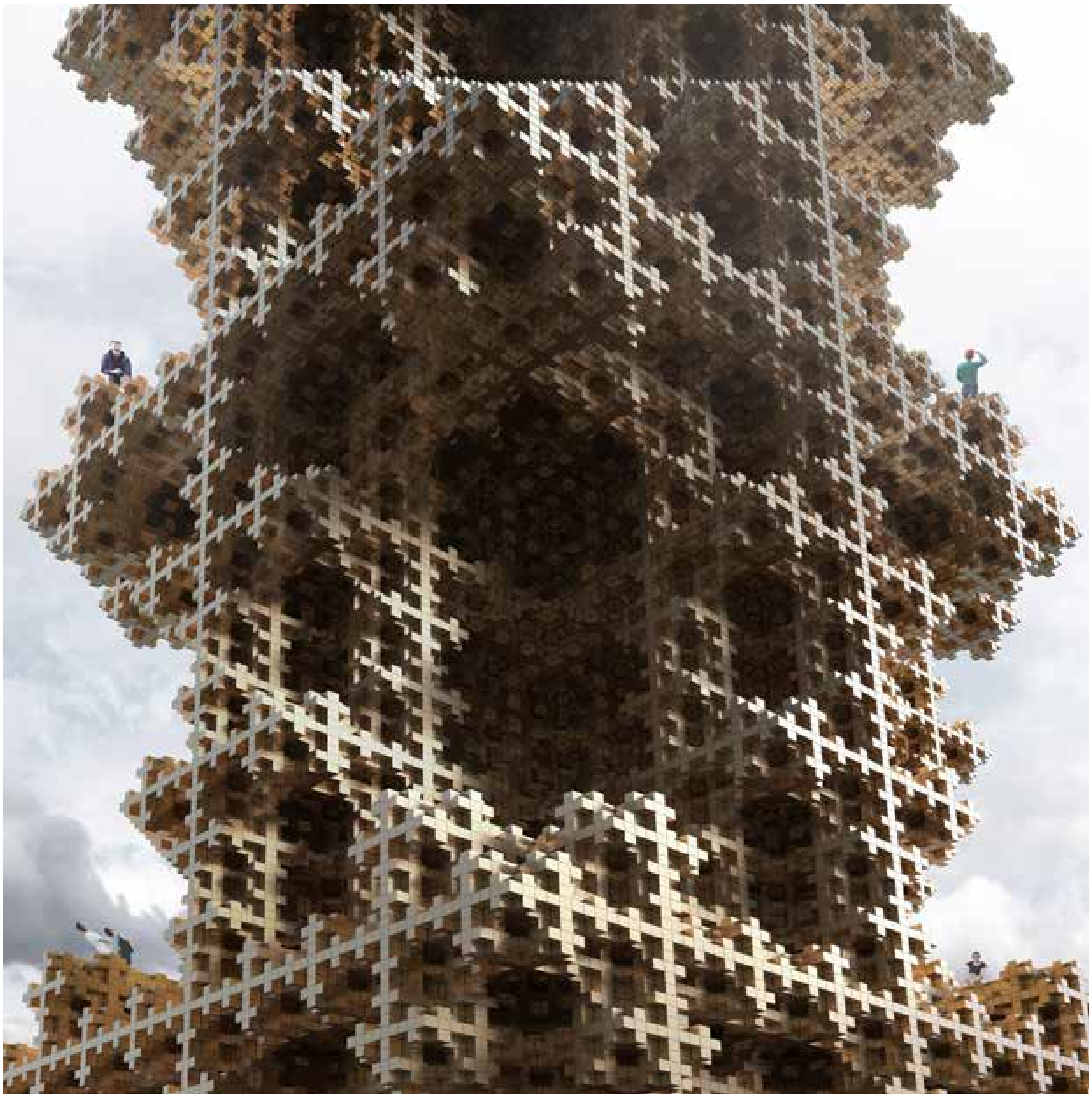


Figure 31 (opposite page): C. Tiles (2008). Ceramic. Design: *Daniel Widrig Studio. Source: author.*

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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Seizing the Real: From Global Tools to Design 3.0

Philippe Casens
Nathalie Bruyère

104—117

This article reflects the design community's interest in Global Tools, a 1970's radical movement in architecture and design, born in Italy and corresponding to a shift from design considered as a practice to a cultural movement that is able to propose new paradigms. Activists involved in making, such as Victor Papanek (1973), in a post-nuclear culture in *The Whole Earth Catalog* (1971), and by several actors in Aspen, Colorado in 1971, precipitated this movement to the design community. The movement questions the impact of a mass production and consumption model generating an economic, social, and environmental crisis. Global Tools initiated as a school by Ettore Sottsass and Andrea Branzi, questioning the role of the industry as part of a paradigm in which the issue was not how designers could contribute to industry, but how industry could contribute to society. In this article conceived as an interview, the research activity of *institut supérieur des arts de Toulouse* (isdaT) reveals a manifesto towards making in a social economic and milieu-technology new paradigm, with polemic and conceptual relationships to both Global Tools and Design 3.0.

#global tools

#creative commons

#social solidarity economy

In this interview/discussion between Philippe Casens and Nathalie Bruyère, they discuss their work with Global Tools*, a post-capitalist framework for design and industry seeking methods to involve consumers and users in co-generation processes. Bruyère's upcoming monograph publication with Victor Petit will describe her work at the isdaT. She worked with students and members of the public to test the abilities of new digital and software tools to foster co-creation, in contrast to historical, industrial models of production. This article was conducted as a back-and-forth interview, and it discusses the literature and premises underlying the upcoming research publication.*

Philippe Casens PC Nathalie Bruyère, you have been conducting research for several years, which will be published by October 2020 in a book on *Global Tools* (GT)[1] co-written with philosopher Victor Petit.

What is your opinion on the problematics posed by protagonists of this non-design movement, gurus, teachers, and work colleagues who in all cases had significant influence on the way we see design?

Nathalie Bruyère NB Design is taken here as a creation tool that reconfigures and develops the autonomy of the user towards an ecological transition, towards autonomy of eco-technical-cultural milieu, and interacting with the economy of the *Commons*.[2]

"The making, of any nature whatsoever, must involve a project. It's a cultural issue and not a productive one (it comes naturally right after)." This entails an activity fitting with the notion of project as defined in Italian, "progetto," which means both "projecting" in the sense of design and "drawing," igniting an action through the project (Alessi 2016). *Cultura del Progetto* is a term rooted in Italian Culture and concerns fields beyond design.

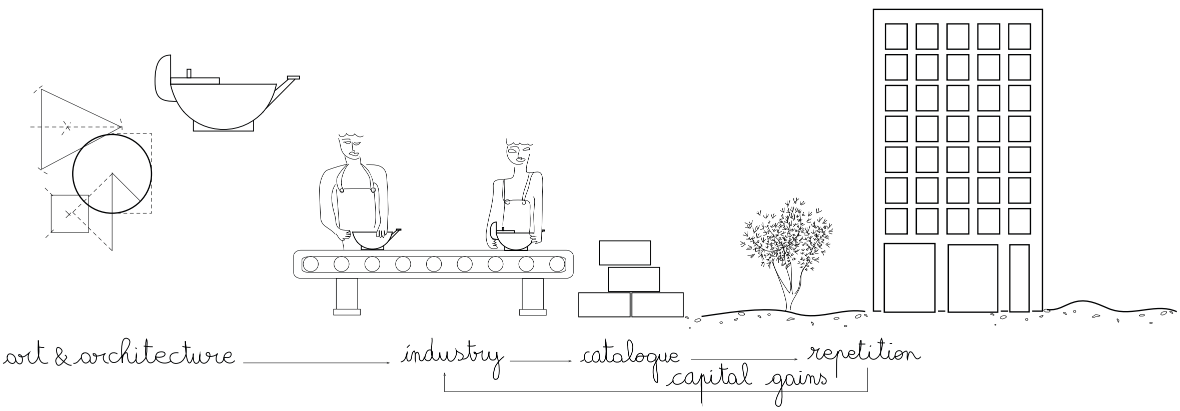
PC Design in Italy is characterised by a relationship between designers and enlightened industrialists, as in the case of Ettore Sottsass and of Adriano Olivetti, an entrepreneur who involved many artists in the design of his typewriters but also the communications and the architecture of his factories, schools, and cinemas. Olivetti was comparable to a Steve Jobs of that time.

NB They say design is the marriage of art and industry. This union was first perceived as an application of Fine Arts to Industry or an application of the Fine Arts Industries. "It took a long time to theorise the transition from aesthetics of the application to aesthetics of involvement: no longer an art applied to the machine, but art involved in the machine" (Petit 2017). What is expressed here is the idea of reproducibility of artistic artefacts by industry (fig. 1).

PC Aesthetics defined not as matter of form and style, but instead as a way to involve consumers through appropriate means and transform them into actors raises a key question: How do you see the role that design should play in mitigating overconsumption? In what way can a radical change, a shift to a new paradigm, be considered? Which problematics within design should we focus on to achieve this?

NB The consumerist phase of design tells us that everything involves ecology: eco-label, eco-services, etc. The catalogue of consumerist life includes all alternatives. This phase is built upon postmodern principles, in which "one of the most important clues to follow could be indeed the fate of culture: an immense dilation of its sphere." This *sphere of goods expands to accommodate even the previously-hypothesised opposite of industry, i.e. ecology* (fig. 2).

An accumulation of the *Real*, the historically original, is a big leap into what Walter Benjamin



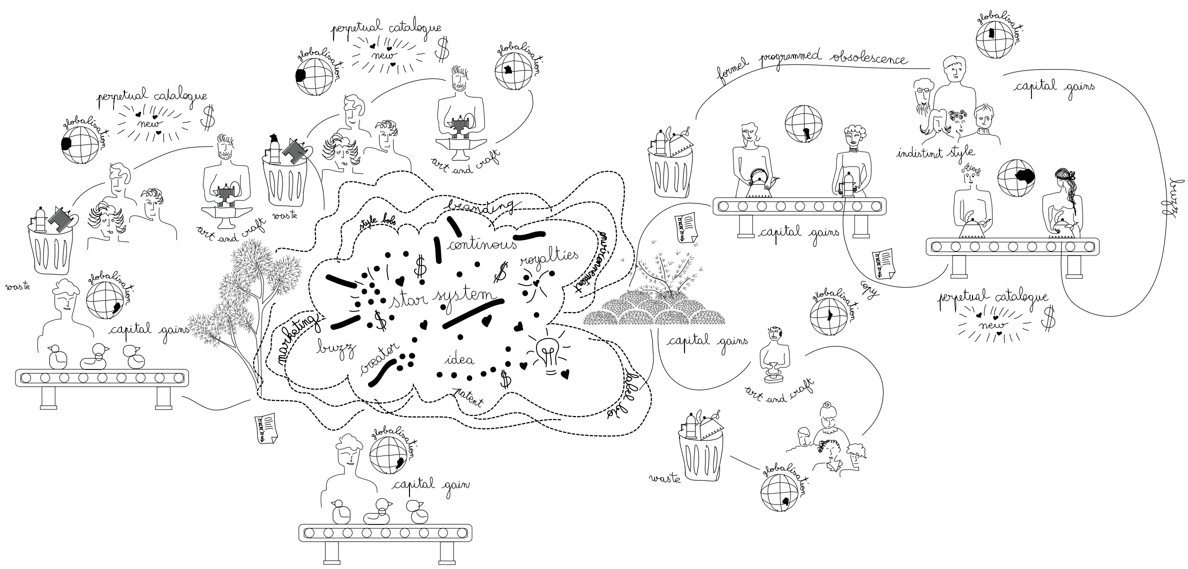


Figure 1: (top): Modernism. Source: *Nathalie Bruyère.*

Figure 2 (bottom): Post-modernism. Source: *Nathalie Bruyère.*

called "the aestheticisation" of reality, which he thought meant fascism. Concerning pleasure, he referred to a prodigious exaltation of this new order of things, a fever of amenities, the tendency for our "representations" of things to excite an enthusiasm and a change of mood that things themselves do not necessarily inspire (Jameson 2011, 20).

PC What do you consider to be the role of design today and how could research into Global Tools, a movement that started 45 years ago, help us face present-day problematics?

NB We are living in a time that "apprehends the concept of the postmodern as an attempt to think the present historically at a time that first and foremost forgot how to think historically" (Jameson 2011, 15). To distinguish, we use the word *Radical* because it is relative to the normative essence of something.

For design, Italian Radicals understood the principles of radicalism in design and architecture at play in the process and subsequent meaning of modernism's failure.

In Radical Notes number 22 (1975, 8), Andrea Branzi concretely exposes the Radicals' notion of Project Culture in Italy as:

> *…the conflict between the systems of international culture (good design or rationalism in architecture, etc.) and local minorities or traditional cultures that grow, hand in hand and at the same time, with the cultural and technological certainties to gradually become the basic theme of a generation. This conflict takes root in culture because there are (and this is very clear) two different and opposing conceptions of the term 'minority culture.' The first consists [of] considering a sampling of objects to be re-designed and proposed through the use of complex technologies defending a set of "historical values." This definition is widely accepted in the bourgeois culture in crisis as the only possibility to re-sew a cultural context in a manageable way* (Ibid.).

It is important to point out that within this schema, cultural conservation supports social conservation.

PC This Radical Project Culture also coined the concept of *Meta-progetto*, or Meta-project, *beyond the project*, as a possibility to graft other elements as ornament. This a-consequential grafting, considered a crime during modernity, allowed designers to hybridise elements together whose relationships could be historical, ethnic, psychological, popular, dramaturgical, or others. How has this approach developed?

NB Andrea Branzi was already writing in Casa Calda that:

> *The historical Amnesia of design, in other words, its ability to position itself as action and not as reflection, as history in action and not in relation to its own tradition, has so far built its strength. It is possible today that this radicality might know a decline, at the time when we rediscover historicism as the basis of the current culture. There are two ways to get out of it: by accepting to exist as a style, in other words as a codified historical language, or by defining a new growth strategy, by accepting to act in the present history and to confront each other with that of the past.* (Branzi 1984, 81)

PC A well-known example of the first approach was the Swatch series (1983), a mass product assuming different expressions. It was the result of the art direction of Alessandro Mendini, former member of Global Tools. It was also considered as a shift in regard to the aestheticisation of deceptively simple looking, mass-produced objects. Why do you describe it as a betrayal of the Global Tools philosophy?

NB What is proposed in the case of Swatch is to use the same technology, the watch movement and electronics, to propose an alternative in terms of languages, like colour and graphics, through different imaginaries. There, we rely on an analysis of behaviour to propose a different organisation of those elements and to justify the changes. But the social status of people as consumers remains the same. It is just about selling another object at a lower cost, re-marketing through *Kitsch* as Alessandro Mendini defined the term (Geel 2014).

> *And this last attitude passes for the biggest social swindle, the biggest ecological deception, by the design management of the company as superior and cultural operation (fascism)*(Branzi 1975, 8).

Chiara Alessi also says:

> *I understood that the design fans love names, maybe this need is written in the very DNA of design, which is born and living in a company's branding or in the designer's branding, claiming an identity and a paternity proper to all those objects of common use which for several centuries were considered anonymous* (Alessi 2016).

PC The shift in meaning towards the consumerism era was between autonomy and creativity. But how did this alternative culture come to be embodied in the figure of the *bobo?*[3]

NB *The bobo is design's appropriation ambition embodied in a character. It's an executive from Apple, a university professor or a journalist, whose leftist ideas boil down to an Nespresso coffee and a sweater from Gap: a way of life that Brooks is ready to consider with kindness, ultimately, if it is accompanied by a renunciation of transforming the social order* (Authier, Collet, Giraud, Riviere, Tissot, 2018, 27).

This figure was born after the 1960s in a fusion of the alternative and liberal culture, thus giving birth to Radical Chic, defined by allegiance to a radical cause. But in a vital way, demonstrating this allegiance because it is fashionable, a way of being seen in a rich society aware of the designer's name present on the catalogues and press.

This corollary of the larger catalogue of strategies induces a partial relocation of work, in order to shift some of the added value in the branding. Consumers want to pay less, which seems banal to them, and simultaneously always want something new.

Design is seen as "caught" in this game of innovation where the designer becomes the knot of narration (fig. 3).

> *This state of indistinction — where the old differences no longer apply — is a mixture of scholarly culture and commercial culture, which has ceased to be considered, as an object of contempt to become in turn a 'source of prestige'* (Foster 2002, 11).

The second approach

> *consists of the search for a different relationship between man and techniques and between culture and spontaneous creativity. Minority culture is the trigger of proposition, of action, to overcome aesthetic codes and official technological taboos in experimenting a purely and directly 'functional and private' use of the artistic means. It need not be understood as universal experience, but as a constructive act directly linked to the creative thrust of groups and individuals* (Branzi 1975, 8).

This approach develops *Project Culture* as it was heard in Italy during the radical era. Radicality is the word for building technical tools for all people's autonomy (fig. 4).

PC You mention a third phase of design, placing the designer as production chain analyst and moving away from the creative advertising slogan as market provocation. This puts the designer at the service of society by questioning the meaning of production. How do you actualise this approach and put it to work?

NB We started from a manifesto written in 2012 as part of our professional and research activity to build these three tools (Bruyere 2012, 479). Our practice is based on analysis of how objects and places are used. It examines relationships between production and consumption. This practice consequently integrates the thoughts and opinions of users into the creative process and the ecosystem, rather than being based on an analysis of economic profitability forecasts.

Social relationships are not exclusively market-driven; in actual fact, the majority are neither of a commercial, nor a financial nature.

Nevertheless, those relations can produce a large number of useful goods and services. Our professional behaviour must guarantee mutual aid and giving practice, even if it aims for market or financial appraisal. More importantly, this valuation must never suffocate non-market relationships.

Once you participated with us in a first experiment on embroidery at Bonnefoy Social Center in Toulouse (Bruyère 2012).

The workshop tested people's autonomy to formulate their own patterns, and by doing so create a valuable relation with their productions, enabling a sense of belonging thus fighting against their own aesthetic obsolescence.

PC The research was then developed into the collective *Ultra Ordinaire* involving your studio. Which methodology did you use? What are the principles that are to be retained from this research? How did you implement them in your professional and academic activities?

NB Three principles emerged:

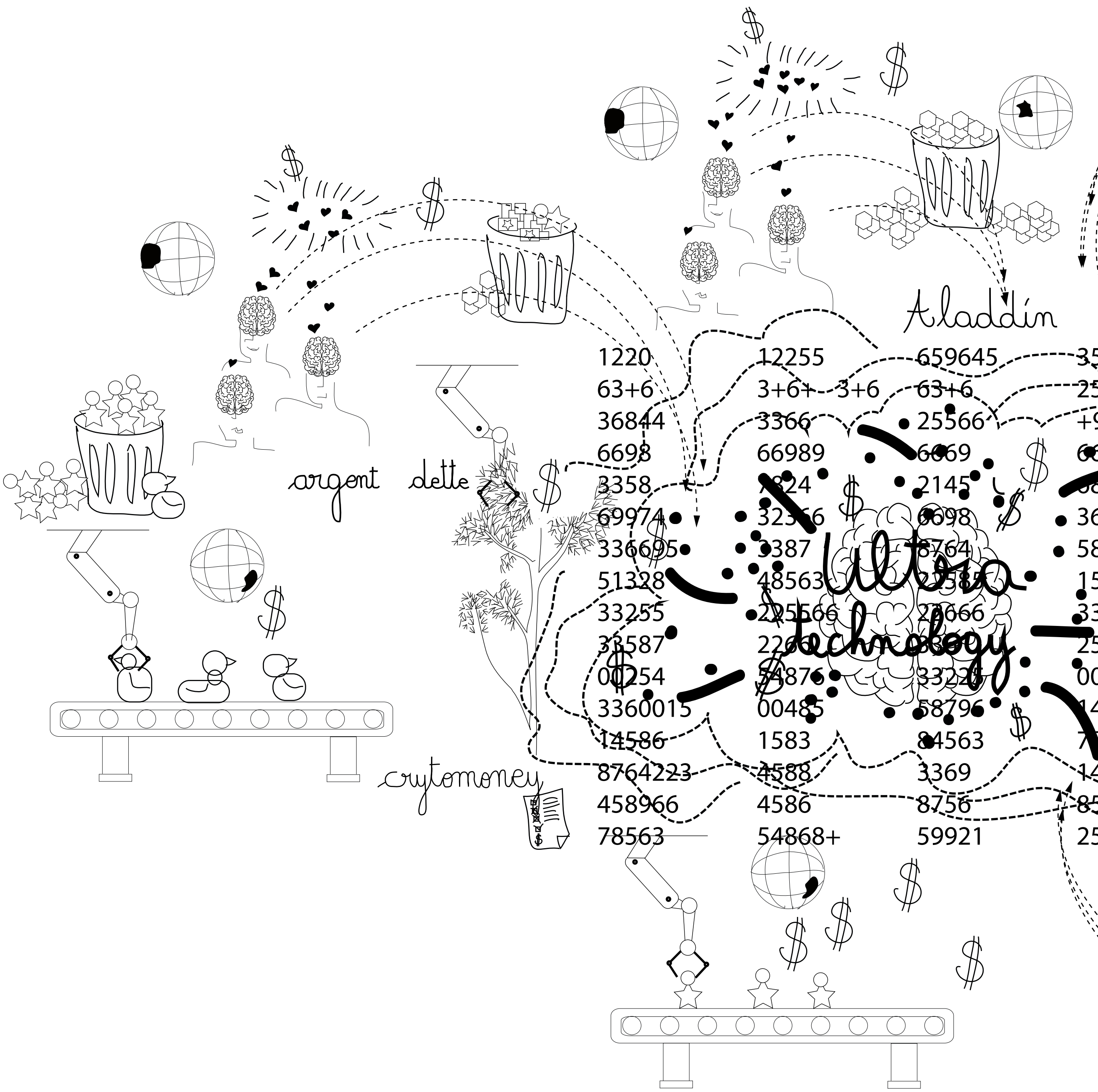
The first principle concerns observation of a context. A situation study through workshops uses the principle of immersion to create and understand the capacities of a context to support an ecosystem. As in the example of the Albi project, which aimed at food self-sufficiency, this resulted in bringing the designer's working tools to a specific eco-technical-cultural milieu site.

The technology was used to visualise the environment, and further analysis allowed the individualisation of the incorporated capital of a person or a group of people. This includes symbolic or material cultural capital, social capital, the network of mutual knowledge capital of a person or group of people, the natural capital of a place, and an infrastructural capital to identify the common practices of a community.

The second principle is the opening of standards. Deconstruction of the design process fosters a certain autonomy in allowing a different composition of an object to contribute to the reduction of obsolescence in objects. This is an approach close to the world of *makers*, who use 3D printers, laser cutters, and computer numerical control (CNC) electronics in Open-source hardware (OSH), as social tools.

In this example we developed a platform enabling users to create embroidery applied on objects, like furniture, lamps, or accessories, and an application which allows users to choose or upload an image as a pattern. The software we developed interprets the image and turns it into a pattern of holes of different dimensions, to create a canvas on a panel or silk, where the user can realise his/her own embroidery.

The same software can transform designs into patterns on wood, which users utilise to create traditional embroidery on paper cut-outs.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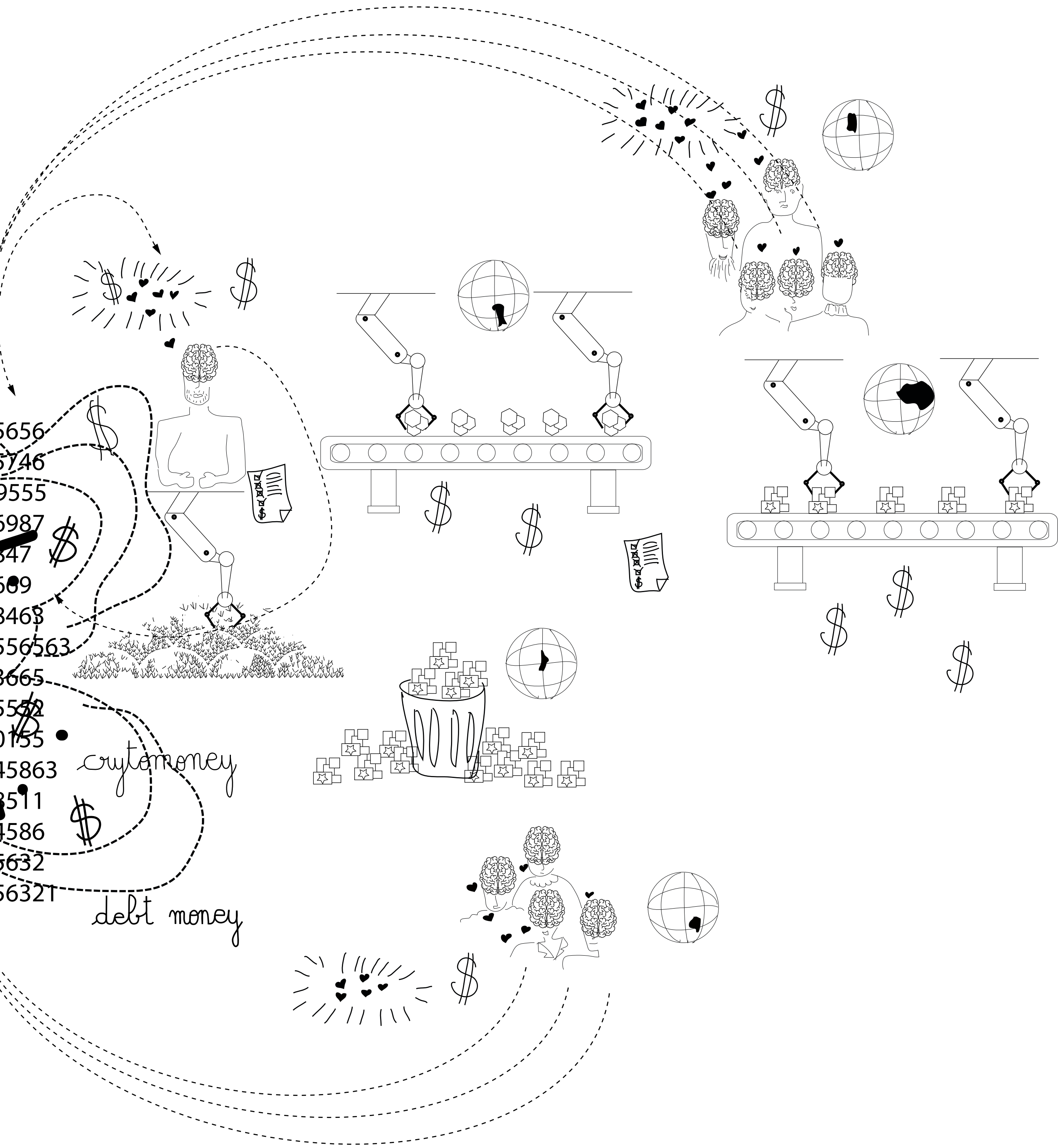
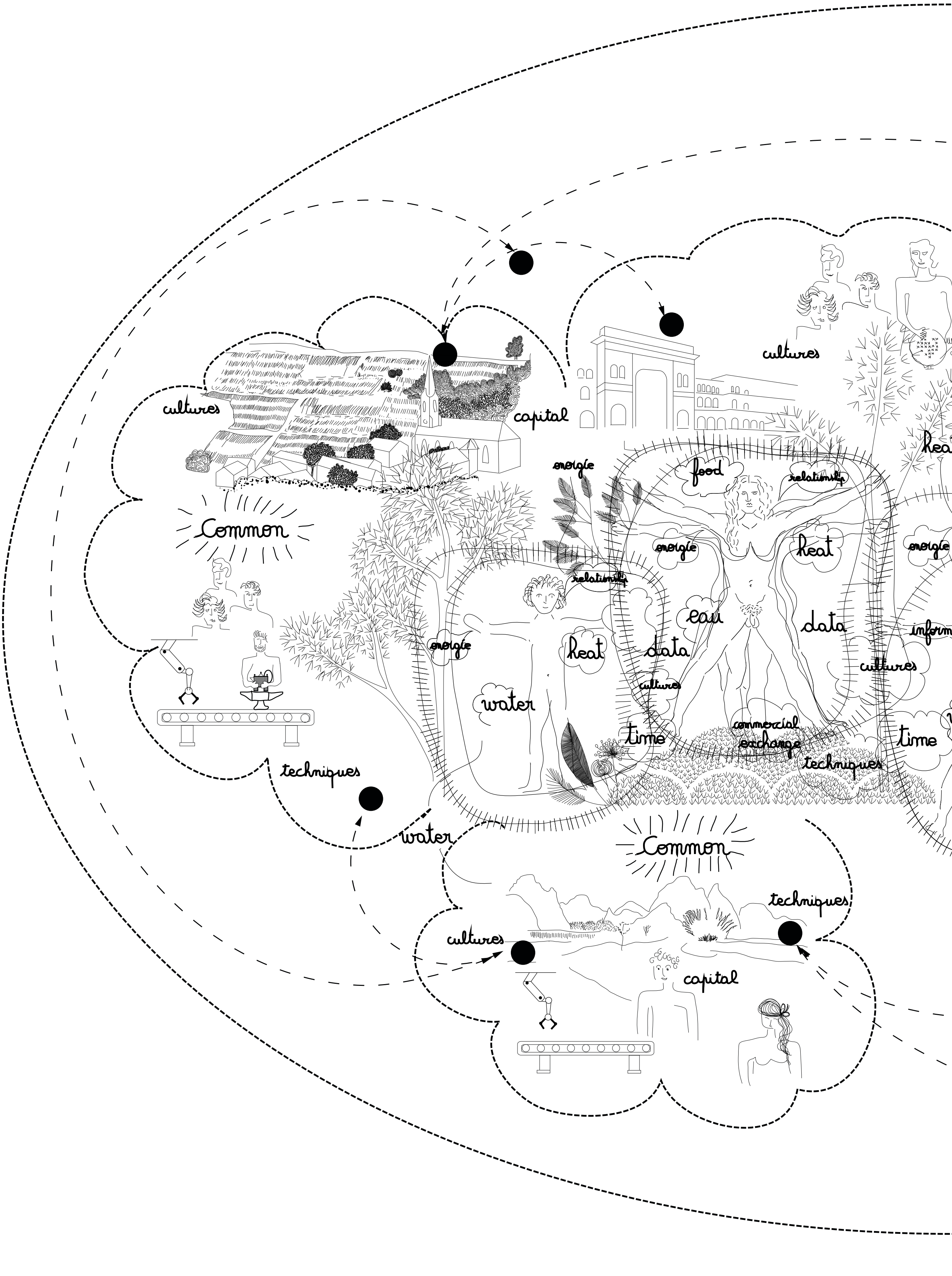


Figure 3: Hyper-normalisation. Source: *Nathalie Bruyère.*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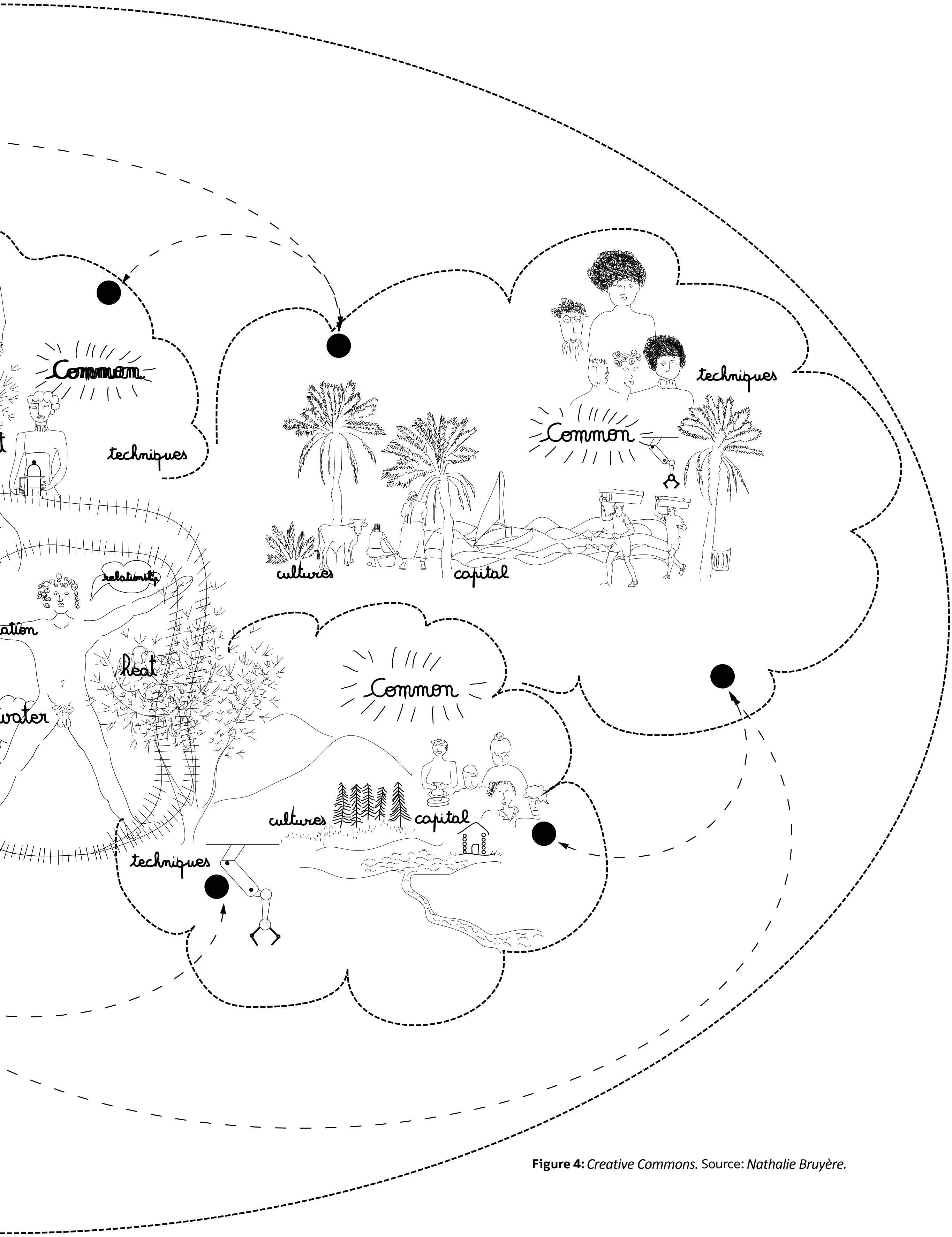

Figure 4: *Creative Commons.* Source: *Nathalie Bruyère.*

PC In your professional activity you also operate at a space and architecture level that concerns another scale; the expression of *dal cucchiaio alla città*[4] expressed by Ernesto Nathan Rogers in 1946 (Rogers 1946, 215) at the Chart of Athens, suggested that designers would use the same approach to draw a spoon or a city. In most cases we see specialists drawing door handles, others windows, others houses, and others cities. When we put it all together, we find that spaces are often uninhabitable. What is the approach you are proposing to this divided, specialised industry issue in architecture?

NB This is about the third principle which concerns the habitability of our worlds: the design of an environment, the project of the mid-place between art, design and architecture, engineering for liveability of the world and the autonomy of users.

Habitat here is used in its primary sense, as a fundamental. It is not a question of designing an environment, but again about autonomy and openness of systems. For example, the renovation of buildings' curtain walls is based on the modern principle of a reparable, alterable architecture.

The hypothesis thus starts with an interaction with the user and questions the structural obsolescence of our buildings. For this, we shall turn the programmatic registry into a design registry and rethink the architecture from missions that are not limited to functional/formal/technical plans, but that refer to their contribution to society, culture, and urbanity, and more specifically to lifestyle.

It is therefore a question of reviewing the notions of *need* and *use* through a re-imagining of their spatialisation in a more autonomous manner, through the design management of architectural elements.

Design is already ubiquitous in architecture practice through catalogues of products to implement. We make this connection more open by inscribing catalogues into libraries, whether computer-aided design (CAD) block libraries on the internet, or more sophisticated Building Information Modelling (BIM) libraries.

The designer as well as the engineer will be working on the opening of this catalogue to allow the practice of users by removing them from pre-formatted catalogues.

In collaboration with Technal products[5] we conceived the BIM library platform containing parametric elements based on thermal and lighting conditions, and also decorative elements, both responding to users' needs.

PC You mention in your book that the inscription of making raises the question of industrial property. How are the *Creative Commons* and other intellectual and industrial property structures facing this reality?

NB As a starting point, it is a question of considering if techniques are appropriable. The project works to open industrial necklines while respecting and protecting the investments and know-how of everyone involved. It means thinking in bundles of legal protection between patents and creative licenses of commons, to allow their free use and a consequent mix of styles. It is about conceiving artefacts as elements used for the habitability of our worlds, not as a catalogue of finished products. It is about working with the real economy by removing parasitic margins.

PC How do the Creative Commons differently impact designers' realities compared to the traditional process of industrial design?

NB We do not discuss the principles of evolutionary economic growth to make a difference within industrial, consumerist design processes. We refer to *swarming*, a phenomenon observed in beehives when a part of the population leaves with a queen to form a new colony. The open use of artefacts, through *open standards*, must enable stable swarming and production through local cultures, still open to existing economic exchanges.

PC Finally you mention the relationship between design and economy. How do the Creative Commons assume a different connotation in this case?

NB It establishes a *frugal*, but not *poor*, design in meaning and form, backed by the Commons. We therefore make a clear distinction between the collaborative economy and the contributive economy as the former serves common sense and common interests, while the latter does not.

> *The former, which will be taken in a very broad sense, is nowadays used to designate a set of particular arrangements (often, but not necessarily based on digital platforms) that connect one actor with another enabling trade monetised goods and services. Other expressions are also often used as synonyms or equivalents: we also speak of sharing economy, peer-to-peer economy, economy on demand or 'odd jobs economy* (Cornu, Cornu, Orsi, Rochefeld 2017, 497).

The latter, the contributive economy, was established around 1993, and concerns the generalisation of the Internet and the creation of websites located on servers via the Hypertext Transfer Protocol (HTTP) standard. This took on new meaning in the last decade through open hardware such as Arduino.

To speak about the economy of the Commons means to find at the same time a political principle and an economic principle.

The political principles which Pierre Dardot and Christian Laval identified as the premise of building a common economy were:

> *any economic form that maintains or creates commons, with the purpose of creating and distributing shared resources for the reproduction of human communities"* (Ibid.).

Similarly,

> *(…) it is only the practical human activity that can make things common, just as it is only this practical activity that can produce a new collective subject, far from the fact that such a subject may pre-exist as rights-holder (*Dardot, Laval 2014, 80).

Notes

1. *Global Tools* wish to develop the first open-source catalogue. The booklets deal with the relations between egalitarian production, human action and the evolution of technical cultures.

2. The Commons refers broadly to economic principles developed by Elinor Ostrom's : "Governing the Commons: the Evolution of Intuitions for Collective Action."

3. From the French, "Bourgeois Bohème," referring to liberalised middle class aesthetes appropriating the aesthetics of working class culture.

4. Italian: "*From the spoon to the city.*"

5. Technal is an aluminium extrusion and manufacturing company. See https://www.technal.com/en/

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Bio

During 25 years of professional collaboration with Italian designers and architects such as Andrea Branzi, Trini Castelli, Pierluigi Cerri, and Isao Hosoe, **Philippe Casens** has experimented with different approaches and developed specific methodologies in the field of industrial production and its communication. His teaching experience began at Domus Academy in 1995, where he directed the master in product design, then at the School of Fine Arts in Toulouse, France, and taught history and theory of design. He then taught materials and technology at NABA in Milan, Italy, before being appointed assistant professor at the School of Design at The Hong Kong Polytechnic University. He teaches design experience in the design practice of MDes and Design history, structure, materials and processes of BA (Hons), product design. His research focuses on multidisciplinarity and complexity in sustainable design.

Nathalie Bruyère is a professor in the design department at the Institut Supérieur des Arts de Toulouse, where she graduated in 1993. After obtaining a master's qualification in Domus Academy in 1994 she and Lorenz Wiegand co-founded the design agency POOL, where they design products for maximum versatility of use. In association with architect Pierre Duffau, she founded studio Duffau & Associés – Ultra Ordinaire, exploring the concept of "plug-ins" applied to architectonic structures to create an imaginary natural ambience and the boundaries between private and the public. The degree of domesticity in relation to the context space aims at the creation of an ambience developed through the demand of the people living there, instead of forcing them to adapt to an imposed environment. These city interfaces transforming the living spaces became something non-specific, mobile, flexible and fundamentally more human.

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027

The Last Ten Years of Traditional Craftsmanship in Miaoxia Village

Kuo Jze Yi

118—129

This article reflects on the disappearing carpentry tradition in a rural village called *Miaoxia* in Sichuan Province China. Since 2015, villagers, social workers, architects, and university scholars have been collaborating to look for alternative development possibilities in Miaoxia Village. The idea of using the local carpentry tradition has been one of the key focusses in the process. Since the Chinese Economic Reform in 1978, the influence of urbanisation and market economy in China has led the Chinese government to rethink the value of rural customs and traditions. While the country has been encouraging progressive economic development, local making culture and development have subsequently been under threat. The collaborations between social workers and design professions in Miaoxia tested small-scale architecture interventions and educational workshops. These experiments have started to record and test out different ways to save carpentry traditions from extinction. This article outlines this process in Miaoxia and asks for new ideas to re-utilise this traditional making.

#craft

#tradition

#community development

#workshop

Introduction

The development of rural settlements in Sichuan province of the People's Republic of China (PRC) was based on the residents' livelihood opportunities and local resources. Throughout the centuries, rural architecture formed and transformed according to necessities, traditions and the ideas of the local people. The old quarter of Miaoxia village in Yaan City, Sichuan province, China, is a cluster of thirty to forty remaining timber houses around the village square. These timber houses were built with a traditional flexible timber frame system called *chuan dou*, which can be modified and adapted to sit on different topography and shapes of land. The carpenters connect structural elements with joinery and no nails, allowing them to be easily taken apart and reconnected. This flexible building system is not only resistant to severe earthquakes, and adaptable to many types of spatial arrangement, but it has also allowed many villagers to transport some houses from other locations to their current locations in Miaoxia. Unfortunately, the demand for this building type is declining, because of the mass production and large-scale building industry of concrete frame structures, and also the PRC's environmental policies regarding the preservation of trees. At the same time, researchers feel the need to preserve traditional culture and wisdom, while finding alternative and appropriate development directions for the future. Facing this dilemma of possible cultural and traditional extinction induced by progressive development, how can architectural researchers and makers explore new possibilities and new ideas?

Experiment 1: Small-Scale Intervention

Since November 2014, Associate Professor Peter Hasdell of The Hong Kong Polytechnic University School of Design has collaborated with Associate Professor Ku Hok Bun of the Department of Applied Social Sciences, to research alternative bottom-up development strategies for Miaoxia Village, where social workers from the Lugeng Center for Advancement of Rural Urban Sustainability were stationed for three years. The first collaboration of social workers and architects resulted in the completion of a community kitchen building that hosted community events and visitors, thus generating an income for villagers. More recently a community guesthouse building was completed in January 2018. These projects together continue to test and develop the bottom-up community development approach framed by the project team's research.

One of the key design decisions in both building projects was to utilise and reinvent the traditional timber frame system to construct both structures. During the process local *shifu*, or "old masters," were commissioned to participate in both the design and construction stages. For the community kitchen, the structural columns plan is exactly the same as the traditional grids set up for houses and other buildings, but the height of each column was adjusted to form a lifted roof structure that opens to the square. To accomplish this design intent, masters only needed to know each column height and modified roof connection details. For the second structure, the community guesthouse, the building plan is angled in the central space to form a diagonal column line, to provoke a new type of interior space and building mass. Similar to the first project, the masters only needed a floor plan indicating column positions and each column's height. Thereafter, step by step, they could resolve different angled joinery and connections. Although this process of utilizing and reinventing traditional building methods seems nostalgic and demanding, it is an arguably faster and cheaper alternative to having these buildings constructed in concrete frames by a regional contracting company. Since the building scale is rather small, and because the villagers can collectively participate in some of the low-skilled and labour-intensive building processes, the projects were therefore economically viable. Through their participatory model and adaptation of local craftsmanship, these projects focus on the social and cultural aspects rather than merely completing a building. From this example, one can foresee opportunities to continue developing traditional building systems if the development remains focused on the small scale, aiming for direct engagement with small communities.

Experiment 2: Rural Craft Workshop

The timber frame system and carpentry tradition in Miaoxia village attracted design students from three major institutions: the Hong Kong Design Institute, The Hong Kong Polytechnic University, and Shenzhen University. Between July 2015 and July 2016 researchers and local craftspeople hosted three carpentry workshops in the village. The researchers also hosted one building workshop based on the same timber structural system at The Hong Kong Polytechnic University during the 2015 *Maker Faire* event on campus (*Fig. 12*). Since carpentry tools and timber logs are exotic items to students in Hong Kong, many students expressed curiosity and the will to work with them during the workshops. The workshops took place over the course of ten to fourteen days.

They tested the potentials of traditional craft in relation to modern generations, and also tested whether traditional craft workshops could become a source of income for Miaoxia village. All four workshops generated intriguing outcomes, but whether this method could become an economically sustainable programme requires more commitment from interested locals. Currently, these craft workshops can only be held seasonally for a maximum of thirty of university students at a time. To be economically sustainable, craft workshops need to be frequent, and the model may benefit from integrating into design education programmes. Historically, students reported gaining practical skills and imaginative ideas from the masters, particularly from a workshop held in July 2016 in Miaoxia village. Perhaps if university curriculums work with villages to pilot one-to-one studies, it could create meaningful and sustainable opportunities for both academia and the village.

The Miaoxia workshop in July 2016 was called “Re-interpreting Rural Furniture.” Students were asked to:

1. Discover local stories in Miaoxia;
2. Practise carpentry or bamboo weaving techniques with local masters;
3. Create furniture that re-interprets local stories; and
4. Document traditional craft and local stories.

Eighteen architecture students from the Hong Kong Design Institute and Shenzhen University applied to join the workshop. They were divided into five groups, practising carpentry with masters while discovering local stories. This resulted in the students proposing and prototyping five furniture projects narrating different local stories. The workshop documented these local stories and traditional crafts, engaged old masters and villagers, tested possibilities to connect design students to the rural traditions, and created inventive design ideas based on local resources. This experiment portrays opportunities to creatively preserve and extend traditional wisdom, if researchers align design education with the rural villages. Below are the brief outlines of the five project outcomes.

Group One students followed a family of grand-parents and two grandchildren to observe how they live together. This extended family structure is a common social dynamic in China, due to the increasing number of parents becoming migrant workers and consequently having to leave children behind with grandparents. This group of students discovered that benches in the village have nearly uniform heights, which do not permit the small children to sit at eye level with the taller grandparents. The students proposed to build a bench that was higher on one side for the children and lower on the other side for the grandparents, thus allowing both children and grandparents to be on the same height level. Due to students' inexperience, the project prototype was built too small, resulting in the grandfather and the grandchild sitting back to back (*Fig. 5*).

Group Two students followed six children in the village, and understood through interviews that the children wanted a collective playground space. The complicated land ownership structures in the rural area, however, did not offer conditions for building a playground. Eventually, the group of students proposed to build a portable slide that can be carried around by children, to avoid occupying a fixed location, and to help solidify their friendship through carrying the structure around together (*Fig. 6*).

Group Three students were fascinated by occasional community-gathering events, such as meal gatherings or outdoor film viewings. Villagers would bring chairs from home or benches from neighbouring houses to join the event. However, this region is known for its unpredictable weather and oftentimes rain would bring the gatherings to an abrupt end, thus forcing the villagers to return home. The group of students built a table that can be flipped around to form a rain shelter, so community gatherings would not be abruptly halted by unpredictable weather (*Fig. 7*).

Group Four students found that meandering village passages are confusing for visitors. Therefore, students proposed designs for a wayfinding system. Eventually the students built a signpost, modified from a traditional timber frame. The organic fabric of the settlement led them to a diagonal intersecting structure, which indicates different directions while simultaneously forming a self-supporting bench for passers-by to stop and rest.

Group Five students were fascinated by how villagers hammered nails into walls of traditional timber structures to hang bags for storage. This storage method seemed practical, but haphazard and damaging to the wooden houses. Therefore, these students proposed a new joinery that clamps and loops around the timber structure to avoid damaging the old building whilst simultaneously providing storage space.

Craft as a Form of Ideas

Miaoxia village was famed for its carpenters. The master carpenters have a particular attitude, and are respected among their communities. They keep a straight and sturdy posture and speak calmly and confidently to communicate ideas. They are in charge of the *ink* (墨斗 or mo dou, in traditional Chinese and *pinyin*), a tool that contains string and ink to mark on the timber logs, to determine the measurement and alignment of the whole structure. Junior carpenters shape the timber logs and chisel joinery. Once the frame is constructed flat on the ground, villagers gather to lift up the structural frames, and the carpenters climb up the frames to connect them, one by one. Once the structure is erected, the carpenters settle the roof rafting and the villagers stand in a line to pass along the roof tiles up to the top of the structure to lay the final layer of the roof. This is how the villagers have built their houses collectively throughout the centuries.

The tradition of building houses is not only about construction; it also involves a ritual ceremony, customs, beliefs and mysteries. For example, the villagers stated that the highest beam of the traditional house structure must be felled on the day the builders raise the structural frame. Furthermore, the tree trunk must be of a particular tree, belonging to another villager. This tree trunk is discretely cut in the early morning without the owner being informed and money is left at the root of the tree trunk to be collected upon the owner's return. Unfortunately, this sophisticated form of communal relationship is also facing extinction.

Miaoxia carpentry tradition was a form of cultural practice, community bonding ritual, economic exchange, and self-discipline. It is one of the unique local traditions that represented the community. Nowadays, the youngest master carpenters are approximately sixty years old. In a decade, this sophisticated culture will be lost forever. The community kitchen project, guesthouse project, and carpentry workshops can be seen as experiments; the project explores and documents the traditions to initiate new opportunities. In this process, Miaoxia carpentry has transformed from skills into design ideas and educational ideas. As research to redefine crafting, it positions making processes as design ideas. As the villagers' ages and social contexts change, it is highly unrealistic and unproductively conservative to wish to maintain craft traditions exactly as they are. By adapting traditional ideas, not merely repeating tedious craftsmanship outcomes, this transformation of practice might offer new imaginative opportunities. Researchers, students, and villagers together can then continue to relate ideas to our history, and extend it to create both familiar and exciting new conditions in architecture.

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Miaoxia Villagers
Carpentry Masters
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Dr. Ku Hok Bun
In-situ Project (Design Research Leadership Team)
Peter Hasdell, Kuo Jze Yi, Tan Min, Clarence Ku
Hong Kong Design Institute Student Collaborators
Chi Ho Chung, Randolph Yik Sun Lai, Theodora Tin Wai Li, Wing Chun Cheng, Wallace Hon Fung Wu, Tak Kim Chu, Stefan Kai Hin Chui, Sai Yiu Yu, Wai Kit Chu, Kelvin Chun Yin Cheung, Ethan Chi To Shum, Hau En Tsai, Suet Ngo Yan, Marco Leung Yin Sing, Horace Chi Ho Yeung, Luis Shing, Sharon Tsoi Yuk Ying, Brian Kai Ho Au, Teresa Tin, Eason Kit Yeung, Chuk Ming Wong, Shing Lap Sy
Shenzhen University Student Collaborators
Zhang Hui Xing, Hong Bi Sheng, Li Shi Zhao, Lin Qi Qing, Chen Xin, Zhu Lan, Tan Chu Jun, Xie Jing Yi, Deng Yuan, Deng Zhi Jian, Weng Ce Kai.

Figure 1 (top): Miaoxia Community Kitchen 1:25 Model, near the site of the kitchen structure. Source: *author.*

Figure 2a-e (bottom): *Chuan Dou* construction sequence, Miaoxia community kitchen under construction in July 2015. Source: *author.*


SYDNEY
UNIVERSITY

Figure 3 – 4 (page 124): Carpentry tools in Miaoxia Village. Miaoxia craft workshop in July 2016. Source: *author.*

Figure 5 (top, page 125): Student Craft Workshop Group One. Bench of Different Height designed by Chi Ho Chung, Zhang Hui Xing and Li Shi Zhao. Source: *author.*

Figure 6 (bottom, page 125): Student Craft Workshop Group Two. Portable Slide designed by Theodora Tin Wai Li, Luis Shing, Chen Xin, Deng Zhi Jian. Source: *author.*

Figure 7 (top, opposite page): Student Craft Workshop Group Three. Rain Proof Furniture design by Marco Yin Sing Leung, Suet Ngo Yan, Xie Jing Yi, Hong Bi Sheng. Source: *author.*

Figure 8 (bottom, opposite page): Student Craft Workshop Group Four. Diagonal Signpost design by Horace Chi Ho Yeung, Sharon Yuk Ying Tsoi, Deng Yuan, Weng Ce Kai. Source: *author.*

Figure 9 (top): Student Craft Workshop Group Five. Twisted Interior Furniture design by Lin Qi Qing, Zhu Lan, Tan Chu Jun. Source: *author.*

Figure 10 (bottom): Master Carpenter Posture. Source: *author.*

Figure 11 (top, page 128): Erecting the structure for the Miaoxia Community Kitchen in July 2015. Source: *author.*

Figure 12 (bottom, page 128): Visitors to the 2015 Maker Faire at The Hong Kong Polytechnic University learned carpentry techniques from the students who participated in the 2015 Miaoxia workshop. Source: *author.*

Bio

Kuo Jze Yi is an architect and researcher. His research focuses on participatory rural community development and sustainable rural building techniques. From 2015 until currently, Kuo has participated in eight community projects in rural China and completed ten community building designs that adapted traditional building techniques of timber frame, stone construction, cave construction, bamboo structure and building with local resources. He has also organised fifteen workshops in rural China, guiding 250 volunteers from different schools to document and explore traditional building culture. Kuo is currently the assistant professor of the Shenzhen University School of Architecture and Urban Planning and the visiting lecturer in The Hong Kong Polytechnic University School of Design.

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Experimental Pressure-Forming: Adding Value through Tooling Improvement, and a Hypothesis for Tooling Provision in Autonomous Development Environments

Daniel Keith Elkin

130 — 149

This paper describes improved *pressure forming* techniques, metal-forming methods related to industrial processes, but suited to lower capitalisation contracting or do-it-yourself (DIY) fabrication settings. Working from literature and previous research, the author describes advancements to the tooling's capabilities, compared to other research vectors for double-axis curvature metal forming. These works connect fabricators' situational constraints to value constructs that surround *making*'s particularity as *research*, and to values driving autonomous development construction networks. This paper asks: what values drive, and what value is added by, improving such sub-optimal fabrication processes? Given industrial and digital processes' extensive capabilities, are there contexts where intermediate technologies are particularly suited? How do those contexts constrain technical researchers' ability to add value through tooling improvement? This paper presents recent technical research, and projects a method to integrate that research into autonomous development fabrication contexts within the Hong Kong Special Administrative Region (HKSAR) and China's Great Bay Region.

#making research

#tooling provision

#metal forming

#construction technology networks

#autonomous development

Introduction

This paper describes technical research into pressure forming metal sheet. Projections from this research suggest a hypothetical tooling provision methodology to test research implementation in existing housing development markets.. Pressure forming relates to industrial standard hydroforming processes, but with tooling size, cost, and complexity suited to lower-capitalisation contracting, owner-builder, or do-it-yourself (DIY) maker fabrication settings. Working from Philip Ayres[1] research and popular publications on the tool,[2] the author describes experimental improvements to the setup (Ayres and Sheil 2012; Mallet 2011).

Pressure forming methods are divided into free pressure forming (FPF) and die-driven pressure forming (DPF). The author describes improved FPF workflows that eliminate welding, increase repeatability, and reconcile the technique with construction technology norms. DPF improvements include reduced setup time, increased design intent form vocabulary, decreased spatial requirements, and better ergonomic design. The author connects these experimental developments to underpinning *maker-researcher* methodological context constraints. Tooling environment, ergonomic, and spatial impacts upon workmanship[3] influence the maker-researcher's technological research, creating a distinct subset of technological research (Pye 2015).

Conceivably, this type of technological research is particularly applicable to the construction technology network (CTN) John F.C. Turner and his colleagues described (Fichter et. al 1972). The CTN is the supplier network underpinning housing development, particularly autonomous housing development, made up of small fabricators, contractors, and suppliers (Fichter 1972).[4] As argued in this paper, CTN members face similar tooling environment, ergonomic, and spatial impacts upon workmanship to maker-researchers. Research among Hong Kong's small to medium enterprise (SME) metalworking community indicates that this part of Hong Kong's CTN feels the impacts of such limitations. Their willingness or unwillingness to undertake experimental metalworking commissions beyond their typical business practice correlates to tooling environment, ergonomic, and spatial constraints upon their workmanship (Elkin 2018).[5] Conceivably this is because, distinct from more formalised parts of the production market, CTN members operate at low capitalisation, operate locally, and approach commissions in a narrow range of incremental, or post-occupancy design intents. Distinct from industrialised producers' relatively more straightforward comparisons between capitalisation and product output, the trade-offs for CTN technological improvement may be substantially different. CTN members likely compare *marginal* improvements in delivery certainty for design intents against tool rent, hazards, and proximate availability to their shops. Arguably, these relationships are similar to maker-researchers' relationships with tooling improvement: tooling that is available, that is safe and easy to operate, and that is spatially-practicable may constitute more significant advancement in CTN and maker-researcher environments than any industrial production ideal, even if the tooling makes new design intents only marginally more feasible.

To test this hypothesis, this paper suggests a tooling provision methodology to transition maker-researcher efforts to CTN members' possessions. The author's forthcoming research in an autonomous housing development environment near Hong Kong suggests a location where new metalworking design intents could meaningfully transition into a CTN. Tai O, a fishing village near Hong Kong, is a rare example of resident-driven housing development in Hong Kong. Concrete "village houses" along the shore populate an estuary, along with wooden-framed, metal-clad stilt houses in the tidal zone (Wong 2000). Tooling environment, ergonomic, and spatial constraints strongly influence members of the Tai O CTN's ability to effect new design intents. Work with Tai O's *shifu* and stilt house building contractors will indicate their uses for the pressure forming tooling. To place the DPF and FPF tooling into their hands experimentally allows consequential characteristics of Tai O's CTN to generate information on the tool's implementation prospects. What uses for the tooling will they find? What improvements to the tooling might they suggest? More critically, will the tooling allow design intents responsive to substantive transition threats in Tai O's development market? Tai O is, after all, under threat from a complex series of environmental and legislative concerns (Lands Department 2016). As it negotiates a transition from a subsistence fishing economy to a tourism economy, demographic and developmental pressures likely prompt design intents beyond the CTN's typical course of business. Historic and cultural development concerns uniquely constrain the CTN's response options such that some transition assistance methods are inappropriate. Can researchers work with CTN members to negotiate this change? While DPF and FPF unlikely respond to threats other than wind and impact loading upon wall-sections, this first test of the tooling provision hypothesis will provide new information on marginal and particular factors that constrain a technological improvement within a CTN, constrained as it is by its circumstances and particular character.

Advancements to the Tooling

The author explored pressure forming, informed by Philip Ayres' writing on the technique, after previous research into Hong Kong's metalworking industry. The process uses fluid pressure, most often water but sometimes mineral oil hydraulic fluid, to deform metal sheets. The process is similar to inflating a water balloon. Ayres' and popular sources' techniques are divided into two sub-categories. Ayres' termed his method "free-pressure forming" (FPF) which inflates a metal volume welded at the edges. Nothing constrains the inflation except the maker's discretion to halt the fluid flow, and the process creates unique, doubly curved metal volumes with shapes determined by the forming blank's flat geometry (Ayres and Sheil 2012). Other sources describe a die-driven process. Two-dimensional dies made from thick metal plates control sheet deformation as the fluid inflates them from below. This process, here termed die-driven pressure forming (DPF), constituted a second set of experimental fabrications.

Initial experiments in free-pressure forming removed welding from the workflow. A doubly hemmed, silicone caulk-filled edge at the edges of FPF blanks obviated perimeter welding as a means to contain fluid. This change makes FPF with galvanised, anodised, and electro-plated steel, or aluminium and copper sheets safer and more feasible. This also placed some limits on viable forming blank shapes. Bending flanges for hemmed edges on a curved forming blank forms compression or tension flanges, making closure between two forming blanks difficult. Eliminating welds between the forming blank and fluid source proved much more complicated. Durable, demountable, un-welded flanges required fastening the flange between two sides of a forming blank. This required the author to destroy the completed, inflated form to retrieve the water supply flange. The author developed a preliminary design for a demountable water supply based on a marine scupper plug. Initial prototypes successfully achieved a watertight, demountable seal between the forming blanks and the fluid supply. A subsequent purpose-built prototype will reduce the attachment opening size, reduce tooling clearance required for inflation, and reduce the pre-sinking required to insert the fluid supply. An Amada Turret Press with forming tooling also allowed experiments testing pre-formed linear patterns on forming blanks. This testing may allow increased control over free-pressure forming, but is so far inconclusive. This iteration of FPF results are effectively uncontrollable, apart from discretion over the degree of inflation and relationships between forming blank shape and resultant inflated shape. Ayres argued that the aesthetic uniqueness of the processes' output, along with labour discretion allowed by makers' control over fluid supply, compensated for this relative lack of control. Labour discretion, especially as a site-adaptability opportunity, could prove a useful characteristic for the technology with further development. Future research with FPF will focus on bringing the technology closer to construction industry norms. The process shown is presently viable with sheet thicknesses less than or equal to two millimetres, suggesting metal cladding, rather than structural applications. Integrating a rear mounting flange on FPF forming blanks, along with corner transitions and waterproofing describe further research vectors for the technology. Meanwhile, popular sources suggested that a similar pressure forming process would be more likely to address these construction technology requirements.

Die-driven pressure forming (DPF) allows metal shell production with a better balance between labour discretion, more certain delivery, and more easily implementable design intents. Relatively simple dies allow certain tile-able shape production and provide one flat surface to the shells, making the process outputs readily applicable as cladding. There is, however, considerable room for improvement to the tooling in its current state. A primary difficulty with DPF tooling as previously designed is the force required to deform a metal sheet. Two-dimensional metal dies between one and two centimetres thick must sit on one side of the forming blank, with a similar thickness bearing plate on the other side to control fluid pressure. This means the tool is usually too heavy for one- or two-person lifting if it is large enough to form metal shells of any significant size. The author's initial experiments, consequently, reside within a 40 centimetre by 20 centimetre rectangular area. This makes the tooling cartable by hand. The resultant doubly curved shells, applied as cladding, are closer to shingles than fully demountable panels. Panels would preferably be larger, and flanged for demountable attachments at top and bottom. The next iteration of the DPF tooling mounts bearing plates and dies on a mobile table to make the tool cartable at increased size. As space is a constant constraint in Hong Kong's crowded environment, where the author conducts research, hinges in the bottom bearing plate of the tool allow it to fold vertically and reduce transportation width. The deployed forming area of the tool will be 60 centimetres by 90 centimetres. The author derived these dimensions from the size of 55 gallon drums, and their constituent ergonomic suitability. Introducing an Ethylene Propylene Diene Monomer (EPDM) rubber membrane into the tool allowed perforated shell production in previous experiments. The future DPF rig will use a double-sided EPDM membrane. This will contain the forming fluid better than a linear gasket between the forming blank and bearing plate, and reduce potential corrosive contact between the fluid and the workpiece. While this will make plumbing the rig more difficult, it will provide dissemination-friendly advantages: it will obviate the need to tap the bottom plate for plumbing, and reduce the risk of marking the forming blank.

Designing the forming dies remains a site for additional feedback from contractors working in a project area. The shape chosen for the deforming metal to expand through unavoidably confines the range of formable outputs. With a broad range of design intents as a constraint, the tool includes multiple interchangeable dies. Generally, the die shapes chosen are tessellating shapes with 1:1 or 1:2 height-to-width ratios. Circular and elliptical dies, while not tile-able, allow parabolic mirror fabrication. The experimental *arabesque*-shape die is a tessellating shape informed by metal flange seaming experience. Minimising corners allows smoother transitions between flanges and seams, rationalising an otherwise-capricious-seeming panel shape. As a user must interchange dies, they should be as lightweight as possible, suggesting aluminium as a suitable material choice. Further, dividing dies into halves makes them easier to handle and transport, and allows shape combination. If possible, vinyl coating on top dies and bottom bearing plates will reduce corrosion and marking.

Achieving fixity during forming remains a challenge. Previous designs for the tool fix the top die to the bearing plate with bolts through the die, workpiece, and bearing plate, and nuts on the other side. This detail is expedient because of the hardware's ubiquity, but seems a major site for improvement because of the long setup and reset time required. Tapping the bottom plate to receive machine screws through the top die allows faster setup, but constrains die shape flexibility, especially since square and 1:2 rectangular die formats are desirable within one rig. The problem of through-holes in the workpiece also remains. Mounting holes for bolts or screws in the workpiece complicates flanging for making demountable panels. A rail for hold-down clamps seems a viable solution. Lead shot bags or other cartable weights are also expedient, though a more weight-effective solution to provide fixity may be a powerful electromagnet. Protected by vinyl or silicone, an electromagnetic ring could force the halves of top dies together, and push them against the bearing plate to direct forming pressure. If electromagnet experiments work, the total elimination of mounting holes, and the obstructive clamp-mounting rail, could allow much more expressive fabrications. This method to achieve fixity would allow multiple forming operations within a single sheet, along with the anticipated vocabulary of repeating panels. The operator's labour discretion would totally control site and expansion of the metal to create a strongly expressive language. Furthermore, the electromagnet may prove the most promising part of the tool if made at once flexible before engaging power, and very rigid when powered. An electromagnetic chain-die may leave user discretion and the length of the chain itself as the only constraints on the tool's form vocabulary.

The Maker-Researcher Methodology and Accompanying Value Sets

The author conducted these experiments as a maker-researcher. To distinguish the maker from the designer, fabricator, or other members of the production economy requires an understanding of his or her fabrication context and priorities. As described in literature on the "maker movement" and other contexts of non-industrialised and/or formalised fabrication work, the maker:

1. Makes objects in a capacity not central to his or her primary employment, as distinct from the fabricator or contractor.

2. Participates personally in fabrication processes, applying her or his personal workmanship to artefacts. Potentially he or she applies this workmanship to artefacts further downstream than delineation or prototyping, even to final artefacts, as distinct from the formalised designer-delineator.

3. Makes use of informal or personally procured fabrication plant and environments, such as maker-spaces, home fabrication or community facilities (Conrad 2017).[6]

Making-research literature, as a subset within design research, emphasises values that differentiate between designers who make things from designers who do not. These circumstances somewhat modify each of the three points above. First, personal makers engage in production distinct from their primary employment as a hobby or secondary interest. Maker-researchers' object production is secondary because knowledge production is their primary concern. This partially complicates point two. Personal workmanship participation underpins the making-research versus design-research distinction. Given that knowledge production is the goal, this personal preference could stand in the way, conceivably of producing relevant, transferable, new knowledge. For instance, should the maker-researcher not seek the maximum workmanship competency available to ensure that research artefacts contribute to technology research's boundary knowledge production? Is their personal workmanship participation not an arbitrary preference or starting bias? Point three is similarly problematic: Should research not seek facilities appropriate to the technological state of the art, rather than depending on background availability and the researcher's personal facility?

Maker-research literature answers this question by privileging certain knowledge generation subsets emergent through personal workmanship participation rather than personal workmanship participation itself. Immediacy and responsiveness between design and fabrication,[7] and the knowledge generated thereby, more closely encapsulate the rationale for maker-researchers' personal participation bias than arbitrary preference. Ayres and other authors describe unique knowledge sets emergent from this kind of relationship, both in terms of form production and research innovation (West and Sheil 2012; Carpenter and Hoffman 1997). Maker-researchers generate knowledge by designing through making rather than designing before making. The process of workmanship itself is as much a site for knowledge generation as the outcome of workmanship. As a result, they may face facility and workmanship constraints similar to colloquial makers, but for different reasons. A personal or hobby maker's facility constraints depend on simple availability. A maker-researchers' facility constraints depend on immediacy, to the point that they may privilege more responsive facilities over more capable facilities, even if both are similarly available to him or her. Therefore, maker-researchers:

1. Make objects in an experimental capacity to contribute to a larger body of knowledge. As distinct from the fabricator, the knowledge, not the object, is the output of the work. This knowledge must contribute and disseminate through larger knowledge generation frameworks as research.

2. Contribute personal workmanship to objects to generate knowledge through immediacy and responsiveness between design and fabrication. As such, maker-researchers may forgo personal workmanship participation when facilities and fabricators are suitably responsive as well as capable.

3. Patronise or develop informal production facilities to the extent those facilities provide greater immediacy and responsiveness between design and fabrication. As such, a maker-researcher's facility preferences may alternate between informal and formalised state-of-the-art facility requirements.

Because of these biases, maker-researchers, compared to other technological researchers, conceivably face greater impact from tooling environment, ergonomic, and spatial impacts upon workmanship.[8] A maker-researchers' directive for responsiveness and personal workmanship may mean tools that are available are preferred over tools that are most fully effective or efficiently productive (Elkin 2018). Immediacy may mandate working independently or personally providing workmanship to the extent of one's ability. This means hazards, lifting weights, and carting sizes directly affect the content and outcomes of the work. Informal facilities may be more responsive than formalised production facilities, constraining the maker-researcher's technological advancements to what fits in their domestic environment or incidentally available spaces. Their mandate for personal workmanship may disconnect their research from the prevailing plant or state of the art in technological research under some circumstances. While these constraints may seem artificial, or simply the result of poor funding and facilities to be improved, they may contribute to a certain subset of technological research as knowledge. Further, as discussed below, they may be uniquely applicable to a particular setting in real estate economy supply chains.

The author's experimental pressure-forming improvements evidence the import of these making-research constraints for technological improvement. The genesis for the research itself began from a tooling environment constraint upon both the author and other fabricators in his immediate context. Tooling and workmanship to produce doubly curved metal fabrications reliably is rare in Hong Kong, nominally non-existent with the exception of rare shifu old masters possessing considerable skill (Elkin 2018). To explore this range of design intents with any degree of responsiveness and immediacy required new tooling, or a considerable improvement in the author's workmanship. With the latter yet to materialise, pressure forming experiments work to surmount this barrier into a responsive and iterative workflow. Similarly, while welders are somewhat common, three-phase electrical outlets are not available in most apartments or even many research facilities. Ayre's previous pressure forming work depends instrumentally on this tooling (Ayres and Sheil 2012). Along with considerable workmanship requirements, this tooling is situationally rare. The prevalence of galvanised and electro-plated steel sheet for Hong Kong's suppliers readily transitions into the second constraint set that maker-researchers face, i.e. ergonomic constraints. Welding galvanised steel sheet is possible and, in Hong Kong's metalworking shops, even common. However, results are categorically poor and, more importantly, this operation vaporises the zinc coating on the steel, which creates hazardous fumes. To be clear, ergonomic constraints are not solely construable as hazards. Simple facts of self-production guide the maker-researcher's technological innovation vectors. The author typically works alone. As a result, solutions to the original tooling constraint must tangibly respond: DPF dies must be light enough to lift. Deployment of the tools must be convenient, safe, and comfortable. Workflow constraints to reduce bending and lifting put the tool at table height. The author fillets or smooths edges when possible, not for aesthetic purposes but out of concern for the worker's hands. This concern, while hypothetically meaningful in all production scenarios, must be consequential for the maker-researcher as the distance between researcher, worker, and designer is zero. Lastly, spatial constraints provide research criteria seemingly contradictory to the tooling improvement brief, and yet critically important to the new technology's implementation. The tooling must fit through a door. The tooling must be mobile. The tooling must survive difficult outdoor and site conditions, as it cannot be stored in the author's living space.

In normative or industrial production contexts, many of these constraints would solely be present through complex and reified regulatory structures. Production technology advancement at the state of the art holds delivery certainty and quantity as its primary concerns and demands that, whenever possible, circumstances must change to make the technology viable. Industrial tooling progression discussed in engineering texts and construction technology literature suggests this as a widespread industry bias (Roser 2017; Ganesan et al. 1996). Producers and researchers must purchase and concentrate ancillary tooling to improve delivery certainty and capacity. Producers and researchers must improve human bodies past their ergonomic constraints, or work to omit them entirely. Producers and researchers must expand or build purpose-designed facilities to accommodate production. Conversely, in the context of maker-researchers' practice, technology must adapt to fit the circumstances. Increased delivery certainty remains a goal, but circumstantial and situational constraints temper the meaning of this goal. Efficiency, in terms of units of output per unit of time, may be a less critical concern. Certain design intents may remain unachievable without significant workmanship quality improvements, while still becoming more feasible than before technology improvement. With complex preconditions compared to the industrial norm, are there circumstances under which this making-research method can objectively add value? Can researchers conceive of making-research, an almost intentionally sub-optimised condition, as a subset of technological research with broad applicability?

Making-Research and CTN's Shared Values

To answer this question one could ask if there are subsets of the production market where available tooling, ergonomic, and spatial circumstances' impacts upon workmanship are meaningful to producers or the consumers they serve. Previous research into Hong Kong's metalworking industry revealed a market of fabricators contributing to what John F.C. Turner termed the "construction technology network" (CTN) (Fichter et. al 1972). CTNs are distinct from other production contexts in that they:

1. Operate at low to medium capitalisation, often dependent on marginal profit from additional commissions within a range of design intents determined by their initial tooling investment.

2. Operate locally or semi-locally, with geographic constraints on members' plant located closely to their consumer base and, often, within members' place of residency.

3. Operate diffusely, consisting of diverse members, with decentralised plant, marketing, motivations and capabilities (Ibid).

Hong Kong's metalworkers, SME fabricators engaged in small-scale fabrication and repair, often fit within these criteria. According to a survey, these metalworkers often work out of one shop within the Hong Kong area. Some have expanded to regional fabrication facilities in neighbouring cities in south China, but most operate in the same neighbourhoods for the extent of their business operation, often over the course of decades. Their added value to the consumers they serve depends on their possession of one or two critical articles of plant, typically a press-brake and/or a welder. They operate independently and seek post-occupancy or single-term commissions in a limited range of design intents, often ductwork production or furnishing commissions.

Experimental design commissions meant to test their production capability found strong correlations between tooling environment, ergonomic, and spatial constraints, and these businesses' willingness to accept new design intents. For example, fabricators were more willing to take on commissions with holes punched in the centre of a workpiece if high-wattage laser cutter tooling was readily available to them, correlating this tooling availability to the design intent's delivery certainty. Designing commissions to remove welding from the production workflow increased the number of fabricators who were willing to take them on. Critically, no fabricators would accept experimental commissions requiring double-curvature metal forming without significant upstreaming assistance. Researchers provided additional computer numerically controlled (CNC) mill tooling and developed a forming buck,[9] after which one fabricator was willing to accept the commission. Such tooling was nominally unavailable to metalworking professionals until researchers provided it. Ergonomic and spatial constraints upon fabrication commissions were intermingled. Fabricators tended to accept commissions more readily if the commissions were subdivided into cartable pieces, preferably under the size and weight of a one-person lift. Given that many fabricators in Hong Kong conduct their work in the street because of small workshop size, commissions that fabricators could assemble on a small table top achieved better results and more certain delivery (Elkin 2018).

In short, the tooling limitations, ergonomic constraints, and spatial constraints Hong Kong's metalworkers face strongly correlate to their willingness and ability to deliver design intents at the boundary of their capabilities. Such constraints are often external to design and research concerns outside the context of SME fabricators and members of a CTN. For certain, transitions into more formalised fabrication environments throughout south China allows these concerns to be secondary or even ignored. As such, correlations between market formalisation, geographic alienation, and reification of material labour constraints are conceivably present. More importantly, technological research through a maker-research framework, responsible to constraints that CTN members share, may allow new insight into technological improvement vectors. The imperatives of normative industrial production may come secondary, when technology implementation is concerned, to the granular constraints upon CTN members' workflow. What is required is a methodology to test this hypothesis, and determine if this connection between maker-research contexts and CTN contexts provides valuable insight.

Tooling Provision into a CTN

Land, materials, tools, labour, and financing are the resources that underpin the housing development market, according to Turner and his research colleagues. Within this market, Turner separates development planning and development action, and suggests, most critically, that research professionals conduct something more akin to planning. As planners, researchers concern themselves with limit setting and resource provisioning, not designing or employing resources as uniquely privileged development actors. To use Turner's analogy, researchers are "rule-makers," not "game players" (Turner 1972). Within this framework, the author hypothesises the next step in this research as a tooling provision methodology. The underlying research question is this: how can researchers help CTN members achieve meaningful design intents beyond their current capability? The hypothesis is that tooling provision, along with consultation as a form of labour provision, will lower opportunity costs for CTN members to achieve new design intents, through precise understanding of their circumstances.

Tooling provision encapsulates the expanded scope of this work as a context transition methodology. The content of the previous research, rather than the particular characteristics of the development context, suggests this method. Any large-scale resource provision, particularly pertaining to land, labour, or financing, is beyond the scope of this work. While this means the rationale for choosing this methodology is somewhat post-rationalised from the initial experiments, the site chosen for the initial case study to test this hypothesis suggests constraints upon the CTN that make tooling provision particularly suitable.

Tai O, a fishing village under HKSAR governance, is undergoing a development transition. Ambient development changes, along with Hong Kong Government Civil Engineering and Development Department (CEDD) planning strategy, describe a future role for Tai O as an eco-tourism destination (Civil Engineering and Development Department 2017). Planners can predict demographic, land-use, and spatial programming changes under these circumstances, for areas developed as concrete "village houses" and areas comprising the original "stilt houses" that attracted tourism to Tai O (Wong 2000). Some are already underway: stakeholders note the repurposing of some stilt houses to guest rentals and bars, and other stilt houses rebuilt after fires have increased in both gross floor area and population density.[10] Paradoxically, two factors constrain development growth within the original village's stilt house technology: first, the Lands Department (LD) mandates any stilt house renovation or construction to use "temporary materials," usually interpreted as wood and metal, not concrete (Lands Department 2016). Second, tourism objectives suggest that redevelopment with exogenous materials or technology would damage the overall appeal of the village's stilt house community. For residents to participate fully, Tai O CTN members are likely to require new design intents to accommodate the development transition: fireproofing and structural stiffening to address densification and commercial land uses, or larger floor and roof framing spans to accommodate assembly spaces. Notably, any material provision must strategically remain within Tai O's technological language. Additionally, the housing development change underway is not so much more housing development, but transitional housing development. This complexity, combined with interviewed stakeholders' exhortations that Tai O residents are cash rich, and complex land tenure and taxation structures, suggest that financial subsidies for CTN members would require strategic trade-offs for implementation.

This leaves labour and tool provision as valuable techniques for implementing change. While providing additional labour as a numerical resource is beyond the scope of this work, labour provision as a technical or skill resource may be viable. Under Turner's instruction to work with residents not for residents, consultation with CTN members, providing skill and knowledge to reduce their opportunity cost, may make the difference in achieving new design intents for Tai O's transition (Turner 1972). However, such expertise provision or consultation strategies create knowledge transfer packaging and dissemination problems. Without either sophisticated representation packaging or continued correspondence with the development market, researchers' expertise may not transfer properly to more than one set of development actors. At this point, the researchers' work transitions from provision to action, dissemination becomes less likely, and political problems may result. Tooling provisions have the advantage of packaging research knowledge transfer as tacit knowledge, something consultation approaches struggle to do. A tool makes accomplishing certain design intents more feasible through its physical character. If placed correctly, at significant barriers in CTN members' capabilities, they provide specific and pre-validated solutions to fabrication problems. In exchange, researchers must package these solutions to a specific purpose: the tool must be designed to resolve a given range of design intents and do so well. As such, *what constitutes a meaningful new design intent to CTN members and residents?* becomes a critical question. Planners and researchers must ensure that tooling provision investments justify the trade-off between purpose specificity and fabrication feasibility, along with embodied capital for technology development itself. Arguably, the answer to this question lies in response to the demographic and development transitions described above, and in critical technologies that address those changes.

In response to these transitions, the pressure forming tooling is unlikely to be convincing. In the present iteration, the pressure forming tools allow doubly curved fabrications applicable as exterior cladding. Applied throughout Tai O's CTN these may allow more impact- and wind-resistant wall sections, which would likely be a relevant improvement given Tai O's coastal location. Parabolic mirrors could be useful for directing solar energy as well, contributing to electricity generation, heating, or food and clothes drying purposes. In spite of these limited applications, one virtue of the tooling provision methodology itself, however, is to remove some portion of pre-rationalisation from the development of the technology. That is, if the author deploys the pressure forming tooling in Tai O, into the hands and control of Tai O's shifu and contractors, their decisions will determine its relevant use. With time, their deployment of the tooling will likely generate unexpected uses and new design intents. At a minimum, their work with the tooling, or even refusal to use it, will provide meaningful research feedback. Turner's methodology-cum-polemic for dealing with housing development in general and underserved populations in particular depends upon respect for and responsibility to these potentials for innovation feedback. As such, to surrender some degree of control and allow others to influence the outcome becomes an essential part of the research. For the maker-researcher and the technological researcher more broadly, this is conceivably a problematic demand: the desire to improve can run contrary to a mandate to listen, facilitate, and support. Upon testing, the tooling provision methodology works to bridge some of these difficulties: it works to connect maker-researchers' skills to package, improve, and solve CTN members' needs for autonomy, flexibility, and robustness. To accomplish this goal, this methodology concentrates maker-researchers' work on tooling design rather than assembly design, using their unique insights to connect technological research in the context of autonomous housing development. Forthcoming research will determine the viability and potentials of this approach.

Notes

1. Ayres discusses what he calls "the persistent model," a hydroforming project whose form and spatial expression responded according to the pressure forming tool operator's first-hand decision-making. Ayres' approach is similar to popular publications on free pressure forming that uses stainless steel forming blanks, welded along their perimeter using, most often, tungsten inert gas (TIG) welding. Discussed in: Ayres, Phil, and Bob Sheil. "Microstructure, Macrostructure, and the Steering of Material Proclivities." In *Manufacturing the Bespoke: Making and Prototyping Architecture*, 220-37. Chichester, U.K.: John Wiley and Sons, 2012.

2. Among others, the Discovery Channel shows *Mythbusters* used the pressure forming technique to make doubly-curved metal torpedo shells more expediently. From: Mallett, Jessica, writer. "Mythbusters Torpedo Tastic." In *Mythbusters*. Discovery Channel. 5 April, 2011.

3. David Pye defines a number of concepts related to workmanship: a worker's *dexterity* and *patience* generally control workmanship quality, taken as a comparison between the workmanship outcome and the *design intent*. *Free* workmanship, as opposed to *regulated* workmanship, allows some relaxation of a worker's dexterity within an acceptable outcome range. *Certain* workmanship refers to workflows where a worker's dexterity and patience *during production* impact the outcome's acceptability less than dexterity and patience *before production*. *Uncertain* workmanship depends upon skilled workmanship during production, as fewer controls are implemented beforehand. Pye's arguments de-couple certain value judgments for workmanship, particularly assumptions that *regulated* and *certain* workmanship equate to *good* workmanship. Pye stresses that workmanship's relationship to design intent allows a more complex interpretation of workmanship quality. From: Pye, David. *The Nature and Art of Workmanship*. New York: Bloomsbury, 2015.

4. Fichter, Turner, and Grenell describe CTN operations and constraints at length in *Freedom to Build*. Notably they suggest that CTN's diffuse character as a resource-managing structure is beneficial, in terms of arrangement, to residents, as well as the most common condition for residential construction economies. Refer to: Fichter, Robert, John F.C. Turner, and Peter Grenell. "The Necessity for Networks." In *Freedom to Build: Dweller Control of the Housing Process*, by John F. C. Turner and Robert Fichter, 255-274. New York: Macmillan, 1972.

5. Refer to the author's index study of small to medium metal working enterprises in: Elkin, Daniel. "Undevelopable: Metal, Curvature, and Tooling-Based Research in Hong Kong's Compressed Space." In *2018 Architecture and Civil Engineering Conference*. *Proceedings of Architectural and Civil Engineering Conference,* Singapore. 2018. DOI: 10.5176/2301-394X_ACE18.114.

6. Literature on the "maker movement" describes the informal fabrication culture emerging in recent decades, such as: Conrad, Dale Dougherty. *FREE TO MAKE: How the Maker Movement Is Changing Our Schools, Our Jobs, and Our Minds.* READHOWYOUWANT, 2017. Some authors connected the maker movement with new forms of economic and real estate development, such as: Hirshberg, Peter, Dale Dougherty, and Marcia Kadanoff. *Maker City: A Practical Guide To Reinventing Our Cities*. San Francisco: Maker Media, 2017.

7. Mark West's initial interest in fabric-formed concrete work stemmed from a search for semi-determinate fabrication processes, allowing faster and more responsive feedback between design and fabrication. West, Mark, and Bob Sheil. "The Projective Cast." In *Manufacturing the Bespoke: Making and Prototyping Architecture*, 132-45. Chichester, U.K.: John Wiley and Sons, 2012. Similarly, multiple authors describe benefits to a responsive designing and making process in: Carpenter, William J., and Dan Hoffman. *Learning by Building: Design and Construction in Architectural Education*. New York: Van Nostrand Reinhold, 1997.

8. Similar relationships exist between spatial and ergonomic production constraints and their consumption, particularly by underserved populations in informal spatialisation contexts. Refer to: Elkin, Daniel, Gerhard Bruyns, and Peter Hasdell. "Appropriate Construction Technologies for Design Activism: Material Research Practices in Response to Globalisation." *Architectural Research Quarterly 22*, no. 4 (2018): 290-309. doi:10.1017/s1359135518000507.

9. Refer to practical references for metal forming either by hammering, or on an English Wheel and a buck to ensure design intent delivery in: Lipton, Tom. *Metalworking Sink or Swim: Tips and Tricks for Machinists, Welders, and Fabricators*. New York: Industrial Press, 2009.

10. This information is taken from an interview with Madame Wong Wai King, author of one of the primary texts about the history and anthropology of Tai O.

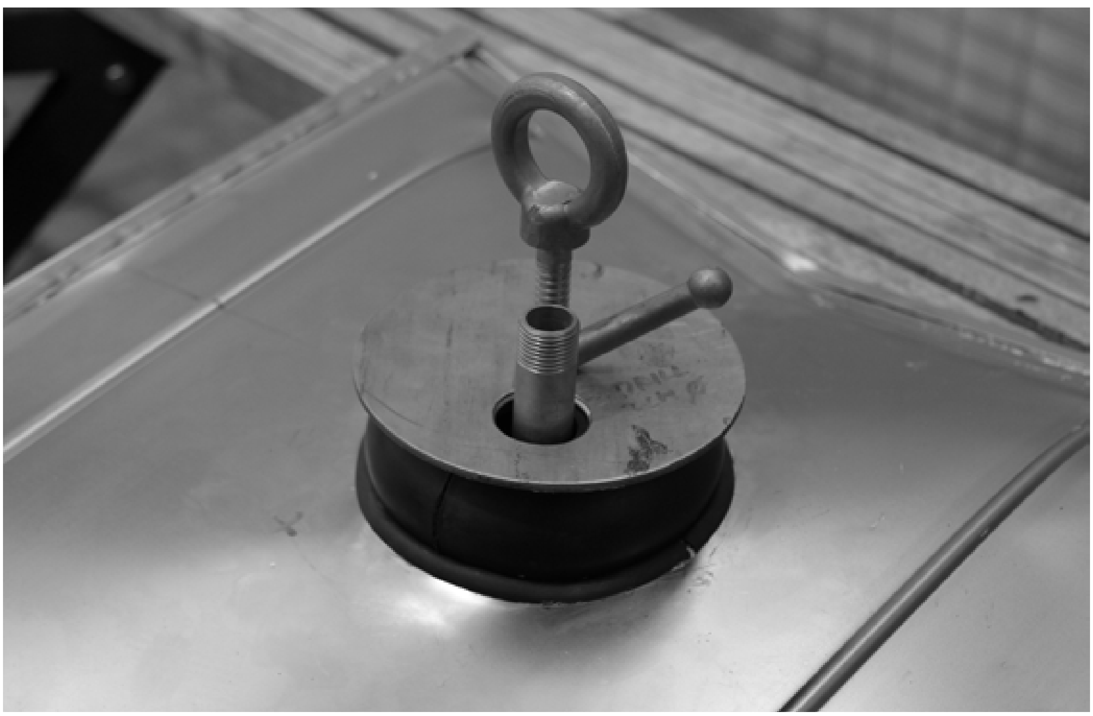


Figure 1 (top, opposite page): Early free-pressure forming test. This test successfully removed welding from the workflow, a desirable change for application to galvanised, anodised, or otherwise pre-coated metals that make welding dangerous or impossible. However, the through-bolted attachment flange on the rear of this test is not removable without destroying the final fabrication. Source: *author.*

Figure 2 (bottom, opposite page): Modified marine scupper plug, allowing demountable water pressure supply for free pressure forming. A rubber gasket adhered to the edges of a hole allows inflation of the metal volume without trapping the water supply attachment inside. To reduce the size of the entry aperture requires a custom attachment, necessitating more investment and better rationalisation of the technology. This is the author's most recent work on free pressure forming, as die-constrained forming has become the primary focus. Source: *author.*

Figure 3 (left): Current pressure forming rig, with a hexagon-shaped forming die. Source: *author.*

Figure 4 (right): Resultant hexagonal formed shell. As Ayres pointed out, one distinctive quality of the pressure forming process is that deformation amount is at the user's discretion up to the limit of the material, allowing labour discretion into the fabrication and design process. Note the deformation of the sheet near the through-holes for bolting the forming rig together. These make flanging for demountable panels difficult, making elimination of this fixing method a priority. Source: *author.*

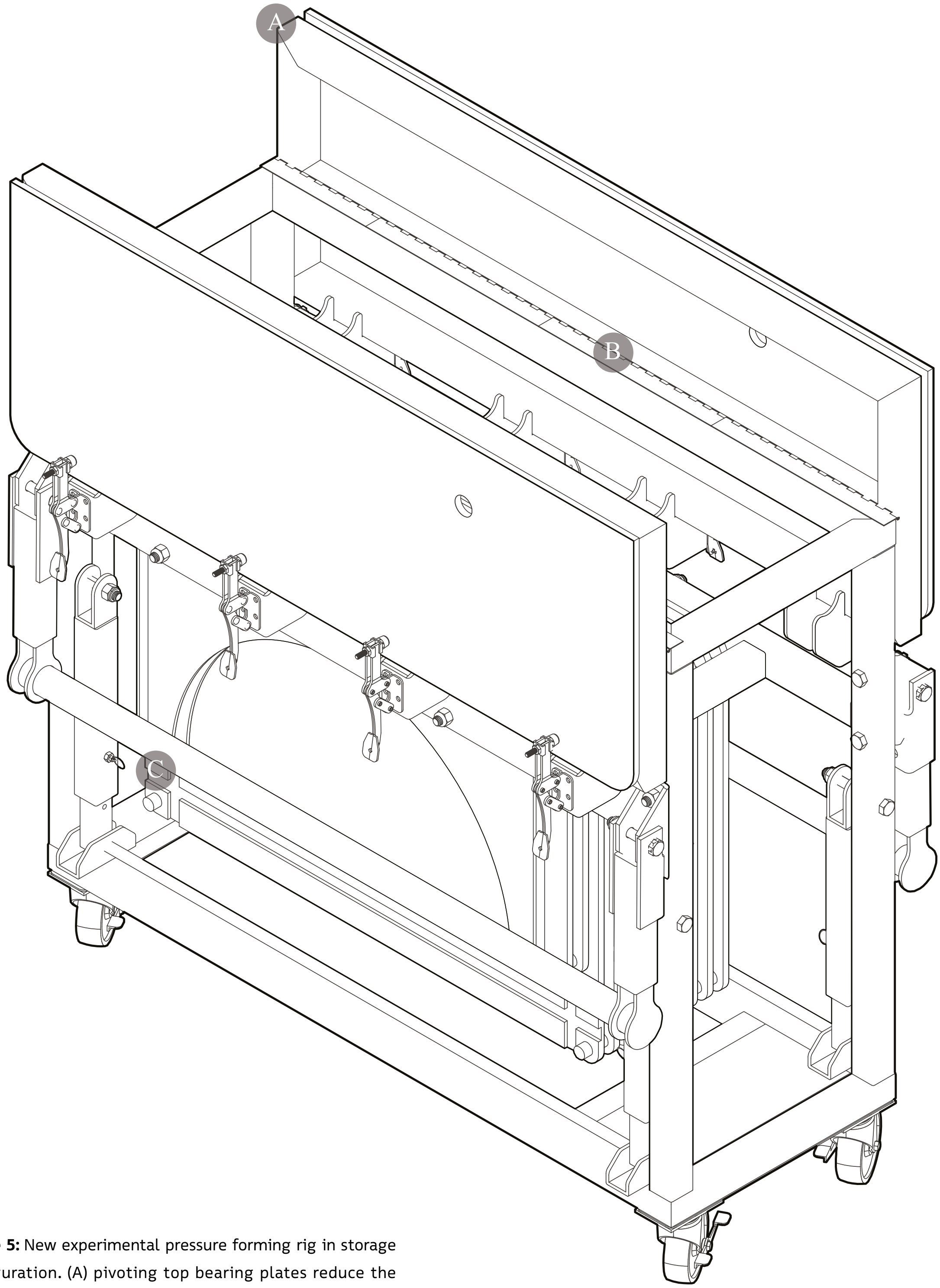


Figure 5: New experimental pressure forming rig in storage configuration. (A) pivoting top bearing plates reduce the stored width of the rig to forty centimetres wide from a deployed width of around 80 centimetres. (B) continuous hinges allow operable top bearing plates. (C) die plates stored underneath the rig support have rubber bumpers to prevent noise and vibration. Source: *author.*

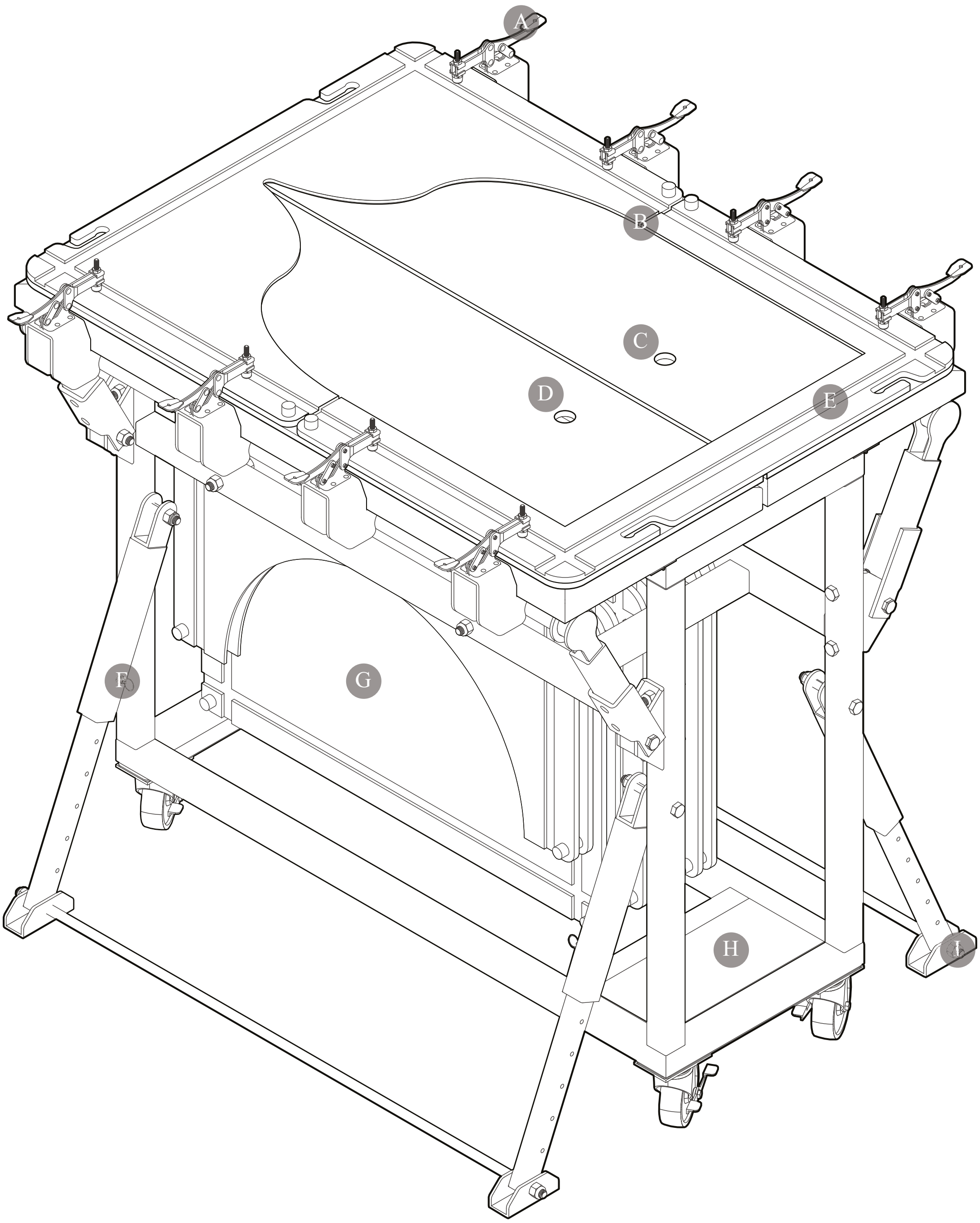


Figure 6: New experimental pressure forming rig in deployed formation. (A) flanges for demountable hold-down clamps provide backup fixity in the event that the electromagnet design does not work or electrical current density is a site-condition issue. (B) stiff rubber gaskets at die jointures will allow inter-changeable dies with multiple configurations. (C) water inlet through bottom bearing plate into double-sided rubber forming bladder (not shown). (D) water outlet pressure release safety valve from double-sided rubber forming bladder. (E) milled pocket for electromagnet fixing frame. (F) telescoping stabilisation strut spring-pin. (G) hanging storage for forming dies.(H) storage surface for pressure washer/pump. (I) stabilisation strut levelling foot. Source: *author.*

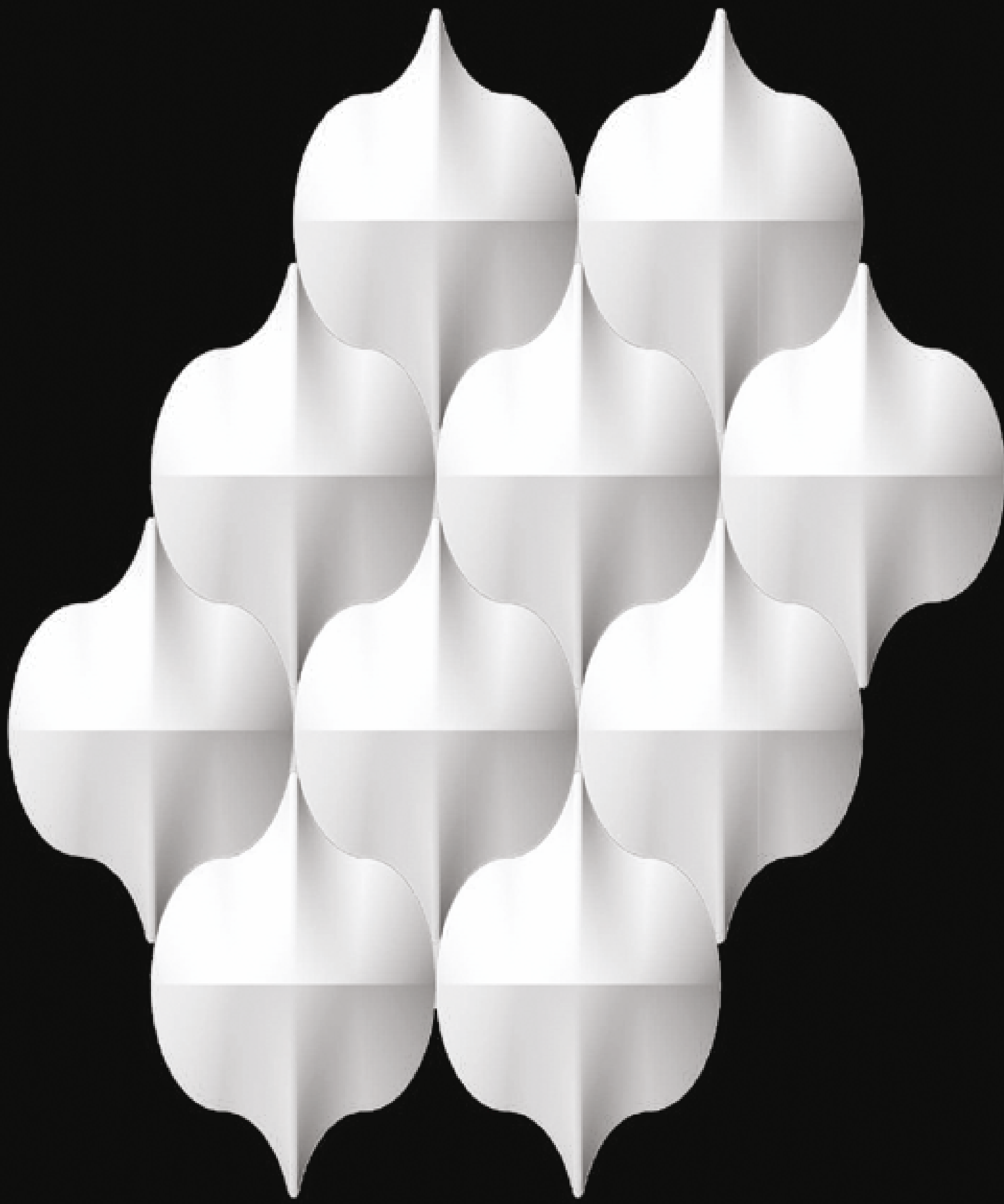
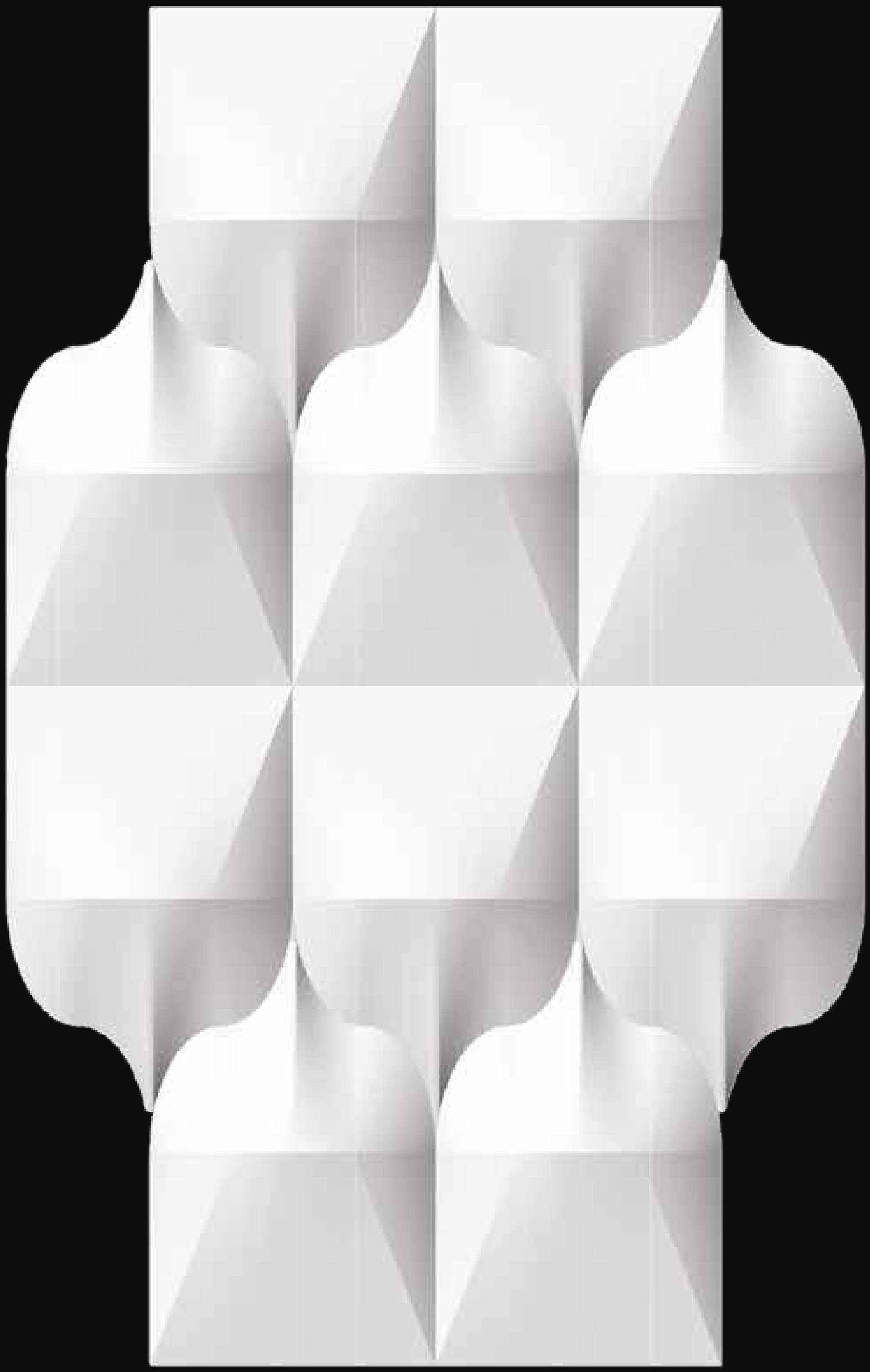


Figure 7: *Arabesque* panelling layout using identical die halves. Tessellating, curved panel shapes eliminate corners to respond to sheet metal forming constraints, where flanges perpendicular to the primary panel surface require joinery whenever an obtuse angle of incidence results. For example, hexagonal panels, which minimise the panels' perimeter length/surface coverage ratio also require more complex seaming operations between flanges. Partial panels at surface edges remain an issue, but the packing-readiness and fabrication suitability of the formed panels rationalise an otherwise capricious-seeming panel layout. Source: *author.*

Figure 8 (opposite page): Interchangeable die-halves allow combined panel configurations, making further rationalisation of other panel arrangements possible. Source: *author.*



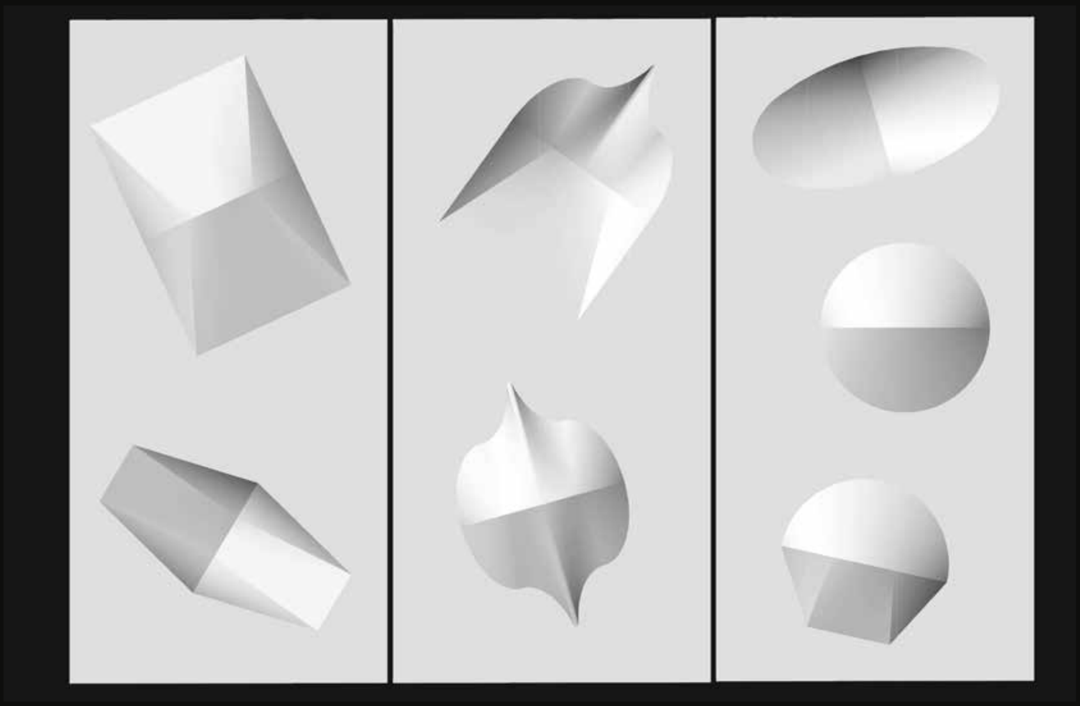


Figure 9: If either an electromagnet or weight bag fixity method can be made workable, complex and site-designated deformation of larger panels would be possible, putting both placement and deformation depth at the discretion of the tool user. Source: *author.*

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Bio

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029

Post Human Craft: A Humble Attempt to Reorient Makers to the Inevitable

James Stevens

150—165

Nearing the end of the second decade of the twenty-first century many craftspeople and makers are waking up to the inevitable reality that our next human evolution may not be the same, that this time it could be different. Klaus Schwab, Founder and Executive Chairman of the World Economic Forum refers to what we are beginning to experience as the Fourth Industrial Revolution (Schwab 2017, 01). Schwab and his colleagues believe that this revolution could be much more powerful and will occur in a shorter period than the preceding industrial and digital revolutions. This revolution will cause a profound change in how we practice, labour and orient ourselves in the world. Rapidly evolving technologies will proliferate the use of robotics and personalised robots (co-bots) that can sense our presence and safely work alongside us. Digital algorithms are already becoming more reliable predictors of complex questions in medicine and economics than their human counterparts. Therefore, the gap between what a computer can learn and solve and what a robot can do will quickly close in the craft traditions.

This article will engage in the discourse of posthumanism and cybernetics and how these debates relate to craft and making. Intentionally this work is not a proud manifesto of positions, strategies, and guidelines required for greatness. Alternatively, it is a humble attempt to reorient makers to the necessary discourse required to navigate the inevitable changes they will face in their disciplines. Thus, the article seeks to transfer posthumanist literary understanding to intellectually position craft in the Fourth Industrial Revolution.

#posthuman

#digital design

#craft

#digital fabrication

#cybernetics

Introduction

Before the Industrial Revolution, artisans practised their crafts framed by preindustrial traditions. Individual and collective human agency is inseparable from craft and the philosophical and ethical tradition of Humanism. The craftsperson is the "liberal subject" in the Humanist tradition and defined by exercising critical thinking to shape material into artefacts of desire. The Industrial Revolution interrupted preindustrial craft tradition with new economic velocity prioritising efficiency and marketability. Preindustrial craft knowledge was centralised into factories and along assembly lines. However, mechanisation aligned with the humanist tradition through collective human agency. With the advent of the digital and information age, craft traditions can now return to a decentralised method of making with new digital tools that can make almost anything from a desktop computer (Gershenfeild 2005). Regardless of the social and economic changes, craft persevered as a constant human endeavour. What appears to remain through all of these upheavals is the necessity that all craft and making is an embodied human activity.

Nearing the end of the second decade of the twenty-first century many craftspeople and makers are waking up to the reality that our next human evolution has the potential to challenge human agency. Klaus Schwab, Founder and Executive Chairman of the World Economic Forum, refers to what we are beginning to experience as the Fourth Industrial Revolution. Schwab and his colleagues believe this revolution could be much more powerful and occur in a shorter period than the preceding industrial and digital revolutions (Schwab 2016, 3-10). This revolution will change how we practise, labour, and orient ourselves in the world. Rapidly evolving technologies will proliferate the use of robotics and personalised robots, so-called *co-bots*, that can sense our presence and safely work alongside us. Digital algorithms are already becoming more reliable predictors of complicated questions in medicine and economics than their human counterparts. Therefore, the gap between what a computer can learn and what a robot can do will quickly close in on the craft traditions. It is easy to see how we may begin to ask what value a human-made object has outside the sentimental imperfections. We could begin to fall further from our connection with the material world and what artefacts mean to us as a society and begin to only understand them as a code or dataset to implement for production.

The conditions that are causing change are not simple or easily understood thus creating anxiety rooted in inaccurate perceptions. The major social changes of the past that upended craft and making never questioned our embodied skill and desire. This skill was legible to us as makers because our process drove input with outcomes dependent on our skill. Regardless of the tool, we provided the sole source of knowledge and skill, and it returned a product of our making — we practised and learned, not the tool. However, this is changing; our tools can now learn from us and continue to learn independently. The cycle of making is no longer only human input with an equivalent output, but rather a posthuman cycle of making whereby the tool has now entered the discourse of learning and making. Machine learning can trigger our anxiety that craft is doomed. Indeed, tools will learn, but our anxiety regarding their place in craft is misguided, as machines neither are, nor are expected to become, sentient. The position of a craftsperson will change because the historic duality between maker and material will become a broader networked digital ecosystem. Therefore, craft will soon face the challenge of an inevitable reorientation of tools and process. This work is a humble attempt at this reorientation through a discourse of evolving technologies and social changes that craft is already encountering. A brief case study will be provided to show a simple example of how the power of Artificial intelligence

(AI) can extend the impact of a single craftsperson. Concluding, the article will take on a few of the leading conversations around this topic but through a filter of craft and making with hopes that the remaining will inform a reorientation of craft discourse.

Situating Craft

Craft is typically defined as a skill practised to achieve consistent outcomes. One might think of a potter at the wheel consistently creating the same vessel to near perfection or a welder fusing steel that can achieve an expected shear load. Most agree that craft is achieved by practice and that it provides consistent, exceptional outcomes. The Encyclopaedia of Diderot & d'Alembert described craft as the;

> *name given to any profession that requires the use of the hands and is limited to a certain number of mechanical operations to produce the same piece of work, made over and over again* (Gendzier 2009).

Preceding organised industry, ancient peoples used utilitarian objects solely created by artisans. In the absence of industry, craftspeople played a defined role within society tending to a body of knowledge handed down through generations of masters, journeymen, and apprentices. The Industrial Revolution interrupted the relative stability of craft through mass-production machines and the division of labour. The cultural response was to preserve and protect the handcrafts, and this manifested in the political writings of Karl Marx, and the critical writings of John Ruskin and the Arts and Crafts movement (Ruskin 1867). These reactions were rooted in an appreciation for craft that differentiated it from industry. The duality of industry and craft set up opposing views of material culture. On one end, the view of craft was nostalgic and sought material links to a pre-industrial past; on the other was the view of modern efficiency defined by speed and egalitarian distribution of a product. It is true that many of the craft processes and artefacts share lineage with their pre-industrial precedents, but it is essential to understand that modern craft is not a result of the past. Modern craft is a manifestation of industrialisation itself, developing alongside industry, both benefiting from the other (Adamson 2013, xiii-xv). The opposition between viewpoints only reinforced the importance of both.

David Pye clarified the distinctions between craft and industry by identifying the craftsmanship of risk and the craftsmanship of certainty. The craftsmanship of risk is a process where the quality of the result is frequently at risk during the process of making and is dependent on the judgment and care exercised by the maker. The craftsmanship of certainty requires comprehensive planning of the process before manipulation of the materials with all variables predetermined and pre-tested to the greatest extent possible (Pye 1968, 20). These definitions still hold today in that they define the primary differences between industry and craft by highlighting industries' aversion to - and craft's requirement for – risk. Both the single craftsperson and the collective industrial process embodied human desire, exceptional skill, and knowledge.

Situating Digital Craft

The use of digital tools for communication, design, and fabrication to produce craft objects has profoundly influenced material culture. The most apparent influence is in the limitless possibilities for generating complex forms. The computer allows for unlimited possibilities and complexity not dependent on the material world. Digital modelling tools such as Rhinoceros and Grasshopper are acting in response to the demands of digital practice. Perhaps the most profound influence is the streamlining between digital design tools and digital fabrication tools. What is designed can now be readily and directly fabricated using digital technology. Practising digitally has created a process-based change to craft disciplines.

The Digital Revolution brought numerous remarkable and productive virtues, but it has also introduced some potentially inhibiting deficiencies. Most profound is the increased abstraction and tendency toward loss of human touch introduced with digital tools. Because electronic digital tools are ultimately based on numeric control, they require specialised knowledge of an abstract set of commands and symbols. Digital tools do not yet emphasise intuitive and physical interaction and response. They require constant precision and inhibit most rough estimation. Digital tools can create a world unto themselves, with a tendency for an operator to lose themselves in a self-referential world of simulation and required procedures divorced from representing reality or intuitive process. These tools tend to guide the craftsman, rather than the craftsman guiding the tools. Outcomes often resemble abstract mathematical models more than haptic experiences defined by a craftsman through real material and specific historical lineage and context (Stevens 2015, 9).

Although the premise is debated in academia and popular culture, this article identifies digital craft as the use of the digital and the hand in a productive negotiation, viewing craft as a process or activity rather than a category (Adamson 2013, xxiii). When viewing craft through the lens of processes, rather than categories such as pottery, weaving, and metalsmithing, the processes become complex with the loss of the binding traditions embedded in such disciplines. As early as the nineteenth century, craft was most commonly viewed through its material and disciplinary category. The material artefacts produced were guided by "conservative" links to a "traditional" past (Adamson 2013, xvii). This view of craft, fair or not, did provide the craftspeople a set of longstanding and generational knowledge, and more importantly, principles and limits to guide their work.

The word "craft" has evolved along with these changes. Now, disciplinary activities ranging from surgical procedures to brewing beer are self-categorising as craft. Richard Sennett describes Linux system programmers as "a community of craftsmen focused on achieving quality and doing good work" (Sennett 2009, 29). Preceding Sennett, Malcolm McCullough explored the idea of virtual and dematerialised craft asserting that "digital practices seem more akin to the traditional handicrafts, where a master continuously coaxes a material. This new work is increasingly continuous, visual, and productive of singular form, yet it has no material" (McCullough 1996, x). The pre-digital tactile shaping of material was viewed to have a parallel digital equal in computer clicks and bits. McCullough maintains that the act of craft can occur entirely virtually regardless of whether the work results in a physical artefact.

Craft evolved through incremental improvements while maintaining a connection to the past. However, the social, economic, and global change that upended many handcrafts occurred so quickly that we are recently beginning to understand the immense complexity and opportunities provided to a craftsperson engaged in the use of digital technology. Scott Marble observed that digital processes in design evolved into three distinct systems. The first is the replacement of formal geometry with mathematical algorithms. Prior to the virtualisation of geometry, craftspeople shaped material by hand. These shapes can now be mathematically defined, controlled and generated in unlimited quantities. Second, the designer has new control over organisational complexity allowing designs to have embedded data ranging from cost to weight, thereby extending the craftsperson's control over production. The third, and most significant for this study, is the development of digital fabrication (Deamer and Bernstein 2010, 39-43). This development now provides the link between McCullough's dematerialised craft, allowing for materialisation of digital media. Most significantly, this materialisation is controlled by the direct actions of the craftsperson. Marble, however, does not wade into the coming age of robotics and AI, likely to add additional making systems not imagined or understood. All the systems outlined have a clear demarcation between the human and tool and are positioned in the historised Humanist tradition. It is clear that these new systems will take the ideas of dematerialised craft and direct digital making for granted as a standard process of craft and will challenge the duality between human and machine.

Situating Humanism and Posthumanism

Since the inception of Humanism in the Renaissance, the philosophical perspective has evolved and bifurcated to include multiple realms of understanding. Humanism shaped civic life through liberal democratic principles and framed a path to a more reasoned life as an alternative to mystical and religious positions (Keeling and Lehman 2018). Architects in the post-war era began to revisit Humanist architecture that not only considered human proportions as paramount but situated the human as the primary receiver of the built environment. It is when humanism is framed as a body of literature and discourse that it provides insights into craft and making through its assignment of agency and autonomy to the human. The human action of craft and the embodied actions required in making align with the humanist literary discourse by attributing the conscious and intentional human subject as the dominant source of the agency most worthy of scholarly attention. Diane Keeling and Marguerite Lehman summarise literary humanisms' values to constitute a human being as follows:

1. Autonomous from nature given the intellectual facilities of the mind that control the body,
2. Uniquely capable of and motivated by speech and reason, and
3. An exceptional animal that is superior to other creatures.

Keeling and Lehman (2018) continue by reaffirming that humanist principles are infused in all Western philosophy and reinforce a nature and culture dualism where human culture is distinct from nature, a dualism that is also apparent in the act of craft. It is this duality that is in question in posthumanism discourse. The humanist assumption that we are liberal subjects of autonomy is rejected for the view that agency is distributed through an environment or network that the human participates in but does not intend to control. To illustrate, Keeling and Lehman summarise their contrasting points for what constitutes posthuman thought. Posthuman cognitive systems are:

1. Physically, chemically, and biologically enmeshed and dependent on the environment;
2. Moved to action through interactions that generate effects, habits, and reason; and,
3. In possession of no attribute that is uniquely human but is instead made up of a larger evolving ecosystem.

An environment and ecosystem defined in this discourse is related to a complex network or interconnected network, therefore not necessarily excluding an architectural environment or the ecosystems of the physical environment. As humans developed sophisticated systems of architecture to separate themselves from the physical environment and intellectual structures to stand apart from other terrestrials, humanist values reinforced what we observed in ourselves as superior enlightened beings. This historicised certainty was challenged however with new networks and new cybernetic environments of our own making.

Cybernetics and the Discourse of Posthumanism

At the close of the twentieth century, Katherine Hayles published *How We Became Posthuman (1999)*. Her publication searches for answers to the boundaries between human and machine and how we are evolving or devolving with technology. It probes the question of what makes us "human," and if we will continue to value the "liberal subject" or alienate it (ibid). The inclusion of this text is an epistemological transfer of domain that could be seen as invalid. Therefore, the validity for craft must expand to include the primary characteristics of inscription and incorporated knowledge. Indeed, the discourse of posthumanism preceding and following this publication is robust and divided into valuable philosophical positions. However, an account of these positions and their place within this discourse are outside the scope of this work. Therefore, the boundary provided by Hayles is just one of many possible frameworks to speculate on a multitude of scenarios whereby technology and the human are intertwined. This framework allows for discourse around what is essential to humanness and what is not. It allows this article to ask the question: *are we extending our abilities or are we devolving into information?*

Provided is an outline of a discursive understanding of cybernetics, or the science of communication and automatic control systems. These critical moments of understanding resulted from what is known as the Macy Conferences held between 1945 and 1954 and helped define the epistemological foundation of cybernetics. Hayles explains this in three plateaus of understanding:

The first model of cybernetics grew out of an understanding of the biological systems of homeostasis. The concept is founded on the idea that living organisms have the ability to maintain steady states regardless of environmental changes. Therefore, information was seen as a quantifiable choice in a feedback loop with the organism regardless of environmental conditions. The programmer feeds input data and the machine returns output in a binary loop.

Secondly, from dialogue and debate of the first model of thought came the understanding that cybernetics may also emulate the biological system of autopoiesis, or a self-encoded system that develops not by what it observes but how it is encoded to respond to its unique needs. The ideas presented the possibility that systems construct reality rather than observe it and that system components could work together to replicate themselves. By removing the observer, cybernetic information could be defined as an entity separate from material instantiation and could be "calculated as the same value regardless of the contexts in which it was embedded, which is to say, they divorced it from meaning" (ibid, 53-54). This isolation of information is in her view how information lost its body.

Thirdly, autopoiesis leads to a larger understanding of emergence. This is to say that the system has the ability to evolve on its own. This is seen in contemporary systems of augmented reality (AR), virtual reality (AR), and Artificial Intelligence (AI). Emergence uses the feedback loop of information understood by homeostasis but adds both an input and output of information, thus collecting, processing, and evolving independently (ibid, 10-11).

Hayles provides the following "suggestive," rather than a prescriptive list, of what the posthuman view is (Hayles 1999, 3):

1. The posthuman view privileges informational patterns over material instantiation, so that embodiment in a biological substrate is seen as an accident of history rather than an inevitability of life.
2. The posthuman view considers consciousness, regarded as the seat of human identity in the Western tradition long before Descartes thought he was a mind thinking, as an epiphenomenon, as an evolutionary upstart trying to claim that it is the whole show when actuality it is only a minor sideshow.
3. The posthuman view thinks of the body as the original prosthesis we all learn to manipulate so that extending or replacing the body with other prostheses becomes a continuation of the process that began before we were born.
4. The posthuman view configures the human being so that it can be seamlessly articulated with intelligent machines. In the posthuman, there are no essential differences or absolute demarcations between bodily existence and computer simulation, cybernetic mechanism and biosocial organism, robot technology and human goals.

Hayles divides human practice and knowledge into two dualities: first, an incorporating practice that is encoded into bodily memory by repeated performances until it is habitual. Opposed is inscribing practices that can be cognitively mapped and encoded (ibid, 199). Hayles continues by providing five distinguishing characteristics of knowledge gained through incorporative practices (ibid, 205):

1. Incorporated knowledge retains improvisational elements that make it contextual rather than abstract, and that keep it tied to the circumstances of its instantiation.
2. It is deeply sedimented into the body and is highly resistant to change.
3. It is incorporated knowledge that is partly screened from conscious view because it is habitual.
4. Because it is contextual, it is resistant to change and obscure to the cogitating mind. It has the power to define the boundaries within which conscious thought takes place.
5. When changes in incorporation practices take place, they are often linked with new technologies that affect how people use their bodies, and experience space and time.

Hayles continues to summarise by stating:

> *Formed by technology at the same time that it creates technology, embodiment mediates between technology and discourse by creating new experiential frameworks that serve as boundary markers for the creation of corresponding discursive systems. In the feedback loop between technological innovations and discursive practices, incorporation is a critical link (ibid).*

Testing Posthuman and AI Craft

To test how incorporated and inscribing knowledge can be engaged in posthuman craft, researchers conducted an experiment using a ceramic 3D printer modified to allow for digital (inscribed) and manual (incorporative) control (*Fig.*

1). The principle that guided the tool's design was to have distinct tasks relegated to the computer and the human hand to produce artefacts that an Artificial Intelligence (AI) database can learn and analyse. The choreography allows for consistent digital control of the x, y, and z-axis while also allowing for manual interruptions. An artefact created in this way differs from the digital model that generated the g-code that directs the movements of the printer (*Fig. 2*). By allowing improvisations, the research team was able to produce a multitude of artefacts from the source shape, a cylinder that served as the control object made without alterations by the operator (*Fig. 3*).

In describing the unique work of a craftsperson, historians and artisans relied on comparing unique artefacts to each other to define styles and traditions and more specifically a collection or a work by an artisan that occurs over a designated period. The research team completed a broad set of unique improvised prints that defined a collection for the AI to learn (*Fig. 4*). All improvised prints in the collection are unique hybridised digital and handmade artefacts that have a geometric relationship to the control cylinder. To measure these modifications, all of the artefacts printed and improvised by the operator were 3D scanned (*Fig. 5*). The re-digitisation of the prints provided a digital 3D model to scale that was compared to the control cylinder. The AI database then understood common deviations that were analysed. These improvised deviations built a morphological dataset that is unique to the operator who made the modifications and the output collection. The AI returned to the research team a large quantity of data that were used to reconstitute AI-improvised one-of-a-kind artefacts (*Fig. 6*). The new AI artefacts were then printed using a standard 3D printer. Thus, the craftsperson's tacit knowledge and tool dexterity was not degraded by AI but extended by a cybernetic ecosystem.

There is potential for artisans to teach AI the formal and morphological properties of a given collection. This then can be learned and replicated by the AI, allowing the craftsperson the freedom to move to the development of new and inventive collections that the AI can later be trained to produce. This new division of labour removes replication by the human hand and makes paramount the conscious mind required to create a new artefact. This case study demonstrates that AI was capable of learning how one human operator could improvise digitally fabricated objects and teach AI how to emulate their sensibilities. Most significantly, the objects created with AI are an extension of the human who originally made them. They are direct products of the craftsperson's hands and thus extend the productivity and economic impact of fluid improvisational making. AI allows higher productivity, but the human maker is essential in training. If done in partnership, this workflow allows the human craftsperson to extend their influence and impact while still maintaining the necessity of handmade artefacts in the age of AI.

A New Discourse for Craft

The duality set up by the inscriptive and incorporated knowledge is not seen as a path that must be selected but as a place for humans to fluidly reside. In a statement striking to any craftsperson, Hayles states:

> *The recursivities that entangle inscription with incorporation, the body with embodiment, invite us to see these polarities not as static concepts but as mutating surfaces that transform one another, much like the Mobius strip.... Starting from a model emphasising polarities, then, we have moved toward a vision of interactions both pleasurable and dangerous, creatively dynamic and explosively transformative.*
> (Hayles 1999, 220).

When discussing the future Hayles attempts to privilege materiality over information in the discussion of cybernetics by stating:

> *If my nightmare is a culture inhabited by posthumans who regard their bodies as fashion accessories rather than the ground of being, my dream is a version of the posthuman that embraces the possibilities of information technologies without being seduced by fantasies of unlimited power and disembodied immortality, that recognises and celebrates finitude as a condition of human being, and that understands human life is embedded in a material world of great complexity, one on which we depend for our continued survival* (Hayles 1999, 5).

Hayles' contribution rests in the area of cybernetics and literature. However, her definitions and defining characteristics of inscription and incorporation practices fall within the epitome of craft reconciling the encoded variable alongside the improvisational human. The discourse surrounding the posthuman is still evolving since the publication of this text in 1999. Although engineers are no closer to developing a truly sentient machine the debate continues around what posthuman means and if it is a positive evolution or negative devolution. Questions about the validity of embodiment and materiality, as human form and action, are necessary for being human or whether intellect, knowledge, and experience can be fully *downloaded* to a machine, from cells to bits. Despite these intellectual debates, how these technologies will impact the economy, society, and craft, is still not understood. Given the rapid pace of their development, understanding may arrive only in hindsight.

The contemporary craftsperson must be aware of how new technological developments will impact social and economic systems. With the rise of AI and other disruptive technologies, both manufacturing and the service industry may no longer exist and therefore will not be outsourced to populations with low wage bases. Some reports indicate that up to 40% of current jobs may be eliminated over the next 30 years (Schwab 2016). As with many of the past economic and social upheavals these jobs will be replaced with new, but fewer high-skilled jobs. Of course, these are only economic speculations, but they carry with them an undeniable warning: our policymakers must engage in and understand technology so that they can lead their nations to a sustainable future. Developed economies like the United States and China are far from insulated from these changes. Many argue that given the significant infrastructural obligations of these nations their stability could unravel given the disruptive potential that AI and robotic automation may have.

What these questions provoke is a possible third path, one that is not purely a technological utopia of digital making that excludes the human and minimises labour, but one that uses technology to extend human creativity and human potential. It is the nature of capitalism and liberal democracy to maximise profits and minimise labour obligations so such a third proposal may seem idealistic and naïve. However, the leaders of our nations in the future may once again become vexed by even further social inequality. Marx identified the conditions of mass inequality in capitalism and predicted a revolution in industrialised nations where manufacturing degraded the worker and built wealth for the industrialists (Marx 2009, 7). Although his predictions did not come to pass, the principles identified in his concerns were the impetus for the rise of the Communist Party and the Soviet Union that had their origins in protecting the worker from mechanisation. Current populist movements in Western capitalist societies such as Brexit may be the first rumbles of the repercussions of the Fourth Industrial Revolution.

These possible reactions are occurring even before capitalism has been tested by the possibility that AI and robotic automation could supplant many workers into a new useless class (Harari 2017, 322).

This discourse is not nihilistic, nor does it dictate a bleak view of the future. In contrast, the debate probes ideas of what makes us human, more specifically, what makes us humans that are compelled to craft and make. Those engaged in studio-based practices that depend on traditional craft must be mindful of the inevitable disruptive technologies that this work recognises. The contemporary craftsperson must acknowledge what is to come and begin to understand how to position craft into a new networked system not entirely under their control. The example given in this article only shows one of an infinite number of possibilities of how craft can productively enter the Fourth Industrial Revolution without sacrificing human agency. The contemporary craftsperson now has the opportunity to choreograph human and machine to achieve artefacts not yet imagined.

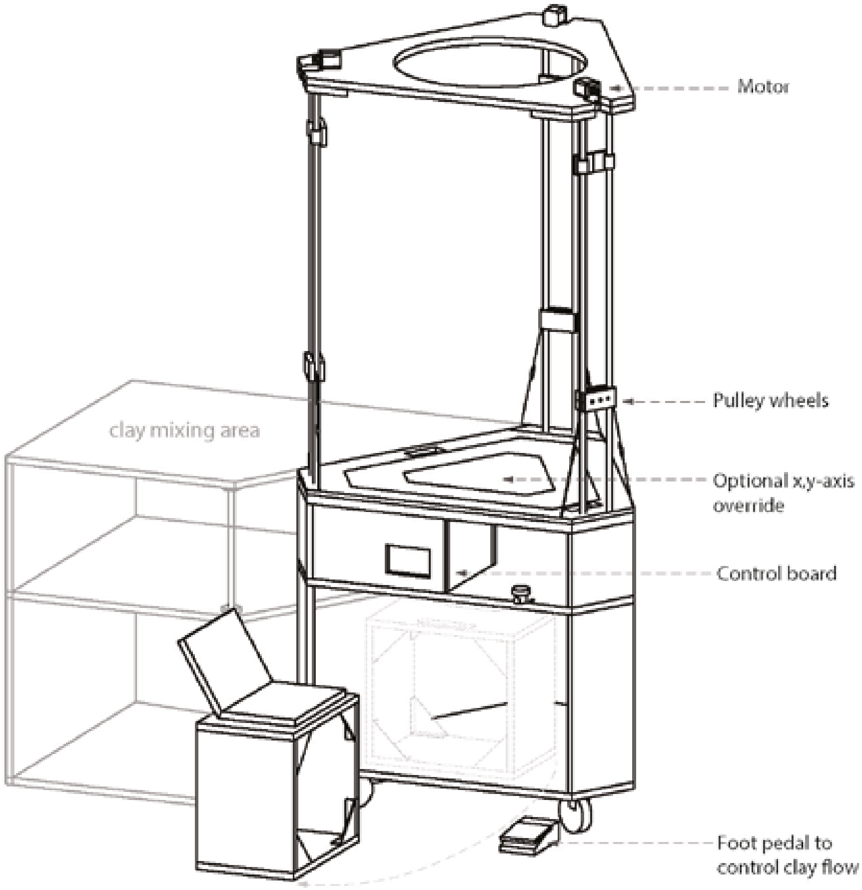
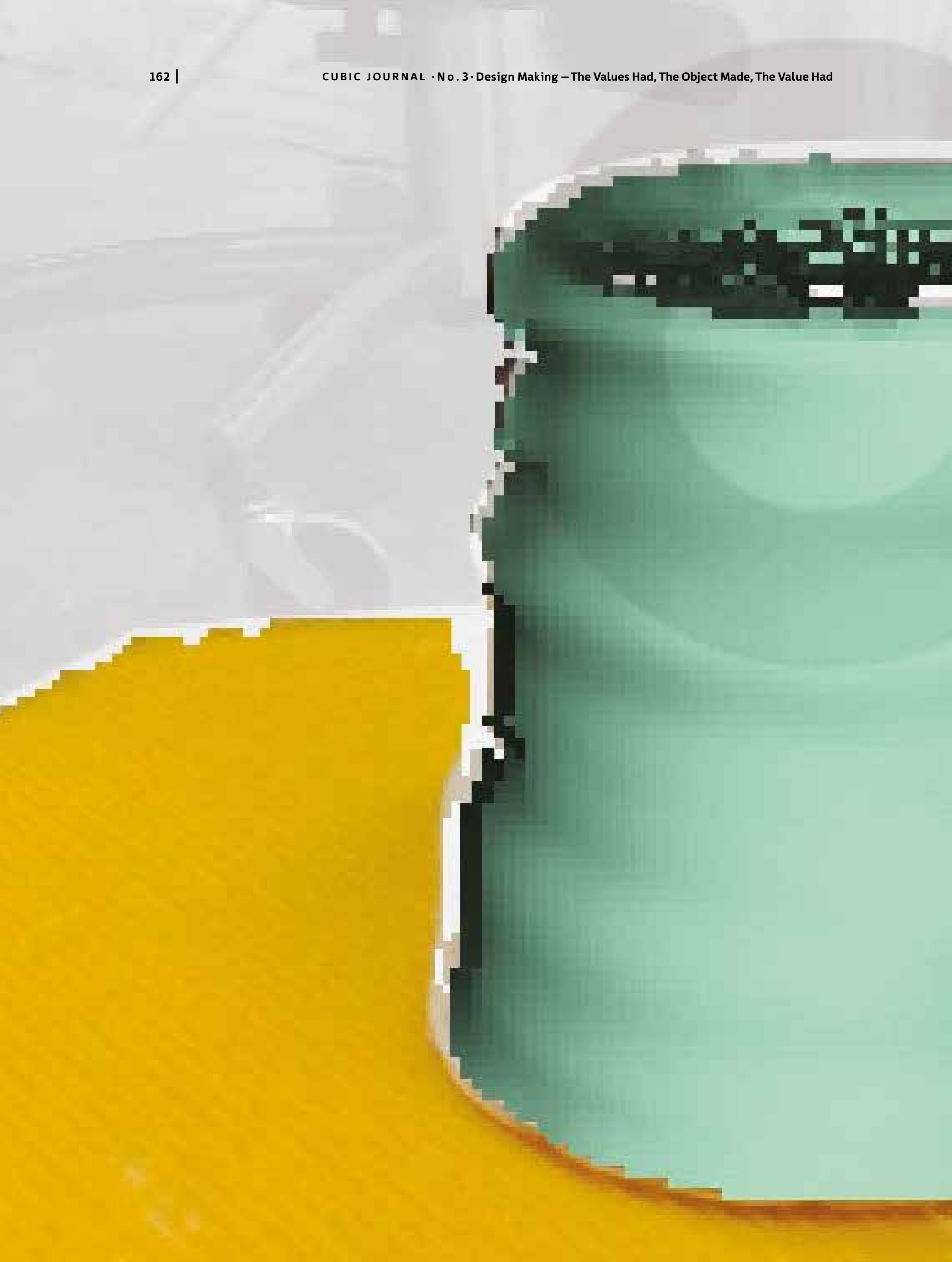

Motor
Pulley wheels
clay mixing area
Optional x,y-axis override
Control board
Foot pedal to control clay flow

Figure 1 (top, opposite page): Custom 3D printer designed for craftsperson improvisations. Source: *author.*

Figure 2 (bottom, opposite page): Craftsperson using manual x, y-axis controls to improvise ceramic form. Source: *author.*

Figure 3 (top): Control artefact (left) compared to improved artefact (right). Source: *author.*

Figure 4 (bottom): Portion of the improvised collection of artefacts. Source: *author.*



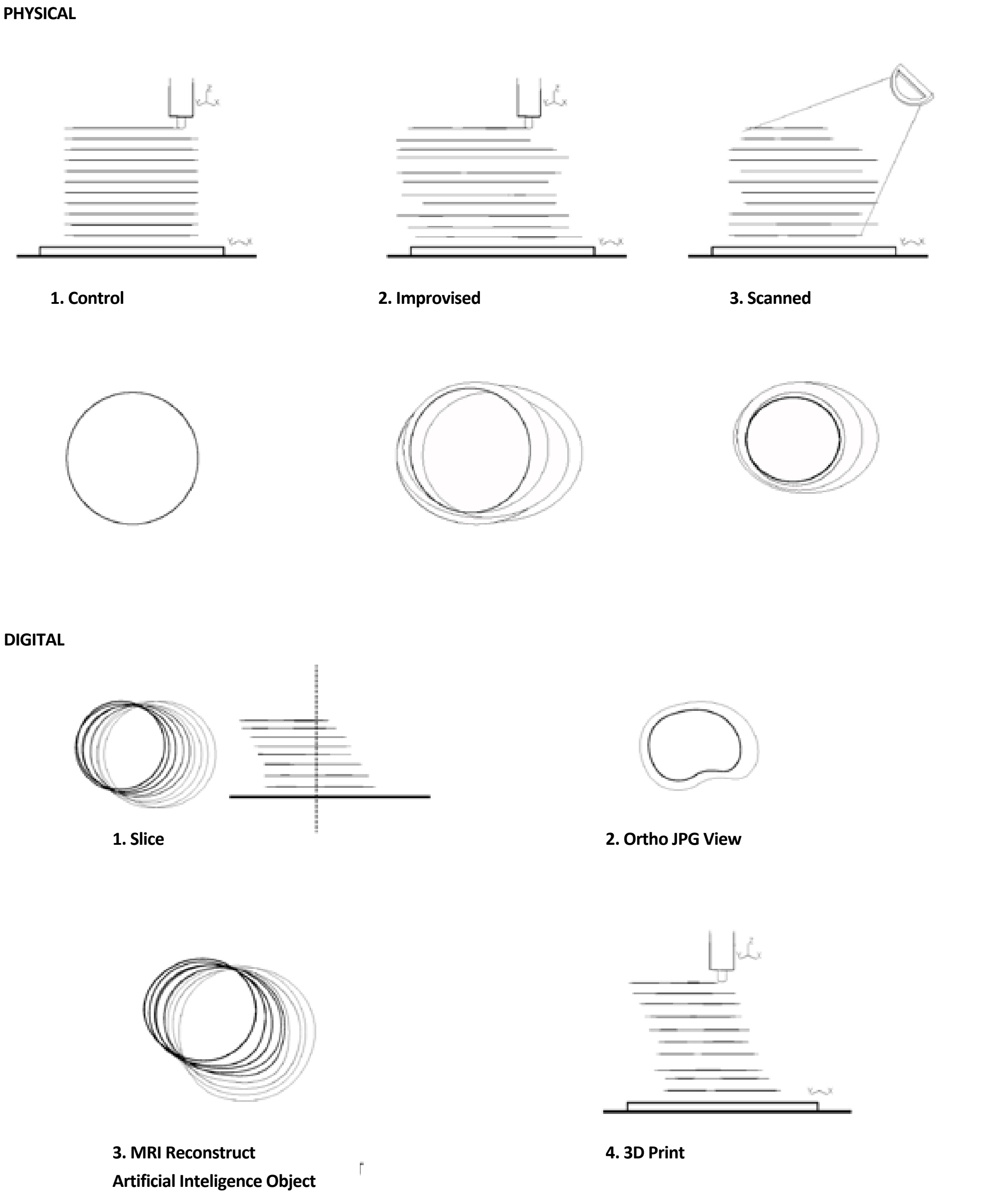


Figure 5 (page 162–163): 3D Scan in progress of improvised artefact. The pixelated image was captured during the scanning process. Though not in high visual resolution, the scan image includes the topological information vital to digitising a one of a kind, hybrid artefact. Source: *author.*

Figure 6 (top): Primary steps in the process to create AI artefacts. Source: *author.*

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Bio

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An Education of Intuition and Process: Learning Architectural Design at Hong Kong Design Institute

Eddie Chan

166—181

This paper is a positioning statement and expository article describing design and fabrication projects built by students and faculty of the Hong Kong Design Institute's (HKDI's) Architecture programme. Through a series of experimental design-build projects, HKDI faculty teaches students the knowledge and experience to be gained through personal fabrication work, whether wholly manual or digitally assisted. The author stages the work against a series of excerpts from notable architects' writings, describing a field of study relating tacit knowledge, architectural education, and fabrication specifics students explore through projects in Hong Kong and South China. Lessons and summary bodies of knowledge drawn from these preliminary projects define the path forward for HKDI's spatial design pedagogy and research.

#architecture education

#fabrication

#making

#hong kong

Introduction: Intellectual Precedents

Learning a skill is not primarily founded on verbal teaching, but rather on the transference of the skill from the muscles of the teacher directly to the muscles of the apprentice through the act of sensory perception and bodily mimesis. This capacity of mimetic learning is currently attributed to human mirror neurons. The same principle of embodying— or introjecting, to use a notion of psychoanalytic theory—knowledge and skill continues to be the core of artistic learning. The foremost skill of the architect is, likewise, to turn the multi-dimensional essence of the design task into embodied and lived sensations and images; eventually the entire personality and body of the designer becomes the site of the design task, and the task is lived rather than understood (Pallasmaa 2009).

My own suspicion of the enormous generative part played by architectural drawing stems from a brief period of teaching in an art college. Bringing with me the conviction that architecture and the visual arts were closely allied, I was soon struck by what seemed at the time the peculiar disadvantage under which architects labour, never working directly with the object of their thought, always working at it through some intervening medium, almost always the drawing, while painters and sculptors, who might spend some time on preliminary sketches and maquettes, all ended up working on the thing itself which, naturally, absorbed most of their attention and effort (Evans 1996).

Precision can be about the tolerances involved in components, while accuracy is an instinctive thing. Precision has to do with the skill of crafting, whereas accuracy is about how fine the instinctive understanding may be. No matter how you hone and tune it, accuracy remains a kind of gut reaction. When people enter a space, they should be able to feel it as well. It's the difference between something learned and a talent (Salter 1989).

Architecture and Architecture Education

As an architecture student, it is an inevitable part of the journey that one must *make* – models, collages, prototypes, etc. Yet, once the student graduates and enters the professional environment, it is common to find that most of the working hours are spent on digital work in front of a computer. Architectural models and prototypes are often produced by in-house or contracted model makers for presentation purposes, not as an integrated part of the design exercise. Why, then, is making, the *hands-on* experience, still an essential part of architectural education?

The three excerpts above summarise views on architecture and architecture education in relation to making and physical, hands-on, experience. To borrow Peter Salter's interpretation (ibid.) of the two terms, architecture is a practice that demands a high level of *precision* in its construction, and *accuracy* in its design sensitivity. It is a profession that requires a rational mindset as well as an artistic one. Although architecture is often associated with other artistic practices, unlike other artists, as Robin Evans (Evans 1986) observed, architects seldom have first-hand experience in actualising their work. Architects rely on a large team of builders, craftsmen and technicians to realise their work.

At school, we learn architecture by reading, writing, drawing, modelling and visiting exemplar architecture. Students represent research and design proposals in text, scaled drawings, and fragmented models. Through these media, we learn to communicate with others the physical construction of architecture as well as the spatial quality of the spaces we design. Understanding architecture through these texts, drawings and models is like reading a piece of music without hearing it: it is a rather inconvenient form of communication that requires a good deal of imagination and articulation of thoughts to mentally compose a holistic image of the envisioned architecture. Until the conceived architecture is realised, most of the envisioned architectural quality is speculative. It is unlikely to bring an architecture to reality if the speculative representation of its vision fails to convince the client. As such, making through direct, physical engagement with the subject matter is vital and effective to build up students' abilities to bridge the gap between concept and realisation.

As Juhani Pallasmaa (Pallasmaa op. cit.) pointed out, acquiring knowledge is an experiential process. If a student is to learn how to design with brick, it is insufficient to merely read books or attend lectures. She or he should be encouraged to gain first-hand experience by visiting a brick factory; going down to a clay pit; seeing how water is pressed out of the clay; learning how to form a brick from the mould; feeling the difference between a dry brick ready to be fired and a brick fresh from the mould; examining the colour variations of bricks from the kiln; breaking a brick with a hammer; soaking a brick in water; mixing mortar; building a brick wall; building a brick arch; surveying as much brick architecture as possible.

Even though the student still has no experience in designing brick architecture, one would be convinced that he or she has a good amount of academic knowledge and practical experience about the material and what it can do. More likely she or he should be able to design in brick. Furthermore, if the student has learnt to make such in-depth inquiry on one subject matter, one would expect that the same person can apply a similar methodology to learn about timber architecture, concrete architecture, or other building technologies.

Introducing the Culture of Making at HKDI

"We learn how to build by building," my tutor Michele Roelofsma used to say. There is a fundamental difference between an architect who enjoys making and an artisan or a craftsman. When an architect makes an object, however beautiful the object might be as a work of art or craft, it always carries a meaning beyond the object itself that feeds back to the architecture discourse. Mario Bellini (cf. Bellini, Business of Design Week 2017) once said that he enjoyed designing furniture, and out of all types of furniture, he enjoyed designing tables the most because he felt that a table was like a miniature building In a similar cross-disciplinary translation, architects rely heavily on making of objects as an *intervening medium* to sharpen their aesthetics and our understanding of space, materiality, and human habitation. They observe the world via the objects we make. Architects test and evaluate the accuracy of our instinctive understanding of the world through materialising our ideas in various scales and media. As a part of architectural education, it is important to encourage students to make. It is more important that the made objects are put to the test in real situations so that students can evaluate their designs and vision against the complete process and outcome. Full-size construction is essential to provide such evaluation opportunities. The projects selected for this paper are full-size live projects that cover a variety of scales and design-construction methods. Some are designed and fabricated almost entirely by digital tools. Some are done almost entirely by manual labour with a *construct and improvise* methodology. Each project has its unique process and each of them informs us of something valuable about the teaching and learning of architecture. The design-construction processes of the projects are summarised in Table 1.

Oil Street Bamboo Installation
Project Leader: Eddie Chan.
Project Type: Public Participation Design Workshop.
Duration: 4 days (2 weekend workshops).

The *Oil Street Bamboo Installation* looked at traditional Chinese handicraft using bamboo splits and paper joints that are common in the making of festive products, such as paper lanterns and bamboo decorations for Chinese New Year and Mid-Autumn Festival. The basic skills of this craft are easy to learn. Therefore, it is possible for almost anyone to engage and participate. The design potential lies in the flexibility and lightness of the material. Five students and ten local participants hand-wove a bamboo mesh of 2 x 8 meters in three days, before playing with the mesh to see what forms could be achieved for the final installation (*Fig. 1*).

Halo Modular Unit
Project Leader: Eddie Chan, Paul Mui.
Project Type: Student Competition +. Post competition development.
Duration: 2 weeks competition + 2 months post development.
Sponsor: Halo Creative & Design Limited.

The *Halo Modular Unit* was a student design competition for a prototype of mobile living unit that was transportable and easily assembled. The winning design was a *flat-pack* architecture module consisting of four standardised panels and six joining members that could all be digitally fabricated. On-site installation is designed to be quick and machine-less, almost like scaled-up Ikea furniture (*Fig. 2*).

Very Hong Kong Installation and the Tamar Park Installation
Project Leader: Eddie Chan, Jason Tang.
Project Tutor: Susanna Wong, Thomas Chan.
Project type: Design Studio.
Duration: 8 weeks (Design + Construction).

Students built the *Very Hong Kong Installation* and *Tamar Park Installation* under the digital design studio *Pattern to Fabrication*. The design studio explored how patterns were used in architecture from traditional two-dimensional motifs to contemporary three-dimensional façade design. With the help of parametric tools, a component-based design was applied to the two projects that used standardised plywood and recycled timber planks as construction materials (*Fig. 3-5*).

Meinan Village Bamboo Pavilion
Project Leader: Eddie Chan, Kuo Jze Yi .
Project type: Summer Studio + Workshop.
Duration: 7 weeks (5 weeks Design + 2 weeks Construction).

The *Meinan Village Bamboo Pavilion* project was an intensive design and construction studio in which the core group of students was responsible for most of the project from meeting the client and user and estimating the construction cost to design and construction. Extensive material research was conducted to understand both the potential and limit of the material. Full-scale mock-ups of bamboo joints were made to test students' craftsmanship, and to experience a first-hand feel of the weight of the material (*Fig. 7-10*).

Knowledge Gained through Educational Making Projects

Parametric Design & Digital Fabrication ≠ Automated Construction

Although automated construction is already widely in practice in smaller-scale manufactures, such as cars and electronic products, automated construction in the building industry has yet to be commercialised. Advanced design and fabrication tools are becoming highly affordable and accessible for professionals as well as students. Almost anyone can design and fabricate something with complex geometry or patterns at the domestic scale. However, full-scale construction and assembly of architectural elements still largely depends on manual labour, on or off site. The experience of making these projects taught the students that in order to realise architecture, understanding of material properties, fabrication and the assembly process is crucial.

The *Tamar* Project is a collaborative project with the Environmental Bureau to design and build a park installation out of recycled wooden palettes. The project was embedded into a design studio that looked at parametric design and fabrication. The design concept was to disassemble the palette and reassemble the timber planks into park furniture that serves as benches for visitors. Rectangular planks were cut at 45 degrees at both ends to create a three-dimensional zigzag pattern. What appeared to be a fairly simple material manipulation in the digital model transformed into a huge construction challenge for the students, requiring over two hundred man-hours of material preparation and prefabrication.

The *Very Hong Kong* project was done within the same digital design studio as a collaboration with the Very Hong Kong Foundation which sponsored the fabrication of the project. The team had the flexibility to choose the desired material under the given budget and timeframe. The *Very Hong Kong* (*VHK*) project had another advantage over the *Tamar* project in that the team had sufficient budget to hire a contractor for the prefabrication work. Learning from the other team's struggles, the *VHK* team understood how the component design could optimise the construction and assembly sequence. In the final design, students simplified the construction. They reduced the variations of components from eleven to six. Designers modified component size to reduce their total number, and designed them as an interlocking system to reduce the number of fixtures required for on-site assembly.

Part-to-Whole vs. Whole-to-Part

A close comparison between the Manual project and the Digital project reveals two different ways of design thinking commonly seen, namely the part-to-whole approach and the whole-to-part approach. With the *Oil Street* and *Meinan Pavilion* bamboo projects, research on the construction detail of the bamboo joints was the first priority. The design process can only begin when students have a clear idea of what they are able to do with the material. With the *Very Hong Kong* and *Tamar Park Installation*, although the project briefs required the students to generate the design based on repetition and variation of a 3D pattern module, the construction and assembly detail of the parts was largely an afterthought informed by the formal composition of the overall design. At the beginning, when students worked on the bamboo projects, they had little idea what the final design might be. The image of the final piece gradually came to light as the making and testing of material went along. In contrast, students who worked on the *Very Hong Kong* and *Tamar* projects had clear ideas about the final design in the early stage, despite the fact that the schemes were not material-specific. Most of the detail design came after the design was finalised with the chosen material.

The part-to-whole approach challenges our students' preconception that design is a linear process from drawing to planning to making. In the Oil Street project, there was hardly the need to draw. Tutors and students tested and discussed the design through direct interaction with the material, body, and context. The *Meinan Pavilion*'s dynamic design process blended drawing, planning, and making together. Students made drawings to represent the pavilion design, as well as a construction manual for fellow students participating in the workshop. The team regularly constructed mock-ups to ensure buildability. The project team needed to pre-order materials for the two-week workshop, forcing the team to detail the design as thoroughly as they could. Once they started on-site construction, the team could automatically redesign details to address problems.

Interchangeable Design

In contemporary architecture, flexibility and interchangeability are important design constraints. Architects and their clients no longer expect architecture to *last forever*, but instead, to accommodate alteration, extension, and transformation in order to suit new capacity, purpose, and functions. The systematic approach in computational design forces students to clearly identify the variety of parameters in the design, allowing students to exercise more control in the process and evaluate the relationships between the variables and the constants. The project team designed the *Very Hong Kong* installation for easy modification in terms of material, scale, and formal composition. On the other hand, the empirical approach in non-computational design encourages students to design in a more intuitive environment. Often there are more surprises towards the end of the project because the design process is still active during the construction stage.

Interactive Design

As mentioned above, it is critical that students test and evaluate their design in actual situations. When the students are simultaneously in the roles of the fabricators and builders of their own project, testing and evaluation become integral parts of the design process. During construction, students are constantly examining the design with their bodies, experiencing spaces in light, rain, and wind. With their own hands, they connect with the materiality of the elements that put together the architecture. It is through physical engagement in building/making that they truly understand human, material, and nature. Students wanted to modify the design or to resolve a particular detail not because of an external comment, but because of the instinctive nature of a designer who works to perfection. Such *design, fabricate, and build* experience is difficult to provide in a normal studio environment. This will undoubtedly enable the next-generation of architects to acquire more comprehensive design knowledge at school. It will also open up new design methodologies that allow a more intuitive approach to computational design.

Conclusion

Computational design, digital fabrication and automated construction will play a significant role in the architecture industry. These tools enrich our experience in actualising our design concepts and enable us to design and construct with ever-increasing possibility, precision, and efficiency. Currently, computational tools can help us iterate through pattern, composition, or form, analyse structural, environmental, and cost performance, and fabricate, through 3D printing in concrete, metal, glass, or others. Yet we value the *hands-on* experiential process that connects us to the long history of design and making. Outside design pedagogy, some of these hands-on skillsets will remain relevant for a long time, in environments where technology and skill are constrained. This writing serves an interval summary and review of how the HKDI architecture program utilised live projects as an educational tool to equip our students with the relevant abilities and mindsets. In the future, we will continue to enhance the Design-Fabricate-Build experience as an important part of our pedagogy as we believe it is only through this full cycle of actualisation that the intimacy between an architect and his or her architecture can grow.

Table 1: Digital and manual design methodologies in exemplary design-fabricate-build projects shown.

Project (in chronological order)	*Schematic Design*	*Detail Design*	*Fabrication*	*Assembly*
Oil Street Bamboo Installation	M	M	M	M
Halo Modular Unit	D+M	D	D+M	M
Very Hong Kong Installation	D	D	D	M
Tamar Park Installation	D	D	M	M
Meinan Village Bamboo Pavilion	M	M	M	M

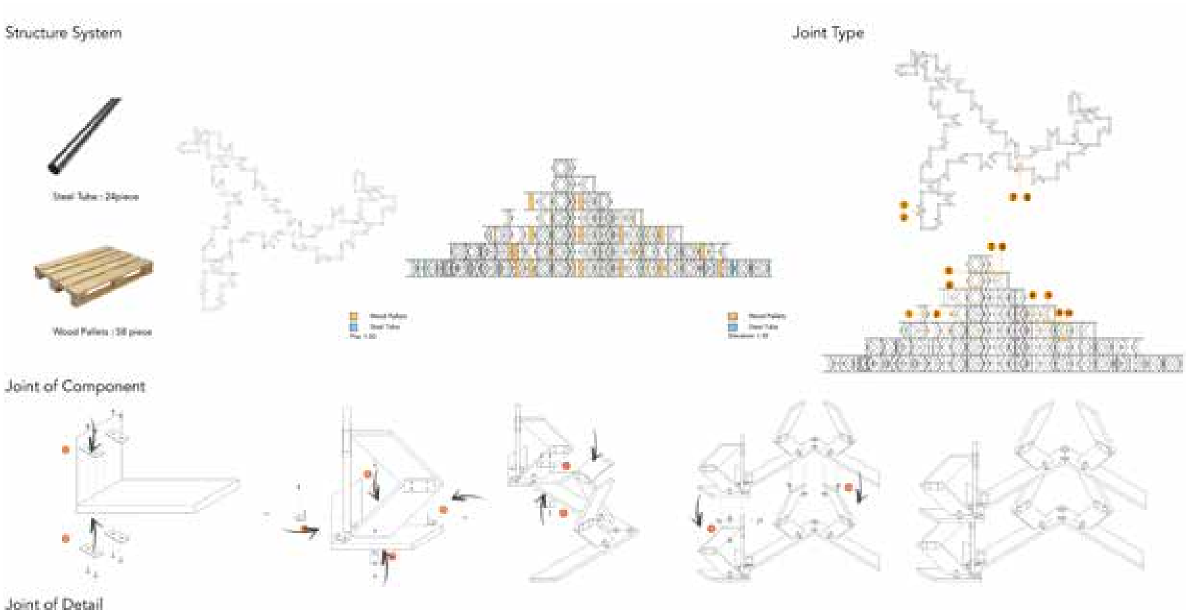
D – Digital (Computational Design)

M – Manual (Non-computational Design)

Figure 1 (top, page 173): A flexible screen that forms a soft grid to enclose human bodies. Source: *author.*

Figure 2 (bottom, page 173): Flexible and interchangeable modular panels with simple joining detail for easy assembly. Source: *author.*

Figure 3: Digital design, manual fabrication - each piece of wood is hand-cut and manually assembled for the *Tamar Park* installation. Source: *author.*



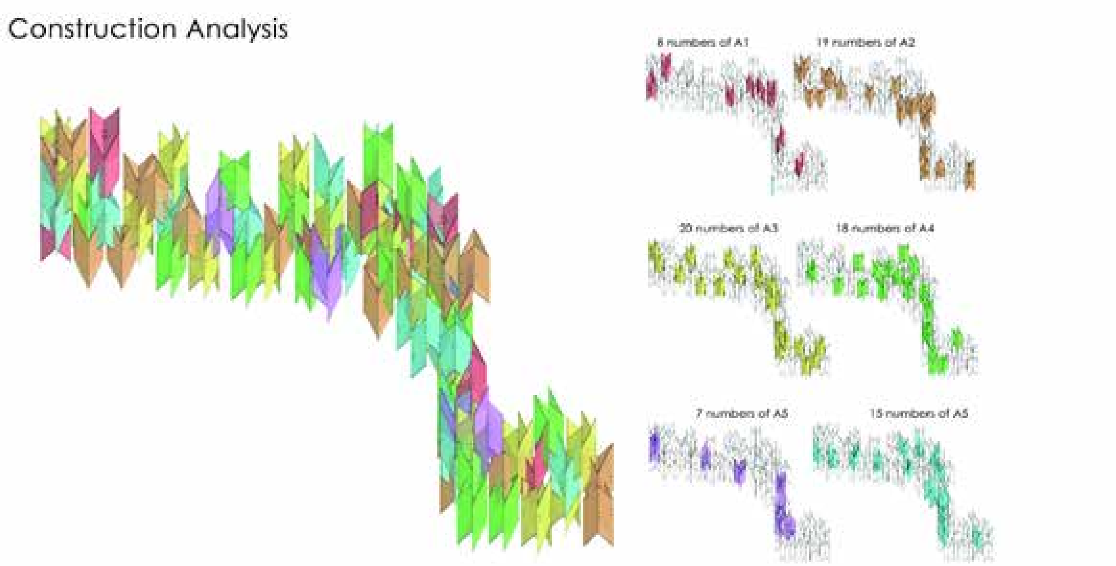


Figure 4 (top): Design concept of the component and the installation. Source: *author.*

Figure 5 (bottom): Organisation diagram of the six variations of the component. Source: *author.*

Figure 6 (opposite page): Components categorised and assembled as a three-dimensional puzzle. Source: *author.*

Figure 7 (opposite page): Bamboo pavilions designed in a variety of roof forms and permeability with standardised pillars that defined the activity zones on the ground. *Source: author.*

Figure 8 (left): Meinan Village Bamboo Pavilion Full-scale mock-up. *Source: author.*

Figure 9 (top): Continuous testing and modification of the shading screen during construction. *Source: author.*

Figure 10 (page 180): In the Meinan Village Bamboo Pavilion human activity is an intuitive response to the environment. Spatial understanding becomes experiential through activity. Source: *author.*

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Bio

Eddie Chan received his architectural education at the Architectural Association and the University of East London before returning to Hong Kong. After practising at architecture offices such as the Ronald Lu & Partners and the Oval Partnership, Chan continued his career as a full-time lecturer of the Architectural Design Programme at the Hong Kong Design Institute where he has been since 2013. His work includes architecture, exhibition design, furniture design, curatorship and community engagement activities.

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031

Arch 002

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182—201

Arch 002 describes a design research investigation using off-the-shelf high-density polyethylene drainage pipe as a flexible concrete casting formwork through a process oscillating between digital design, physical fabrication, and digital fabrication methodologies. Through this process, the project team generated hypothetical architectures that serve to further develop their material counterparts. Drawing on contemporary casting technologies and historical structural modelling techniques, the experiments suggest a system for the encoding mass and force into three-dimensional forms, creating structures that serve as drawings of their creation process. Exploring notions of the readymade and postprocessing, the research explores iterative processes of making to transform normative construction components into transcendent material experiences.

#concrete

#formwork

#readymade

#postprocessing

#3D printing

Arch 002 is an ongoing exercise in flexible formwork, casting 5000 pounds of force per square inch (PSI) compressive strength concrete into readymade corrugated drainage tubing to form an undulating concrete cast. Often used in landscaping, the high-density polyethylene (HDPE) tube can bend and twist to form compound curves in multiple axes along relatively consistent arcs due to the spacing of its 3/8 inch (0.95 cm) ribs. The interest in the tubing as formwork stemmed from the intention to preserve the dynamic ridged profile texture, revealing the hidden formal beauty in a typically concealed building material.

By combining readymade components with transformative material manipulations, the project team is furthering an ongoing research interest in rethinking the use and perception of off-the-shelf construction products. Sheila Kennedy writes in *KVA: Material Misuse*:

> *The building material as a singular and unique element of nature has been replaced by a vast, growing, almost unclassifiable system of disposable, interchangeable products. Though manufactured, distributed, and advertised as distinct entities, the wall/floor/ceiling dissolve into a shimmering artificial infinity of standardised material products, at once banal and terrifying* (Kennedy and Grunenberg 2001, 16).

Kennedy & Violich Architecture's (KVA's) work documented in their manuscript undertook a series of design experiments altering and elevating the normative, starting with the standard material or module as a genesis. In the accompanying essay "The Appeal of the Real," Christoph Grunenberg discusses KVA's work in relation to art history's pursuit of the "real" through "the appropriate, alteration and defamiliarisation of actual objects" and the "establishment of alternative realities, such as minimalism's 'specific objects' …manifesting their unique presence through the production of intense physical experiences of matter in space" (ibid., 64). The project team's investigations with *Arch 002* simultaneously exist in both realms. Sourced from Home Depot home improvement retail stores, the drainage pipe has a direct connection to the homeowner, the contractor, and the layman, each of whom make specific associations with the black plastic tube. The inversion from being buried underground to spanning above ground subverts the assumptions of these viewers. At the same time, the finished forms transcend their casting formwork, becoming visually and tactilely immersive objects on their own.

In "Remaking in a Postprocessed Culture," William Massie also writes on construction materials in the information age:

> *If we use Home Depot as an example, the basis of the demystification of the construction industry is based not only on information transfer, but its result as a marketplace. Home Depot becomes the theatre of operations for material comparison and experimentation because of its size and complexity of product. The individual moves through its aisles as though moving through a three-dimensional catalogue, attempting to synthesise differences in material options, unlike the traditional acquisition of material through specification* (Massie 2010).

Without a critical approach, Massie's "marketplace" could engender mass mundanity. However, the vast array of materials and the opportunity for aleatory spatial encounter provides a browsable library in which to hypothesise new fabrication techniques, drawing connections from one aisle to another and inventing collaborations between disparate materials. The infinite availability of predefined options compels postprocessing into projective architecture.

From the initial textural fascination with the tubing's exterior, researchers' interest grew into an ambition to cast continuous snaking forms, almost as if the concrete were in tension. In early investigations, material opportunities and limitations became apparent. A radius of less than 12 inches (30.48 cm) is difficult to achieve, as the ribs of the tubing pinch too tightly to remove the cured concrete without damage. The tube itself is durable enough to hold its shape while empty but tends to deform under the concrete's weight when filled. Through making, the project team developed a set of parameters and possibilities for future explorations. The team developed a set of fixtures to regularise the radii of bends in the tube. Catenary forms were developable using the structure of the tube and the weight of the concrete, suspending tubes from an armature during the pour. Through the act of making and the knowledge of production, *poiesis*, avenues to evolve the work became apparent.

The readymade mould, never intended to be used as concrete formwork, required consideration of how to remove the cured product from the tube. A labour-intensive demoulding process was completed by using a utility knife to cut through the HDPE while avoiding surface marks on the finished concrete. A quicker release from the mould can be achieved with a grinder and a 1/8 inches (0.3 cm) flap wheel, leaving two intentional seams that bisect the ribs on parallel sides. Once the mould has been removed from the cast, the plastic tube loses its structural stability.

The linearity of the casts and the 4 inches (10.6 cm) diameter thickness combined with the complexity of seamlessly connecting multiple curved segments suggested incorporating rebar into the cast to provide tensile strength around bends. Connections and joinery methods from one arch to the next are in development as a part of the tectonic relationship for a larger system. Current explorations involve casting steel pipes in the wet concrete at the ends. With two sizes that fit one within the other, adjacent arches can simply peg into one another, reinforced by welds or hardware. Further explorations will also explore using off-the-shelf *Y* and *T* fittings, as well as connecting one cast to another with unfilled segments of the flexible tube.

The demoulded form is a volumetric line in space. Analogous to Mark West's fabric formed structures (cf. http://www.survivinglogic.ca), the *Arch 002* experiments responded to their fabrication method in real time. Deforming under the weight of liquid concrete and gravity, West's fabrics bulge and stretch in response to their pinches and seams as they interact with the innate material properties of the fabric itself, leaving a record of these forces in the cured concrete. Similarly, the surface texture of the *Arch 002* casts densifies as the radius increases, while the resistance of the tube to complete deformation mitigates the extent of bending, translating parametric ratios of rigidity to flex into the final form. The project team used digital models throughout the design process to hypothesise different shapes that might be cast, allowing the anticipated design to morph based upon real-world factors as moulds are constructed. As the process oscillated between digital extrapolation and parametric physical fabrication, it achieves a result akin to what Massie describes in his writing:

> *Information is temporarily suspended within the virtual (latent information) until it is physically realised. Pushed from the world of physics, into the paradigm of making, "potential information" is transposed into "kinetic information"* (Massie 2010, 103).

A similar parametric process is found historically in Antoni Gaudí's inverted catenary chain models of arches and vaults. Through a dynamic process of first hypothesising the general form of arch or vault, then hanging weights to stand in for supported loads, then recalibrating based on the force distribution, Gaudí continually tuned his structural designs before building to achieve the perfect form (Huerta 2006). Unlike Gaudí's chain arches, which would be translated into photographs or drawings and then reconstructed in masonry right side up, the mass that forms the structures in *Arch 002* is the self-weight of the concrete, without intermediary representation or translation. "The scripting of assembly and the corporal choreography fold back into what could have been considered drawing," as Massie writes (ibid, endnote 3104). The final construction becomes an embodied drawing that encodes its process of creation.

Working to make the experimental fabrications span structurally, the project team turned to the form of the arch for its logical relationship with compressive materials. Synergy between the load-managing strategy of arches, vaults, and catenary forms and the smoothness of their geometries avoided the impossibility of casting abrupt turns or 90 degree corners with the tube formwork. As a poiesis-driven progression from experimentation to spatial projection, the work followed Delabor Vesely's connections between form and material:

> *In the process of material transformation the inner logic of a building and its material realisation manifest themselves as an ideal material form* (Vesely 2006, 16).

The formal deviations of the arch and catenary forms result as unmediated translations of the drainage tube's material capabilities.

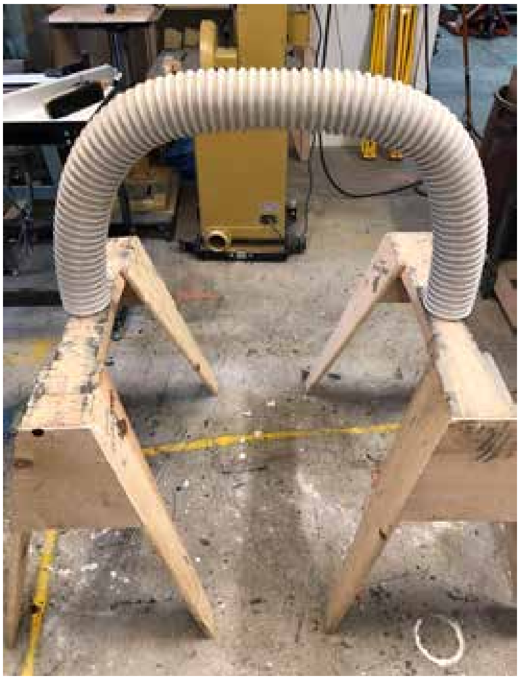
In the course of developing tectonics of linearly-formed concrete, the researchers have encountered a number of issues arising from the counterintuitive mass-to-slenderness ratio of the system. Early experiments with larger and multi-curved forms tended to crack under their own weight in the demoulding process or during repositioning, as the mass can shift and create additional stresses in the material. Any discontinuity in the cast—from multiple pours or trapped air bubbles—increases the probability of failure. Initial solutions to this problem focus on integration of reinforcing bars and segmenting large forms into manageable casts that can be assembled after curing. In composite structures, the tendency of the arch to splay out under its self-weight is compounded at the loci of material shift between the concrete and the steel joinery. In contrast to the rigidity of the concrete, the relatively flexible steel pipe bends under the weight of the arch, torquing the system out of equilibrium. Deviations of the cast-in-place steel connections from perfectly centred and vertically plumb result in a greater inclination of the structure to flare out and corresponding weak moments at the end of the concrete casts. Normative masonry and concrete arch construction utilise tension members at the base or massive abutments to counter outward thrust, which can integrate seamlessly into bridge or wall designs. To preserve the deceptively lightweight-seeming linearity of *Arch 002*, the researchers are experimenting with alternative means of counterbalancing the system. One design trajectory explores casting arched buttresses out of the same formwork, and using prefabricated connection *Y* or *T* fittings to join them. Current efforts focus on casting curvilinear *feet* which ground the arches by expanding the surface area in contact with the floor and embed additional mass to counteract thrust.

The complex casting and demoulding process continues investigation to reduce material failures and inconsistencies. Concrete chipping occurs at locations where the formwork radius is too tight, or when removal using the grinder causes erratic forces on the thin portions of ribbed surface. The team is exploring gentler techniques for improved removal methods, including perforating seams in the tubing prior to casting to allow for easier cutting. To alleviate air bubbles and areas of incomplete casting in the concealed multi-curved formwork, researchers drilled small holes along the upper surface of the drainage tube to allow air to escape as the concrete is being poured. The researchers are also exploring compressing the liquid concrete into the mould from both ends to ensure that the concrete fills to the top of the ribs. The patterning that results from the incompletely filled mould is interesting to the project team as well, embodying the limits of the formwork and the workability of the concrete, with the raised edge of the cast caused by surface tension outlining a section cut through the cast.

As a speculative fabrication process with no defined or prescribed end, the project team can move projection from material into space forward based on the pursuit of tectonic stability and spatial complexity at multiple scales. Using digital models and scaled 3D prints, the team is investigating how a large-scale manifestation based on the material premise would form and how it would perform as a system relative to human scale. Furniture proposals suggest multi-material joinery as one research valence. The length and size limitations of the tubing itself suggest modular part-to-whole relationships between the projective, gravity-less worlds of the digital model and our current way of making. Through comparison, the provocation calls for this way of making to evolve.

In the process, the 3D printed models allude to a traditional methodology for constructing arches. With Fused Deposition Modelling (FDM), models require scaffolding during the printing process to support the molten thermoplastic filament. A raft at the base of the model keeps the rounded surface attached to the printer bed. When the thermoplastic hardens, the structure will self-support and the scaffolding can be removed, analogous to the deconstruction of scaffolding after the keystone of a masonry arch is set, or the removal of jigs once the concrete form has cured in the tube. The control within the 3D printing software allows for variability in the density of supports. Iterative manipulation and consideration of the supports as design elements themselves give insight into potential complex tectonics at a larger scale. The translucent veneer of a millimetre-thick support posits the integration of curtain walls or thin non-structural dividers beneath a structural arch. Thicker and denser supports, on the other hand, reconfigure the load paths, giving significant strength to the arch.

Bringing the arch into and out of the realm of the drawing suspends scale, mass, and force for the team to continually reconcile the methods by which they create. The work aligns with the root word *techne*, "knowledge related to making…known in its final sense as *techne poeitike*" (ibid, 285). In a cyclical process of make – design – remake – redesign, the team defines an understanding of architecture with making as a catalyst between material and form.



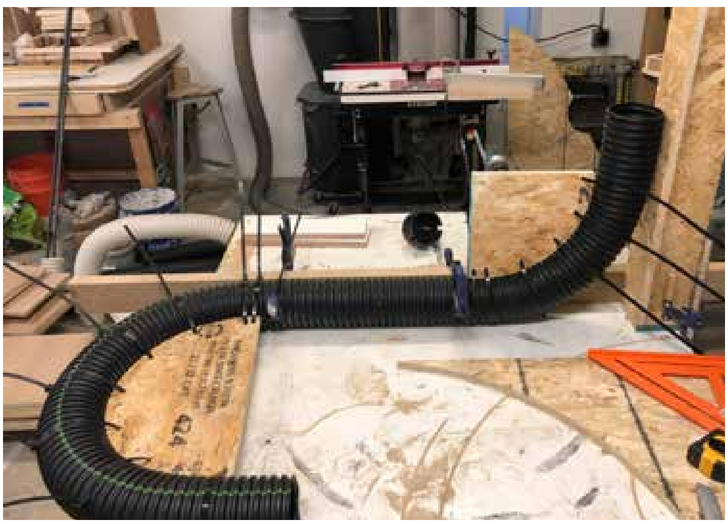


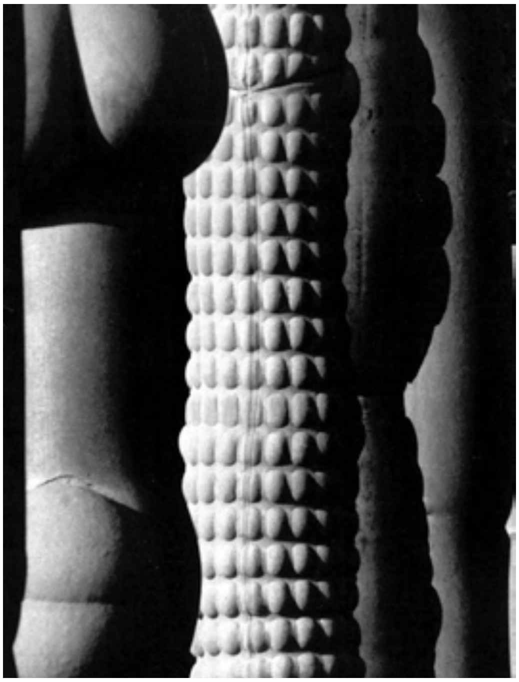
Figure 1 (top left, page 187): Initial prototype.
Source: *authors.*

Figure 2 (top right, page 187): High-density polyethylene drainage pipe, cut open to show ribbing.
Source: *authors*

Figure 3 (middle right, page 187): Cast concrete texture detail. Source: *authors.*

Figure 4 – 5 (middle left and bottom, page 187):
Flexible tube formwork with radius fixtures.
Source: *authors.*

Figure 6: Casting process of a simple arch with one long leg. Source: *authors.*



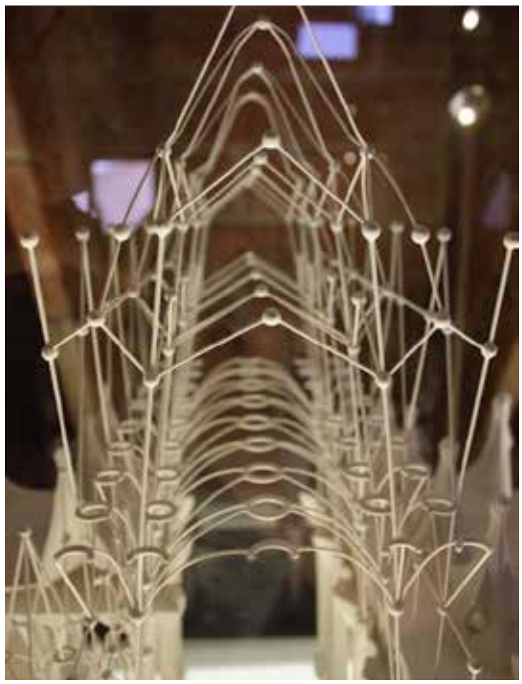


Figure 7 –8 (top left and right): Cast concrete columns by Mark West. Source: *http://www.survivinglogic.ca/.*
Source: Mark West.

Figure 9 (bottom left): Structural Model by Antoni Gaudí displayed at La Sagrada Familia. Source: *Elise DeChard*.

Figure 10 (bottom right): Structural Model by Antoni Gaudí displayed at Casa Mila. Source: *Elise DeChard.*

Figure 11 (top left): Casting process of a multi-curved form. Source: *authors.*

Figure 12 (middle left): Flexible tube formwork with a rope form tie. Source: *authors.*

Figure 13 (top right): Plumbing the cast-in-place steel joinery. Source: *authors.*

Figure 14–15 (left and bottom): Formwork removal process using a utility knife. Source: *authors.*

Figure 16 –17 (top right and left, opposite page): Composite arch structure. Source: *authors.*

Figure 18 (bottom, opposite page): Composite arch structure with cast-in steel pipe connections. Source: *authors.*

Figure 19 (top left, opposite page): Composite arch with cast-in steel pipe connections. Source: *authors.*

Figure 20 (top right, opposite page): Cast concrete texture detail with a grinder seam. Source: *authors.*

Figure 21 (middle left, opposite page): Steel pipe joinery detail. Source: *authors.*

Figure 22 (middle right, opposite page): Steel pipe joinery detail. Source: *authors.*

Figure 23 (bottom left, opposite page): End of cast with imprint of plastic sheet mould cover. Source: *authors.*

Figure 24 (bottom right, opposite page): Incomplete cast due to air in the mould. Source: *authors.*

Figure 25 (top left): Incomplete cast due to air bubbles in ridges of formwork with a broken edge. Source: *authors.*

Figure 26 (top right): Incomplete cast due to air bubbles in ridges of formwork with a grinder seam. Source: *authors.*

Figure 27 (bottom left): Chipped cast damaged during demoulding. Source: *authors.*

Figure 28 (bottom right): Bottom of HDPE tube flattened by the weight of concrete during casting. Source: *authors.*

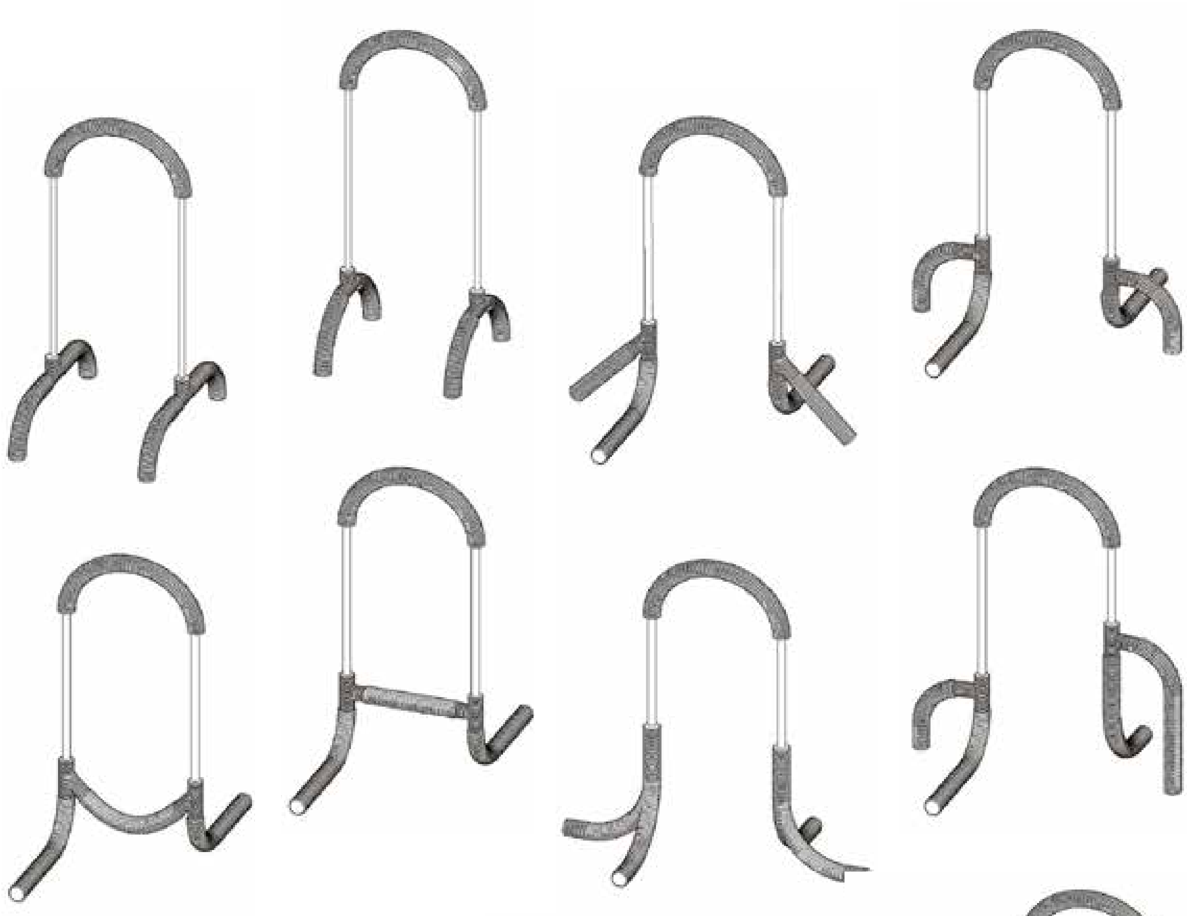
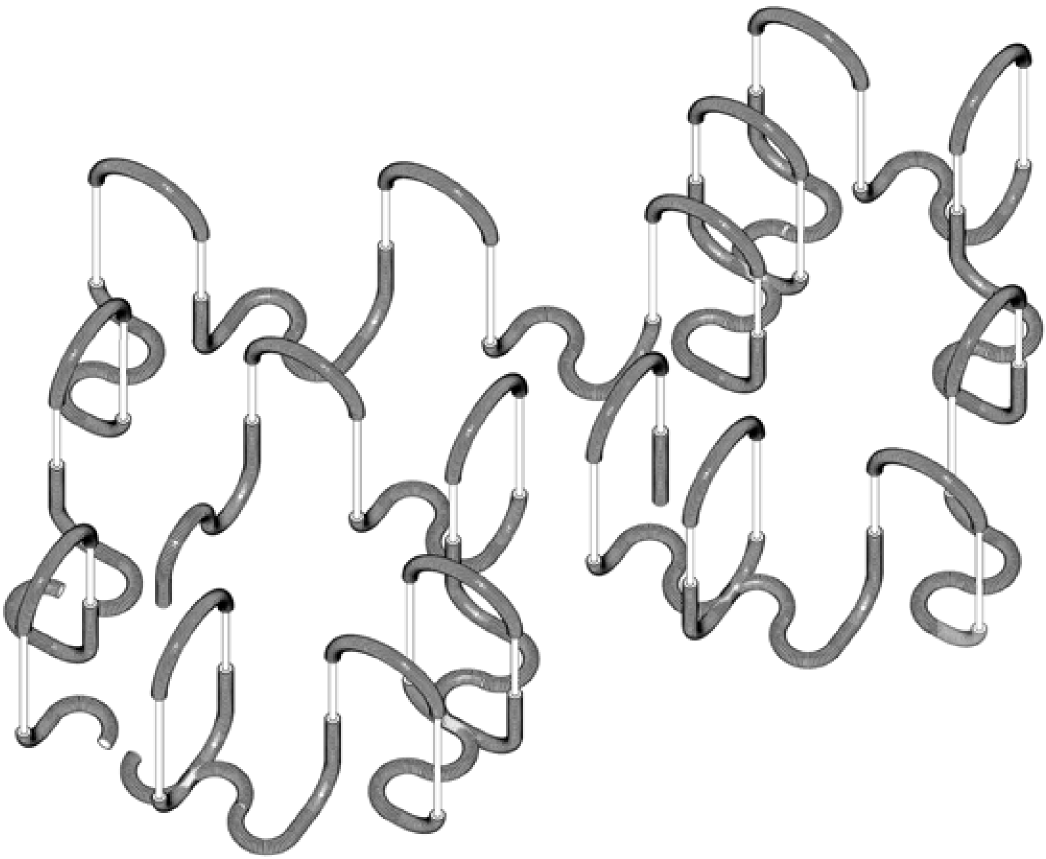
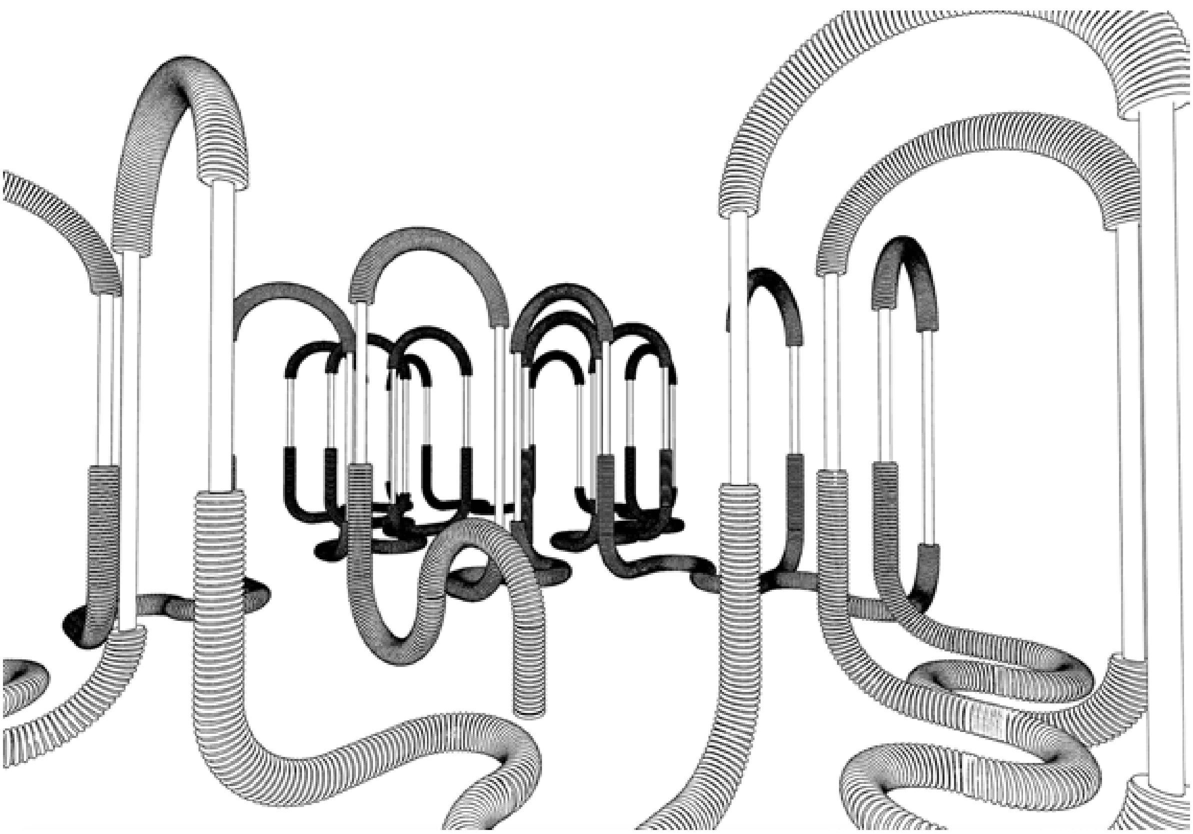
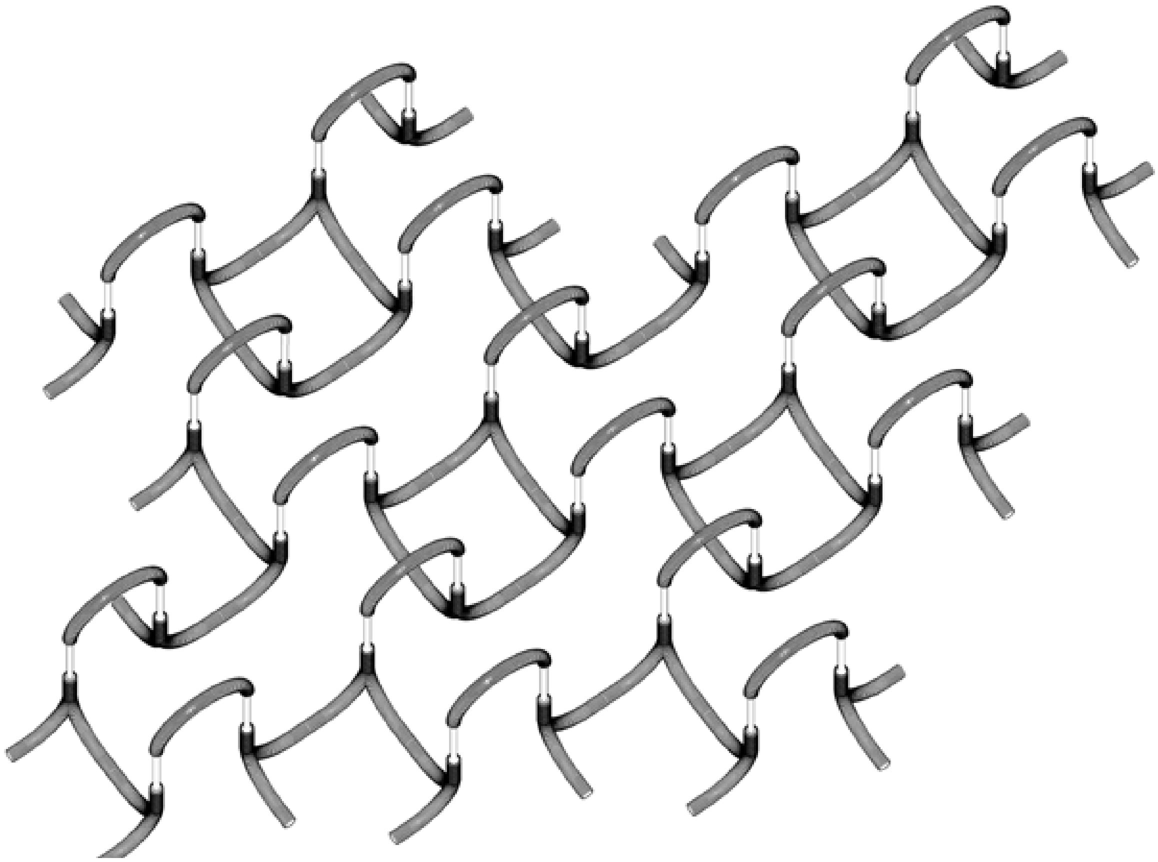


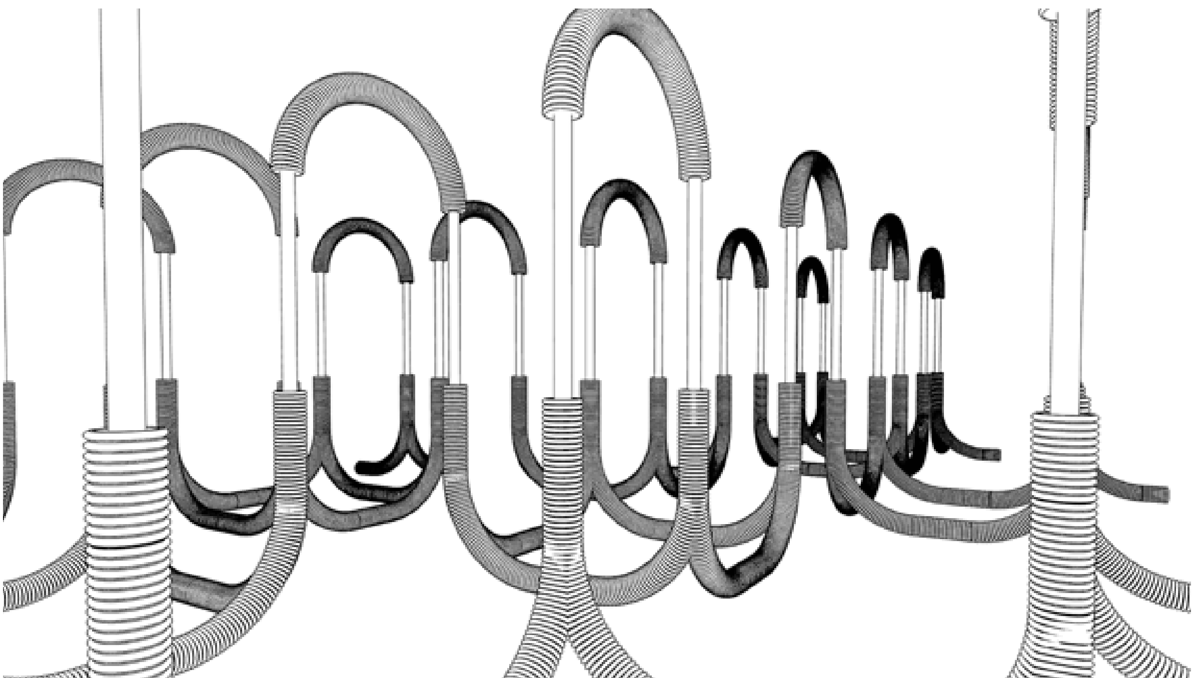
Figure 29 : Arch002 formal taxonomy.
Source: *authors.*

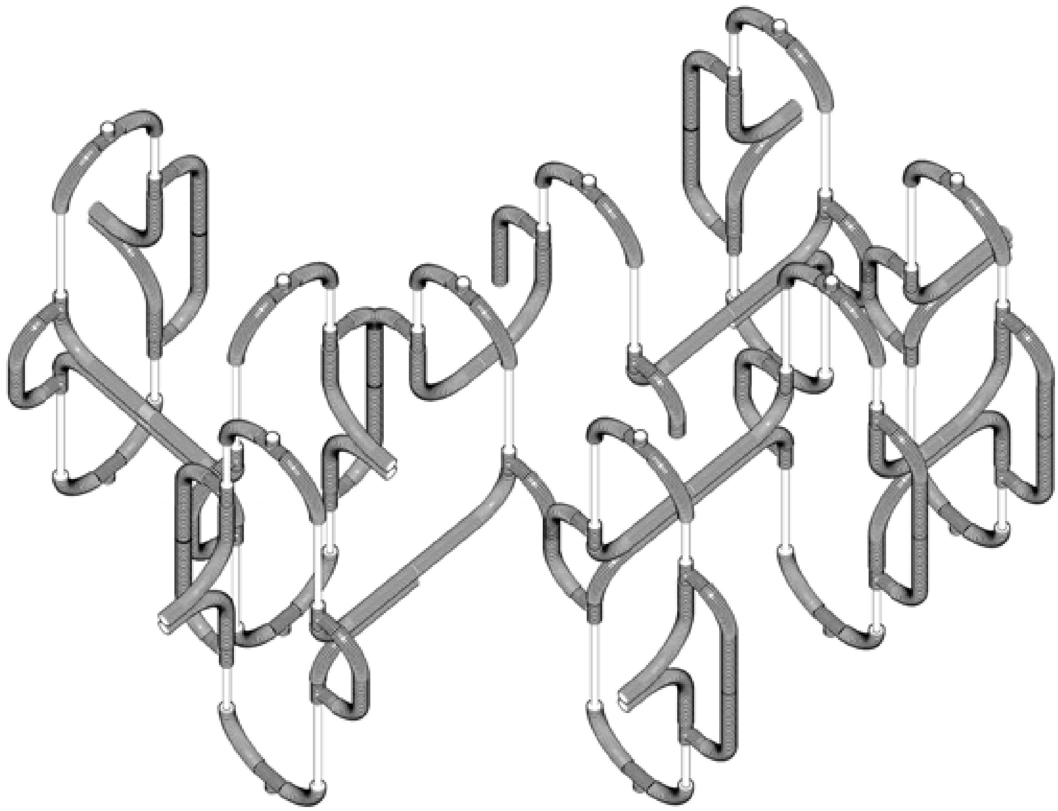
Figure 30–31 (top to bottom, opposite page):
Speculative environment 002.a.
Source: *authors.*











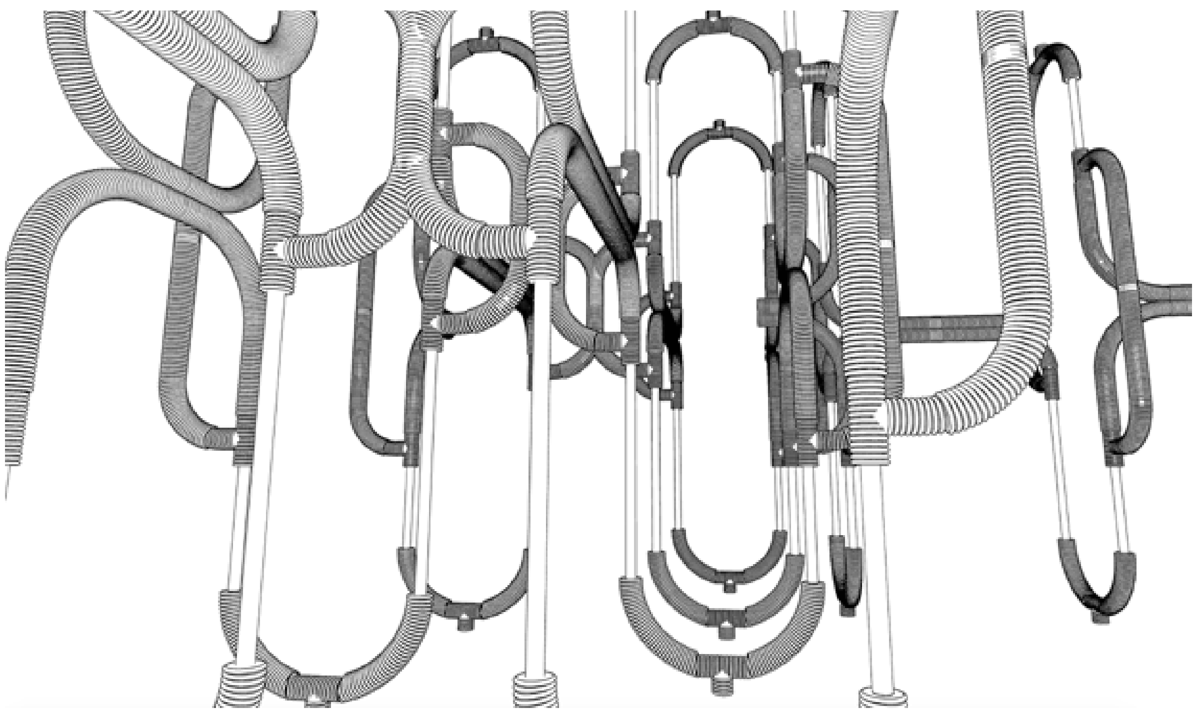
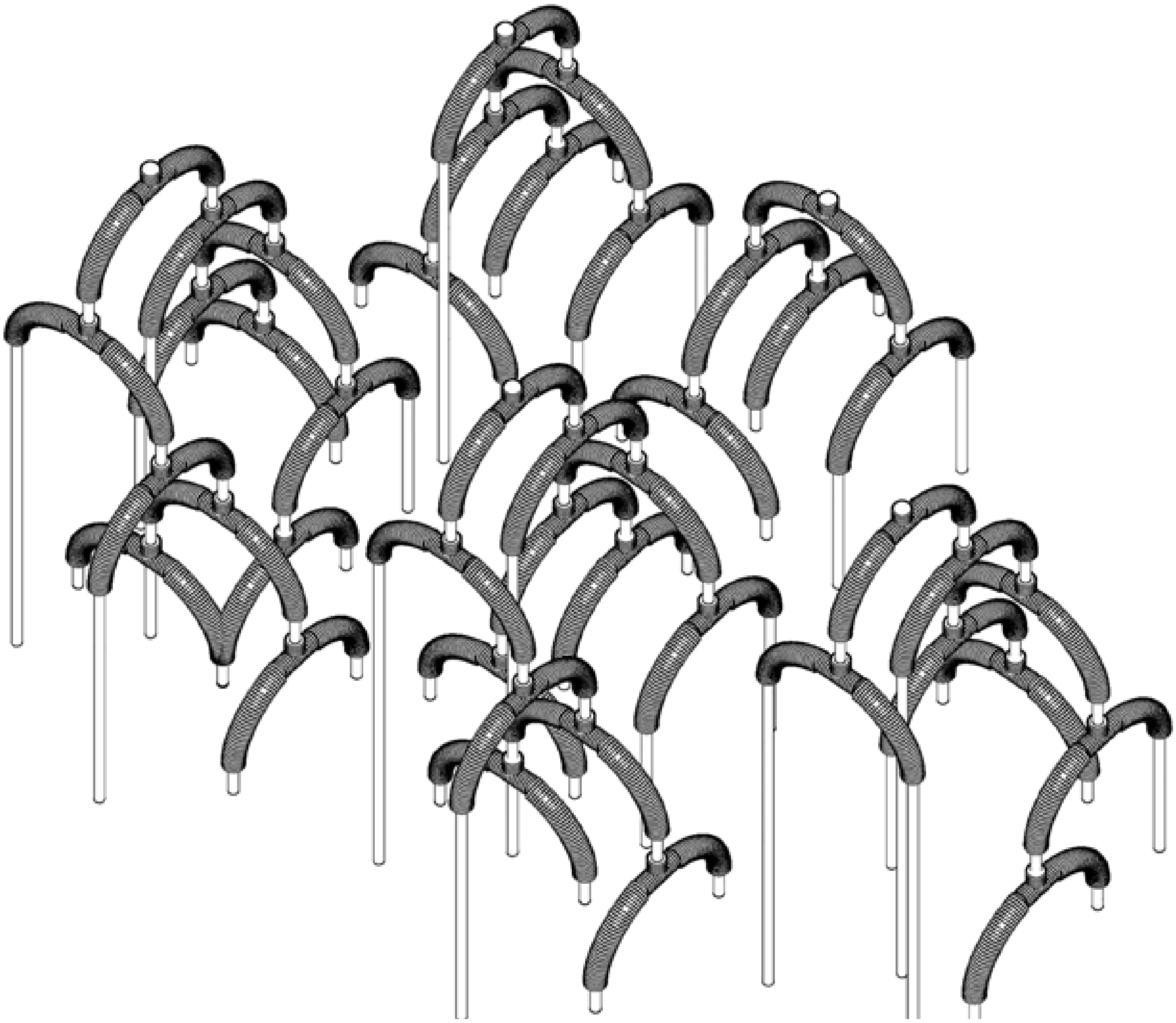


Figure 32–33 (top to bottom, opposite page): Speculative environment 002.b. Source: *authors.*

Figure 34–35 (top to bottom): Speculative environment 002.c. Source: *authors.*



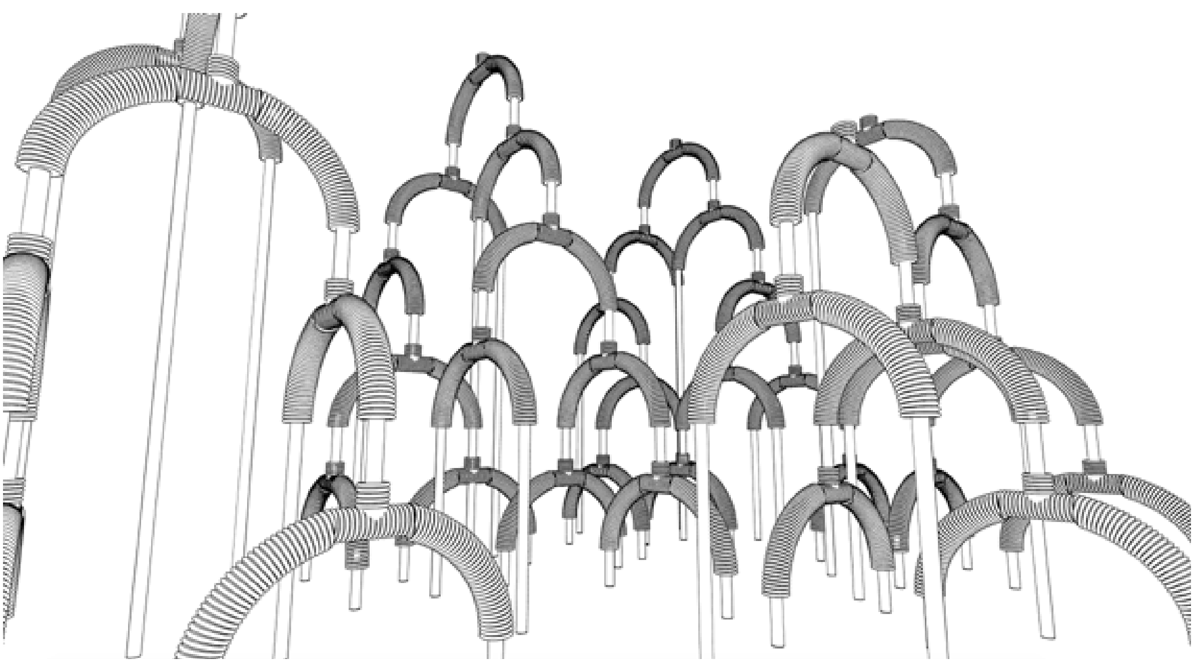
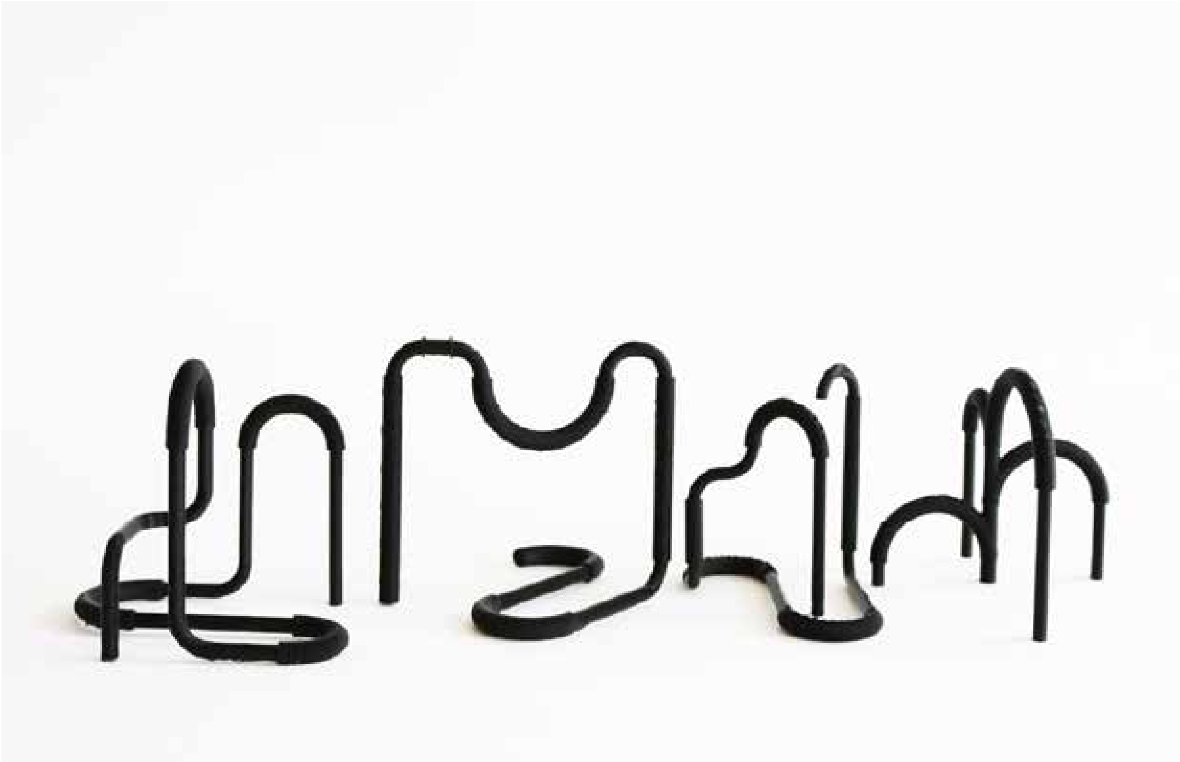


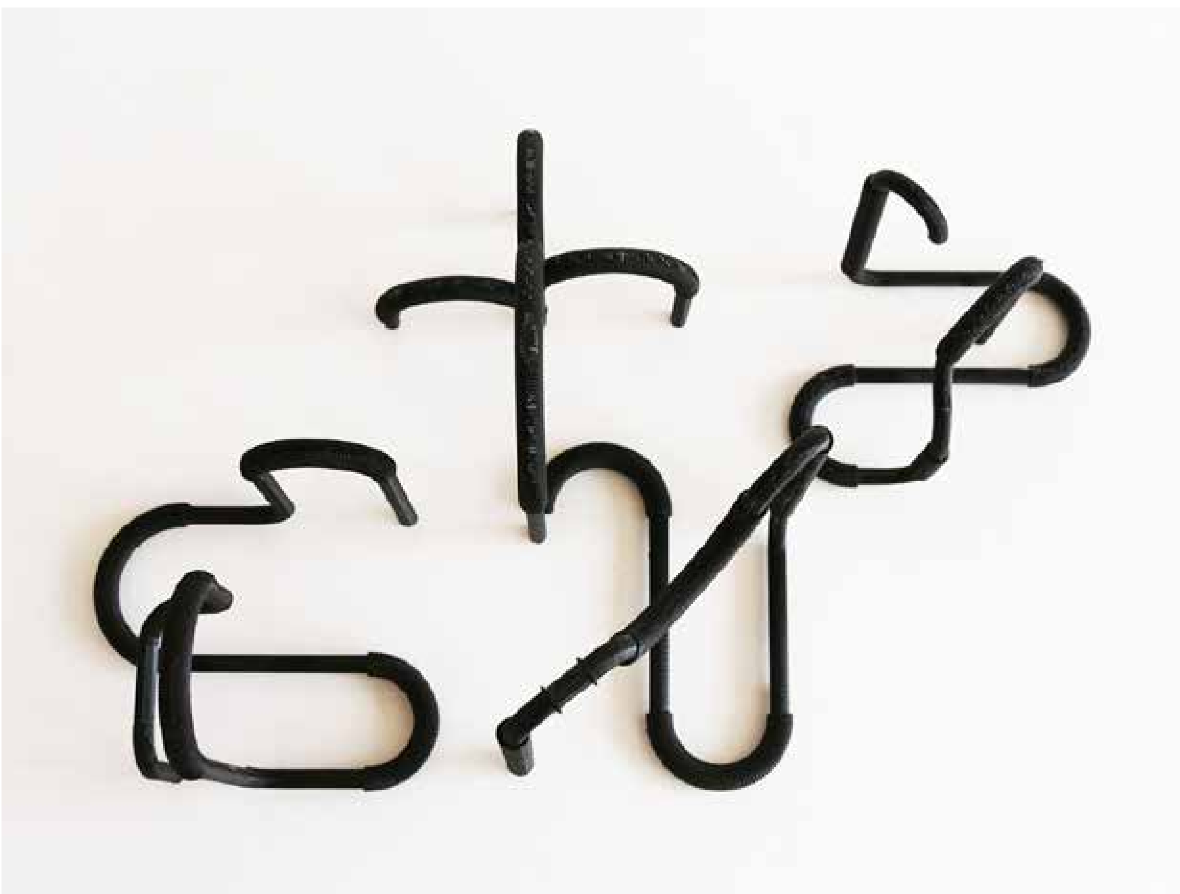
Figure 36–37 (opposite page): Speculative environment 002.d. Source: *authors.*

Figure 38–39 (top left & right): 3D printed model in process. Source: *authors.*

Figure 40–42 (middle left to bottom left): 3D printed model. Source: *authors.*

Figure 43–44 (page 200): 3D printed model aggregation. Source: *authors.*





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Bio

Fernando Bales is an artist, designer and founder of FPB STUDIO. As an inter–disciplinary endeavour his studio delves into the fields of industrial design, set design, architecture, construction, fabrication, and landscape architecture. A graduate of North Dakota State University and Cranbrook Academy of Art, Bales received master of architecture degrees from both institutions. Bales’ architectural products are tactile and reactive, based on his fellowship with craft, analogue and digital. He searches for new techniques to reveal that which is latent. A sincere empathy for space and the ever-evolving elements that form it are integral to his thought process and output. Fernando’s work has been exhibited nationally and has worked for multidisciplinary firms in Seattle, WA and Detroit MI. He currently is a lecturer at University of Michigan Stamps School of Art and Design and professor of practice at Lawrence Technological University. His practice currently resides in Pontiac, MI.

Elise DeChard is a licensed architect and the founder of END Studio, a Detroit-based architecture / design / research practice dedicated to exploring transformational reuse, innovative material techniques, and playfully subversive interventions to transcend the traditional urban experience. DeChard presented projects “Site Spectacle Seed Sprout” and “The Glow of Grime” at the 2017 ASCA Conference in Detroit, MI, USA. Her work has been featured in *Architectural Digest, The Architect’s Newspaper, Wallpaper Magazine, Design Milk, TreeHugger, The Oakland Press, Fox2 News Detroit,* and *Curbed Detroit.* She is the founding partner of Tessellate, an experimental artist-run gallery and residency in a garage in Pontiac, MI, USA. DeChard holds a bachelor of architecture from Rensselaer Polytechnic Institute and a master of architecture from Cranbrook Academy of Art. She was a 2017 CRITPraX teaching fellow at Lawrence Technological University and currently teaches graduate architecture at Kendall College of Art and Design.

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ABSTRACT

Sincerely Yours: Orchestrating Tangible Interactive Narrative Experiences

Daniel Echeverri

202 — 207

This paper briefly reflects on two aspects of narrative: the use of multimodal analysis to understand the relationships between the senses and the narrative, as well as digital and physical content, and the implications brought from this analytical perspective on the design of interactive narratives. The latter, in particular, concerns narratives that involve tangible interaction and physical manipulation of objects. The creative process of *Letters to José*, a physical-digital hybrid nonfiction narrative, exemplifies this reflection. In this narrative, the person interacting with the story takes upon multiple roles, among them performatively enacting the story and unfolding the narrative through different mechanics of play.

#tangible narratives

#trajectories

#multimodality

#tangible interaction

#storytelling

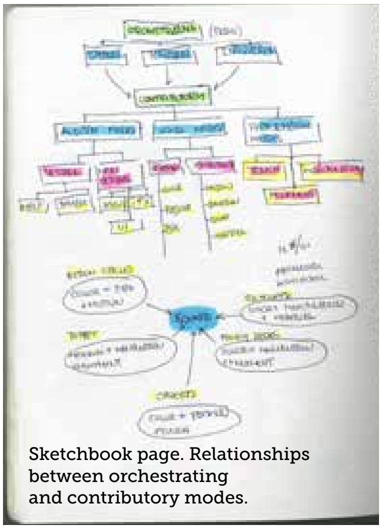
Letters to José is an interactive physical-digital hybrid nonfiction narrative in the form of a series of tangible unfolding story worlds, powered by paper-based physical computing, and combining paper mechanisms with various embodied, visual, and auditory modes. This narrative is based on a compilation of letters written between 1948 and 1957 by Jesús – a young medical student – to his brother José. The letters are not only a portrayal of different everyday occurrences, but also evidence of the social, cultural, and economic changes of Colombian society during the late 1940s and early 1950s. The interplay between sight, hearing and touch, and the role of the interactor-performer, present unique implications on the design of these types of narratives and the orchestration of narrative experience.

With the evolution of technology, storytelling has changed drastically from film and video games to interactive spaces and Virtual Reality experiences. These new narrative media bring interesting considerations to contemporary storytelling. For example, Janet Murray (1997) examines the *Holodeck*–a holographic storytelling device from the TV series *Star Trek*– to illustrate some relevant considerations within these experiences that allow people not only to observe, but to manipulate tangible objects to engage with different characters and events of the narrative. In regard to this type of experience, Marie-Laure Ryan questions whether people will be playing "…a role, inwardly distanced from their characters and simulating emotions they do not really have, or if they will experience their character as their own self" (2002, 593).

It seems the answer to this question is not only about assuming a role or replicating oneself in the narrative, but performing both. This discussion in fact is about the power of interactive storytelling, and the accountability of the storyteller to craft experiences that allow people to take meaningful actions in the story world (Wood 2016). Designers, as storytellers, articulate stories to others through their craft. In the case of designing *Letters to José*, this articulation is the result of a constant dialogue between the designer, the story and the would-be artefacts. The dialogue is characterised as being constructive, critical and reflective. Through this dialogue, the narrative emerges in a sort of metamorphosis from the initial mental representations into an experience. This transformation signifies a continuous relationship between material and cognitive iterations that intend to explore answers to specific aspects of the story. Ultimately, it is designers' goals to carefully plan the orchestration of the experience by mediating between the story and people.

In *Letters to José*, this orchestration depends on the purpose of each auditory, visual or embedded mode: what they communicate, how they communicate, and when they communicate. For example, the story introduces two narrators: one that instructs people on how to act, and one that narrates fragments of the letters. The voice of each narrator has its own tonal characteristic and pace, and they are heard in specific moments: sometimes to trigger an action from the interactor, and other times as a consequence of an action. It could be even argued that the interactor is also a third narrator – a *self-narrator* – as he or she decides what aspects of the story to experience, explore and unfold by acting on the options offered by the narrative. Sometimes these acts are based on the interactor's beliefs, sometimes on their curiosity, and sometimes by impulse and chance. In *Letters to José*, mimetic acts, in which players enact the story, and *diegetic* acts, in which readers narrate the story through play, blend to become performance (ibid). For instance, touching words significant to a story, manipulating an avatar that represents the main character, walking around the story world to observe it, or placing objects inside the physical space of the story, all have consequences for specific narrative events (Echeverri 2019).

This recount is part of the ongoing work from the Ph.D. research tentatively entitled *Experiencing Stories Through Artifacts: A Model for the Authoring of Tangible Narratives* under the direction of Dr. Huaxin Wei. This research proposes a model intended for tangible interactive narratives, which accommodates physical manipulation and characterises the relationship between people, spaces, objects, and digital content.



Sketchbook page. Relationships between orchestrating and contributory modes.

Tactile words: Using conductive ink allows certain words to react to the user's touch triggering audio clips.

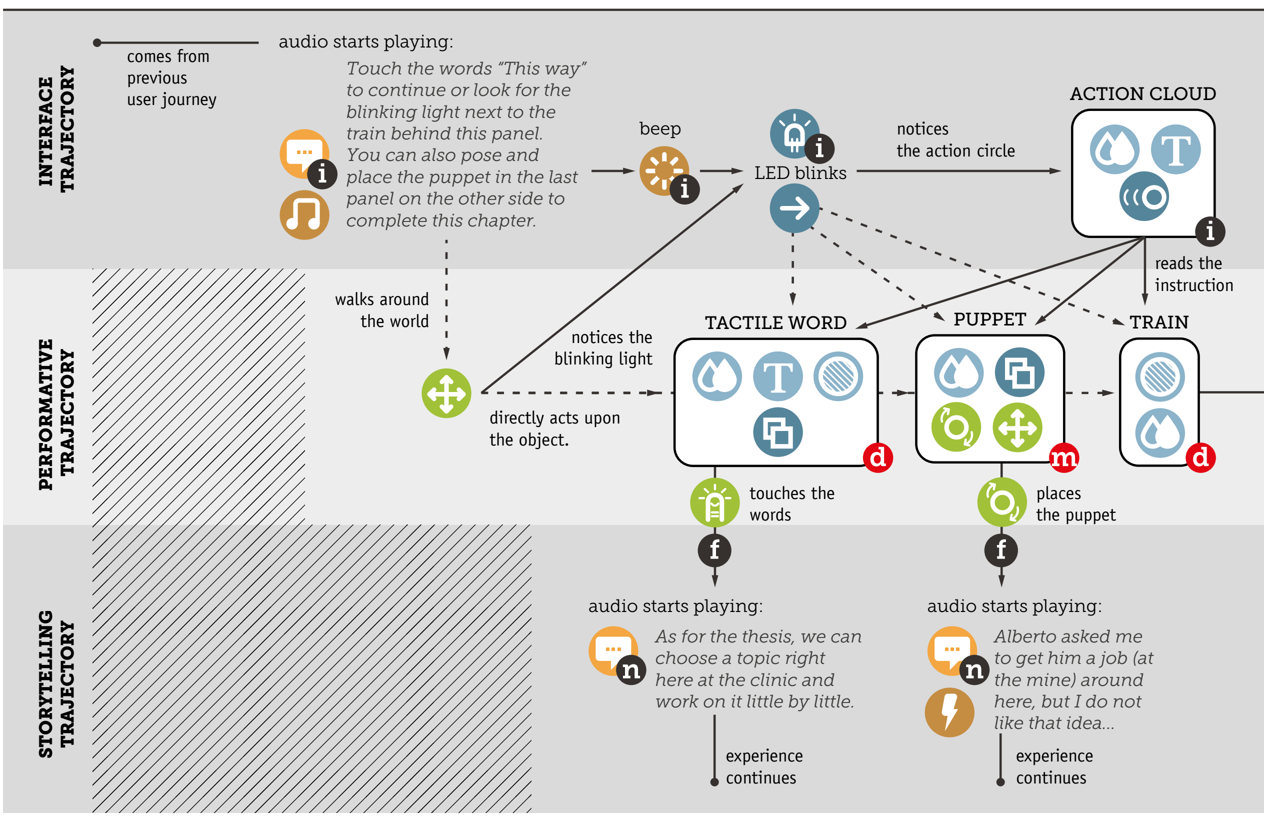
The *puppet*: A posable avatar that allows the user to activate narrative fragments when placed inside the story world.

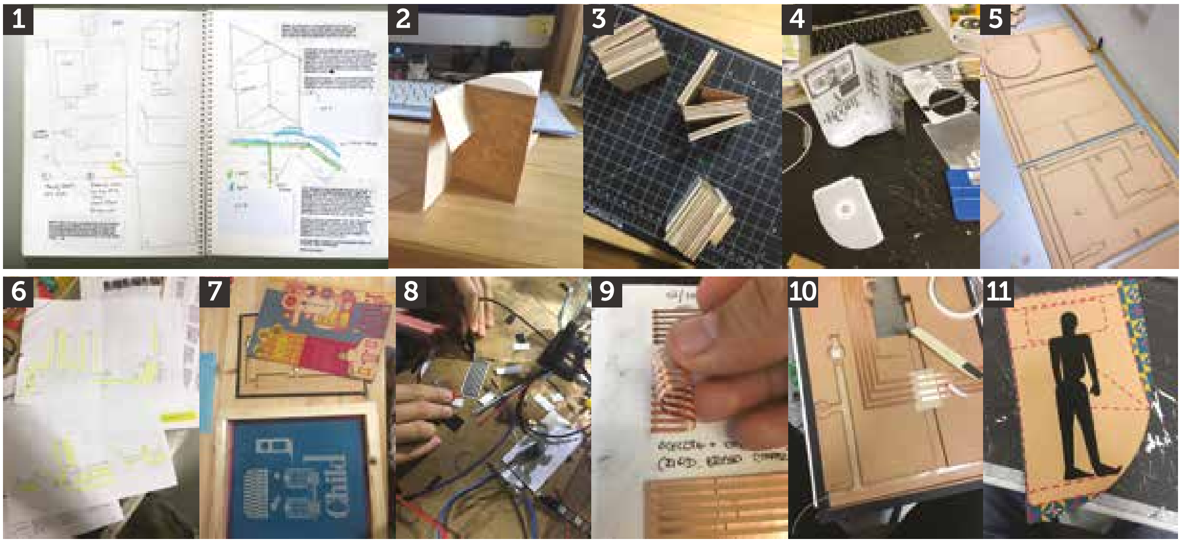
ORCHESTRATING AN EXPERIENCE:
INTERFACE, PERFORMANCE AND NARRATIVE

Trajectories are unique user journeys that retain a certain degree of coherence in regards to an experience. These trajectories are ephemeral relationships between physical and digital elements.

The **interface trajectory** looks at the visual and cognitive cues offered to the user, the **performative trajectory** involves physical performance of the user as well as object manipulation, and finally, the **storytelling trajectory** connects specific narrative events through text, environmental sound, music, and other media. As tangible interactive narratives become increasingly complex, orchestrating the relationships between different semiotic modes their intent is essential. This facilitates the designers' exploration of the aesthetic, functional and material expressiveness of various media as a way to support the narrative.

Each user journey has three type of paths: **sequential**, which are the ones that are defined by the designer, **variable**, which are impulses made by the user, usually not following the order established by the designer but directly acting upon an event, and **adjacent** which connects one user journey with the next.





THE NARRATIVE METAMORPHOSIS: A CONSTRUCTIVE, CRITICAL, AND REFLECTIVE PROCESS

The research is driven mainly through a reflective process; the iterative approach of designs allows the exploration of specific issues through prototyping.

(1) Initial sketches, the narrative fragments are placed in the sketches **(2-3)** Initial mock-ups; they explore formal and material aspects. **(4)** Scaled-down prototype to examine communication and functional features. **(5-6)** Layout of paper circuitry and blueprint of the placement of electronic components. **(7)** Screen-printing electronic ink. **(8-9)** Testing foldable conductive materials: electronic ink on tyvek, and copper foil on acetate. **(10-11)** Final prototype assembly. **(12)** Annotations over prototype.

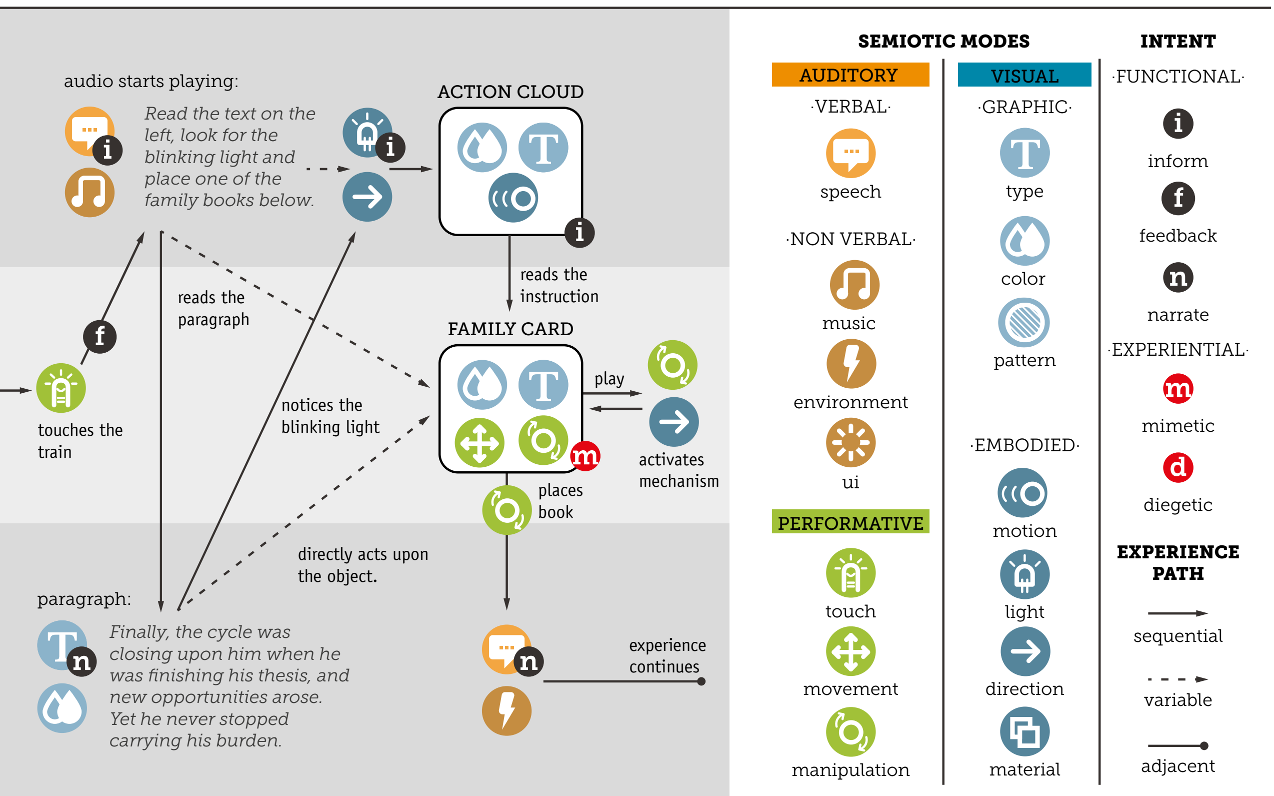


Figure 1: (previous pages): Transcription and annotations of the interaction process. Distinct attention is paid in this transcript to the nested modalities and how they contribute towards the narrative experience. Source: *author.*

Figure 2: The making. Soldering electornic components to adhesive traces of coppper laid on a cardboard circuit. Source: *author.*

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Bio

Daniel Echeverri is a Colombian graphic designer currently based in Hong Kong. He holds a master of fine arts degree in visual communication design from Kent State University, USA. He is also a Ph.D. candidate at The Hong Kong Polytechnic University's School of Design, where he is an interactive media programme tutor in the school's BA faculty. His doctoral research looks at the relationship between agency, transportation and engagement in the context of interactive narrative experiences and explores possible ways in which tangible interaction can support those narratives.

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