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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 *The building material as a singular and unique element of nature has been replaced by a vast, growing, almost unclassifiable system of disposable, interchangeable products.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.

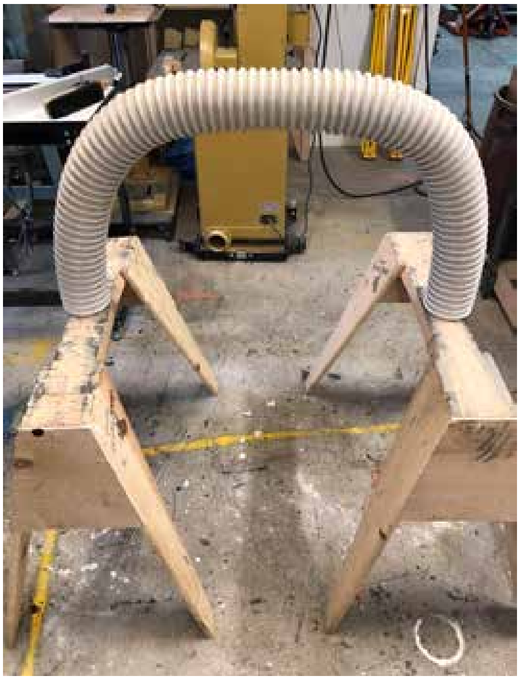
In the course of developing tectonics of linearly-formed concrete, the researchers have encountered a number of issues arising from the counterintuitive mass-to-slenderness ratio of the system. Early experiments with larger and multi-curved forms tended to crack under their own weight in the demoulding 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.

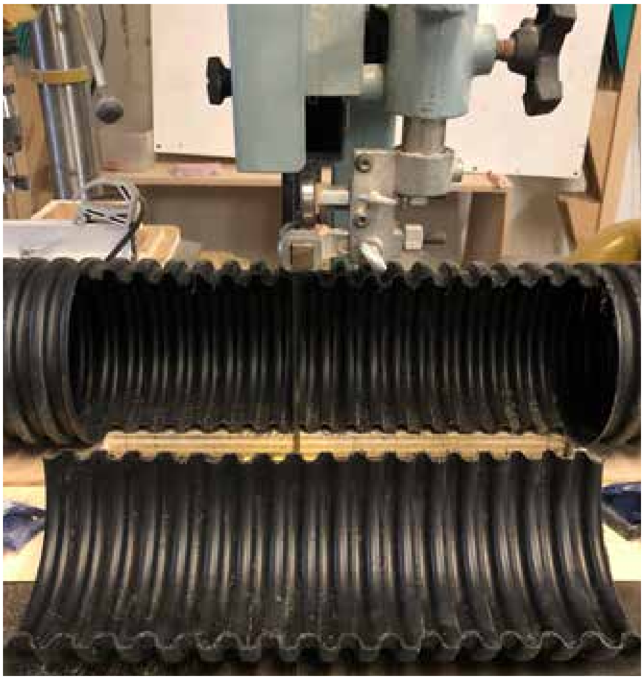
The complex casting and demoulding process continues investigation to reduce material failures and inconsistencies. Concrete chipping occurs at locations where the formwork radius is too tight, or when removal using the grinder causes erratic forces on the thin portions of ribbed surface. The team is 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.





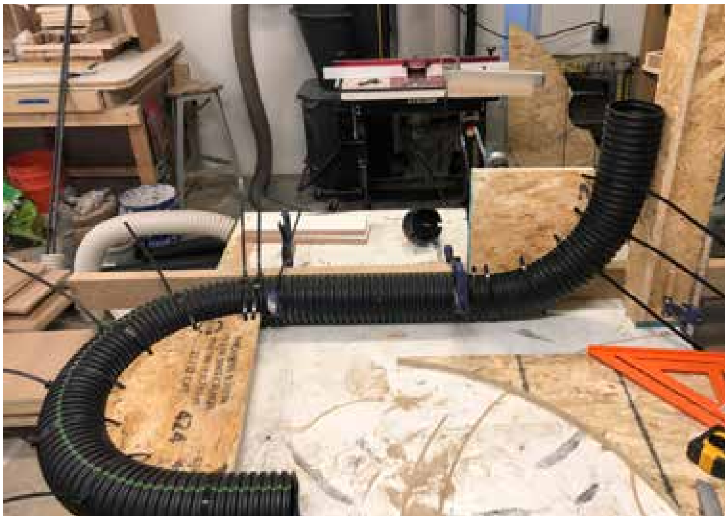


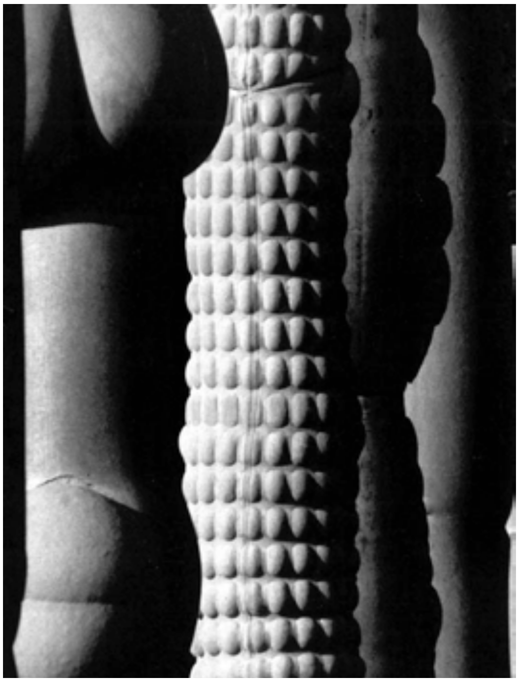
Figure 1 (top left, page 187): Initial prototype.
Source: *authors.*

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.*



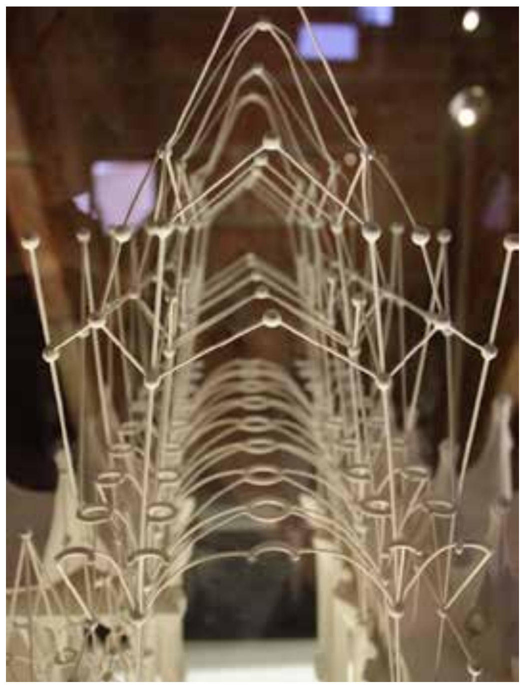


Figure 7 –8 (top left and right): Cast concrete columns by Mark West. Source: *http://www.survivinglogic.ca/.*
Source: Mark West.

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.*

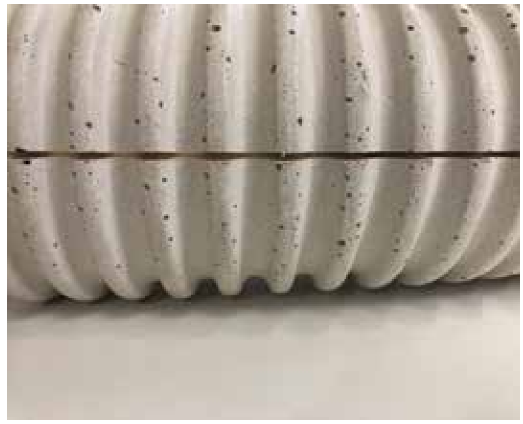


Figure 19 (top left, opposite page): Composite arch with cast-in steel pipe connections. Source: *authors.*

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.*

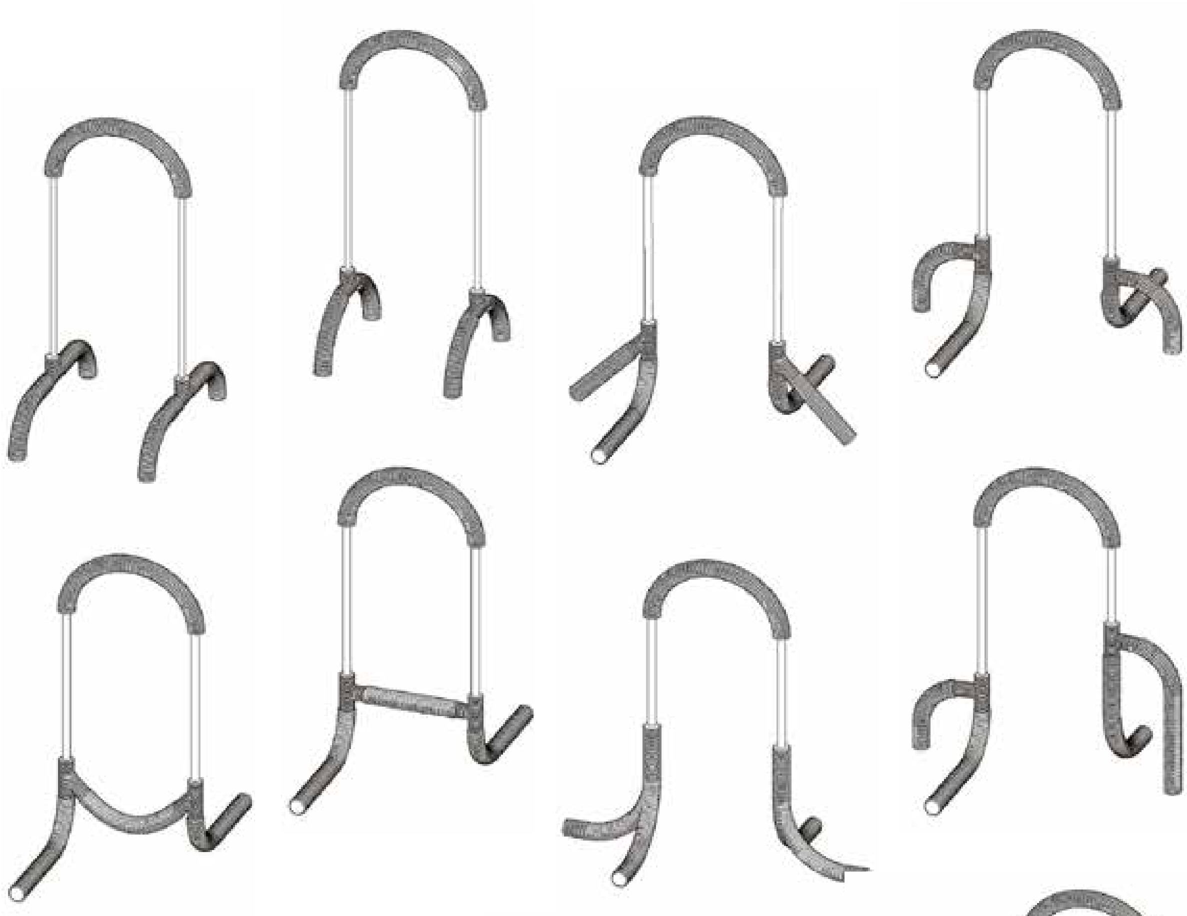
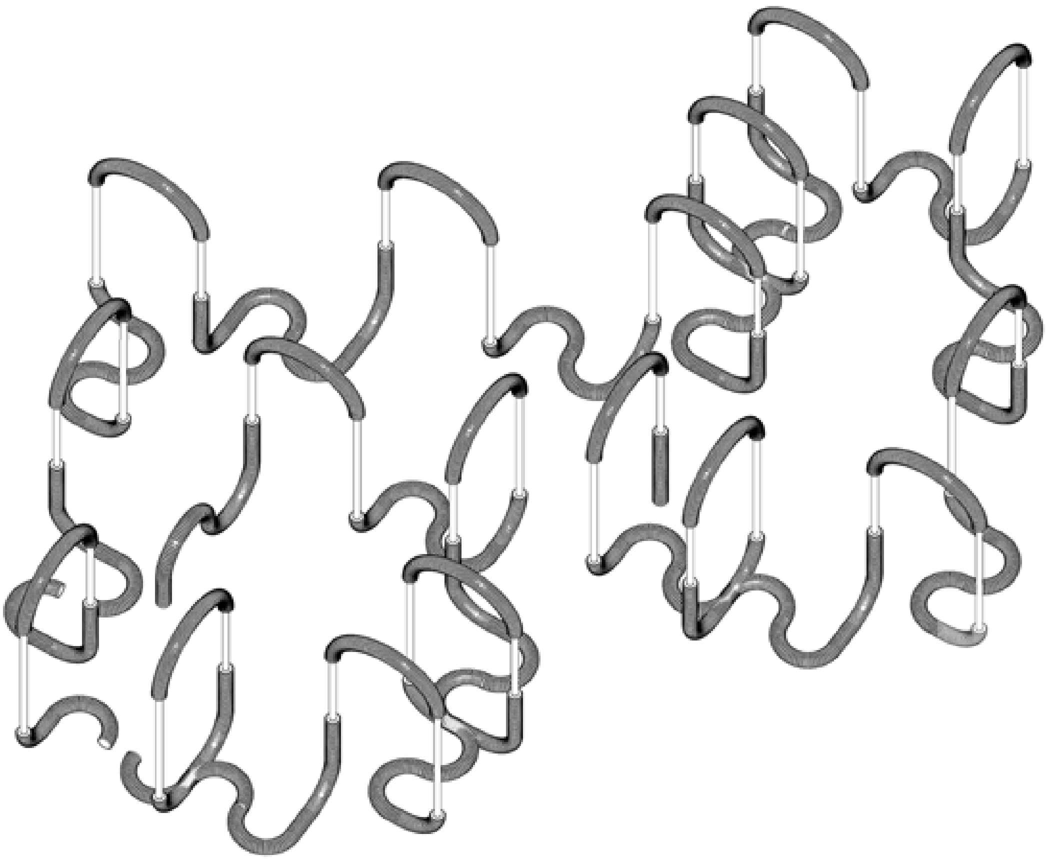
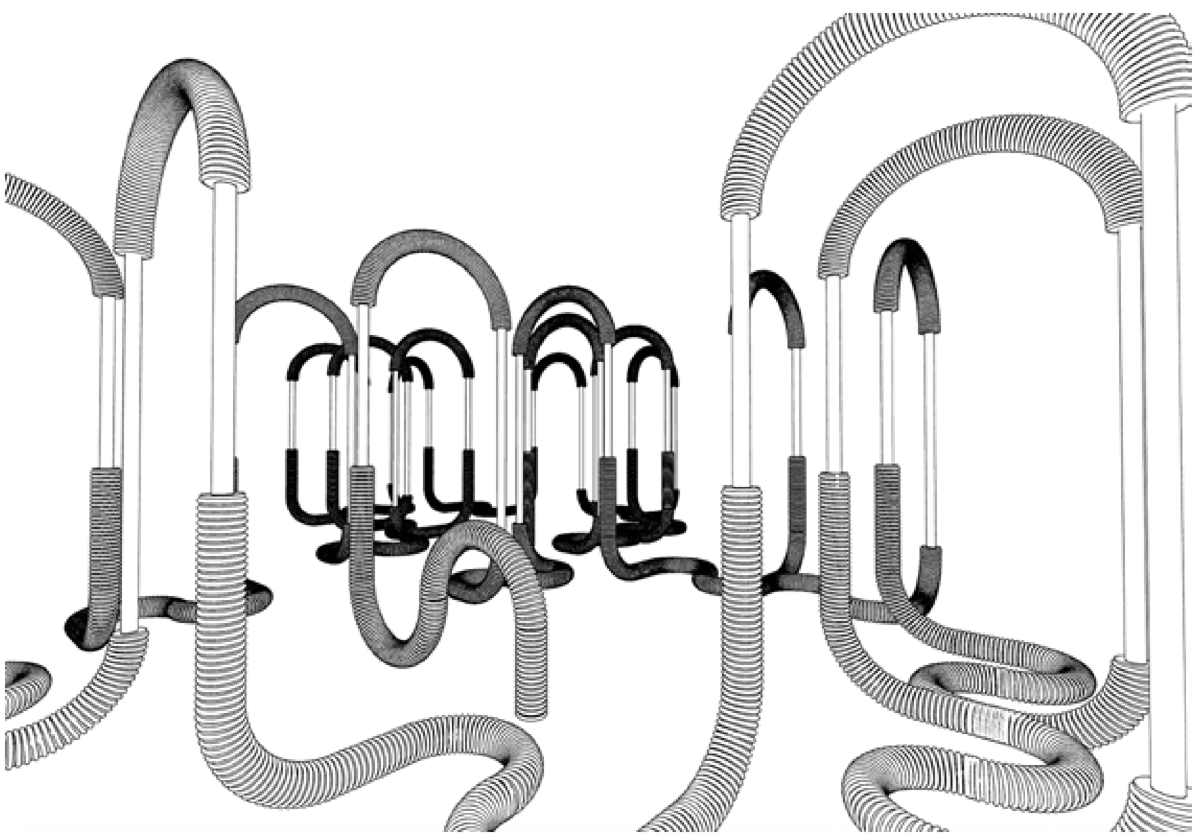
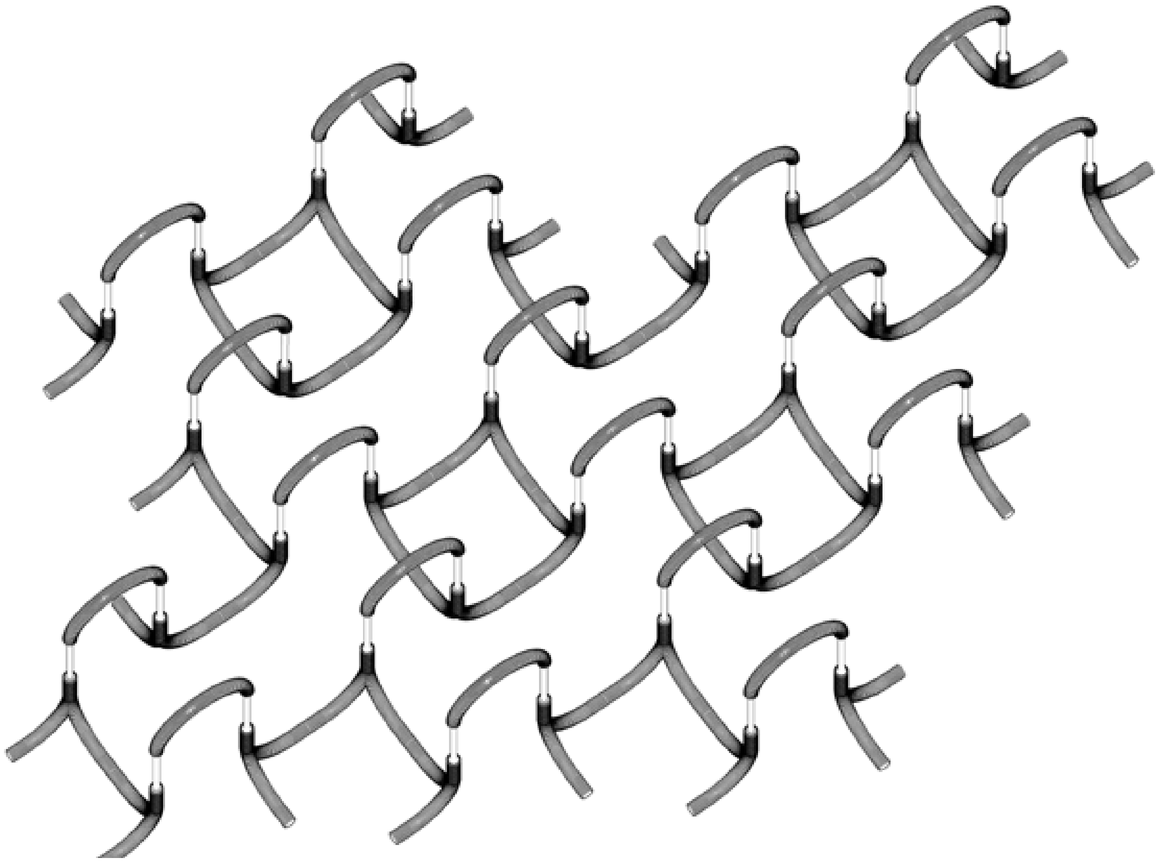


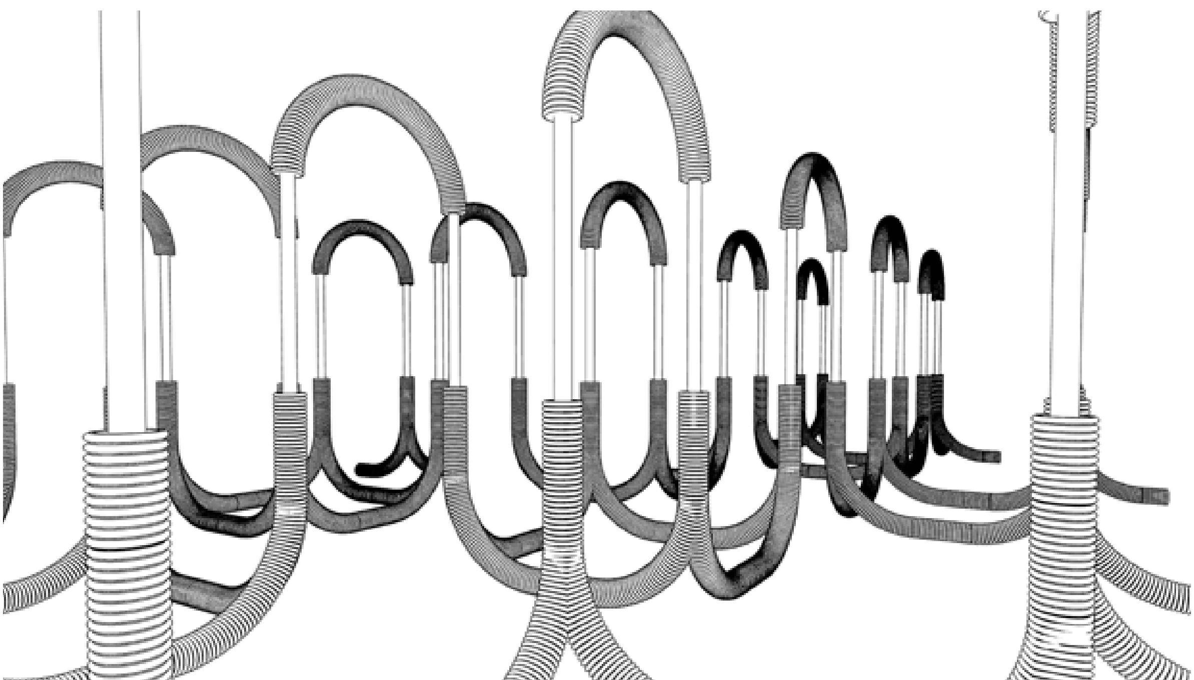
Figure 29 : Arch002 formal taxonomy.
Source: *authors.*

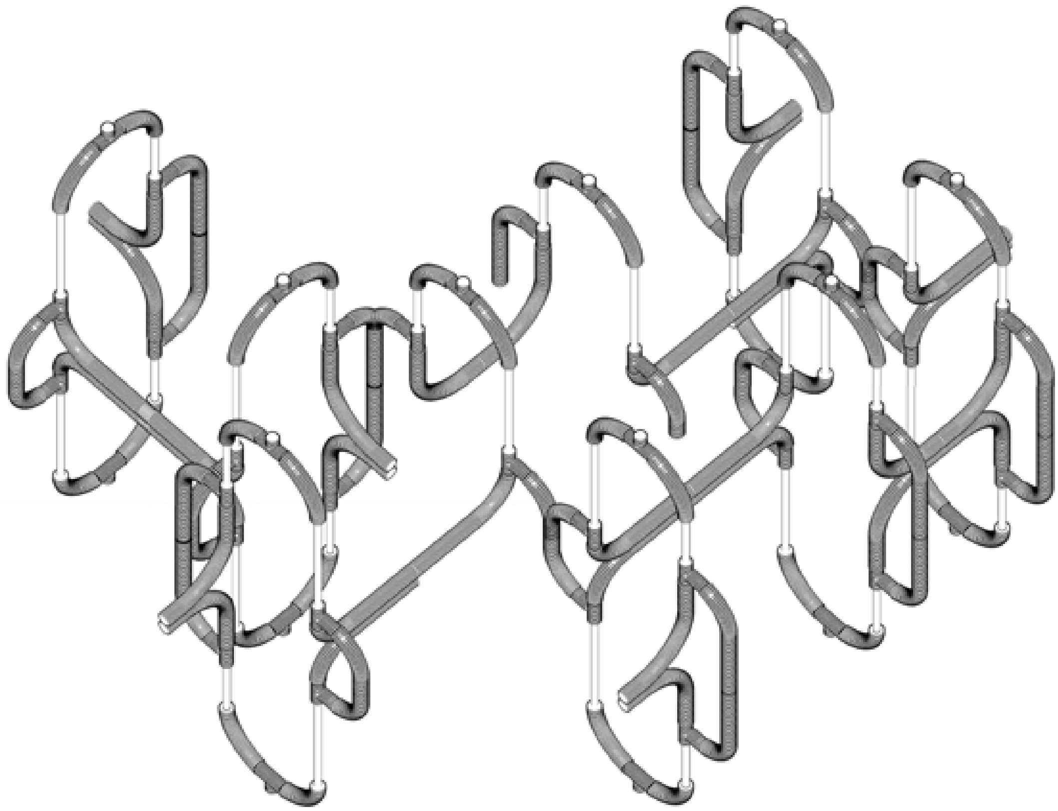
Figure 30–31 (top to bottom, opposite page):
Speculative environment 002.a.
Source: *authors.*











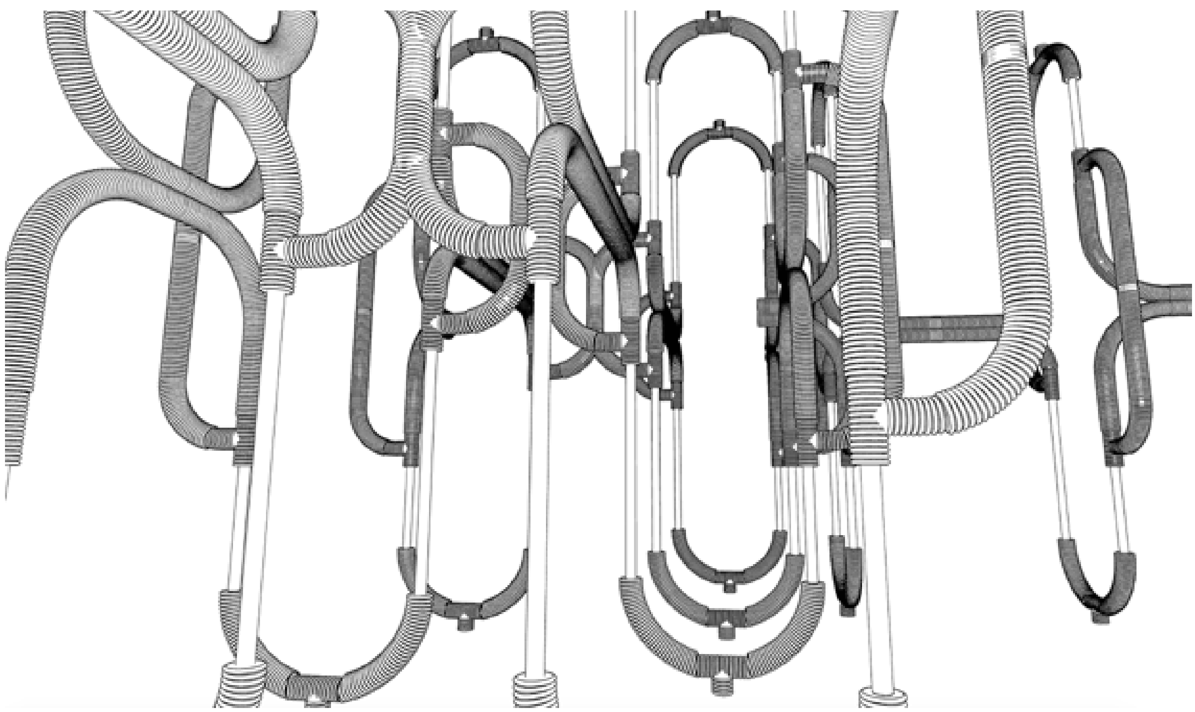
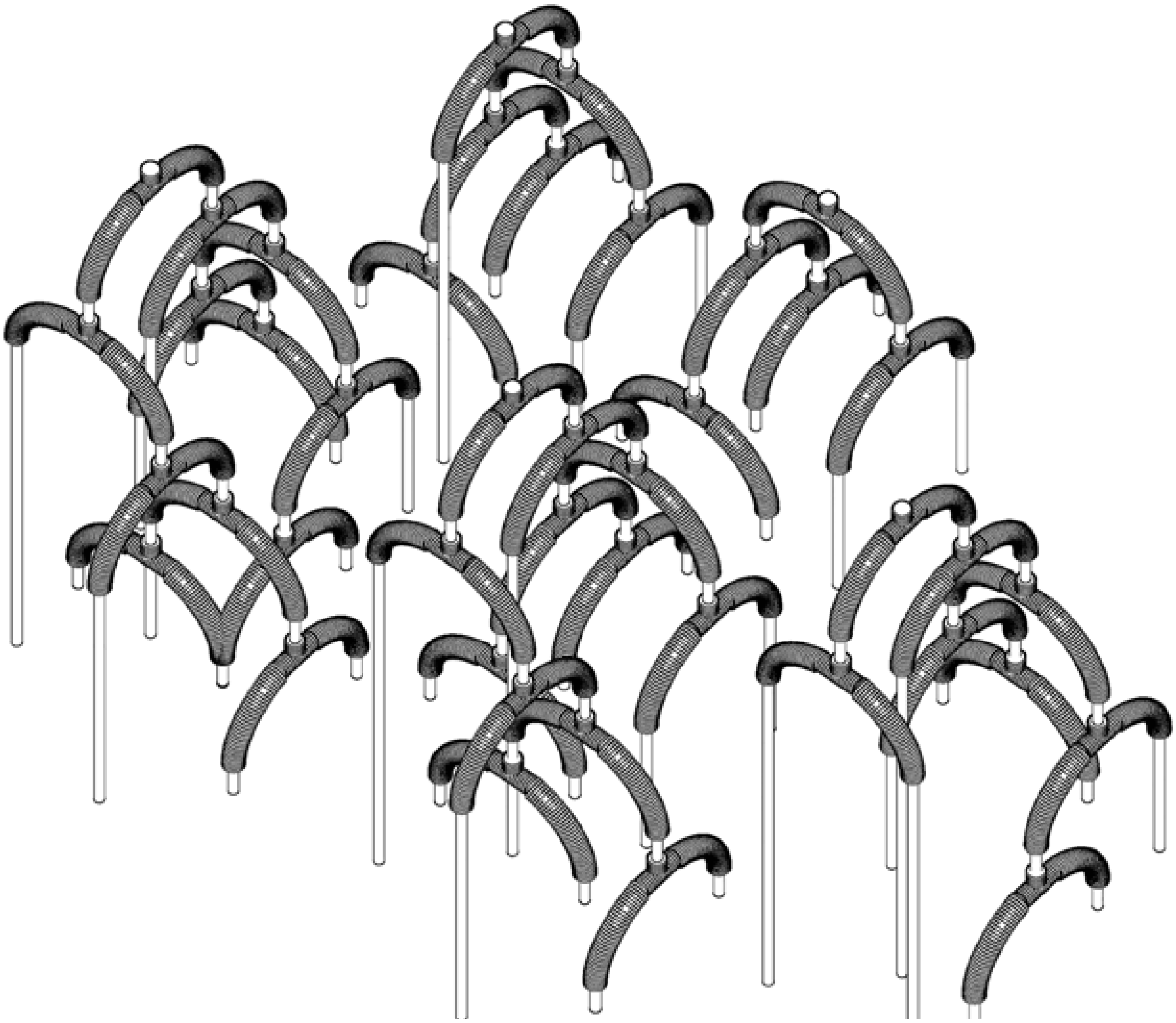


Figure 32–33 (top to bottom, opposite page): Speculative environment 002.b. Source: *authors.*

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



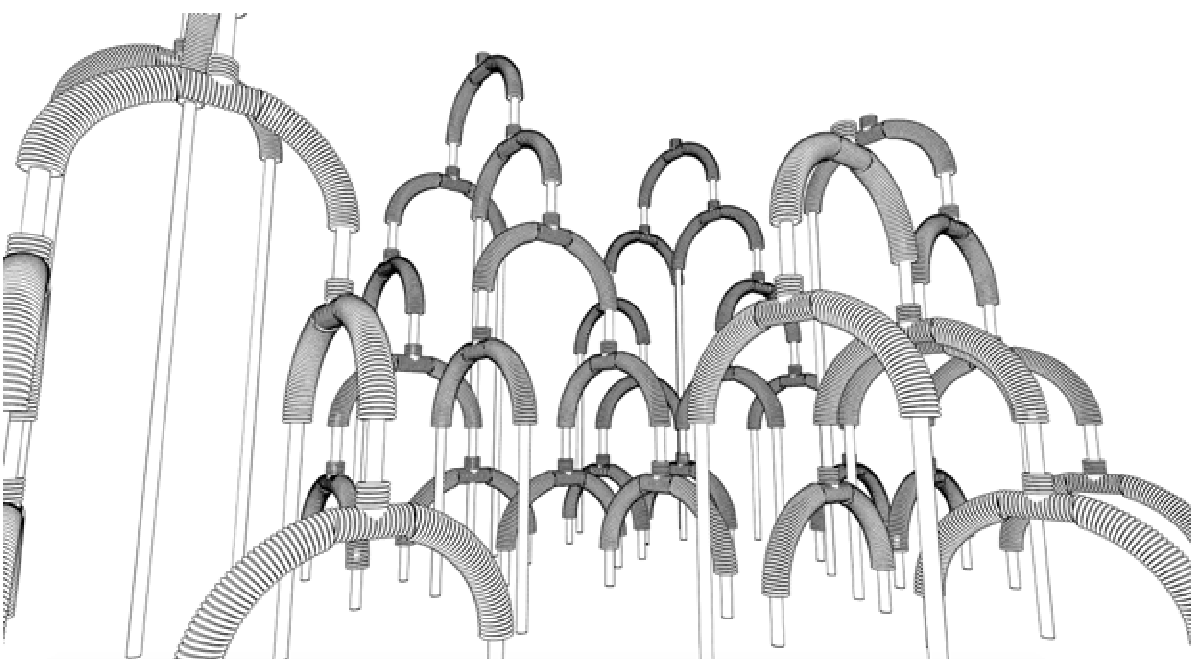
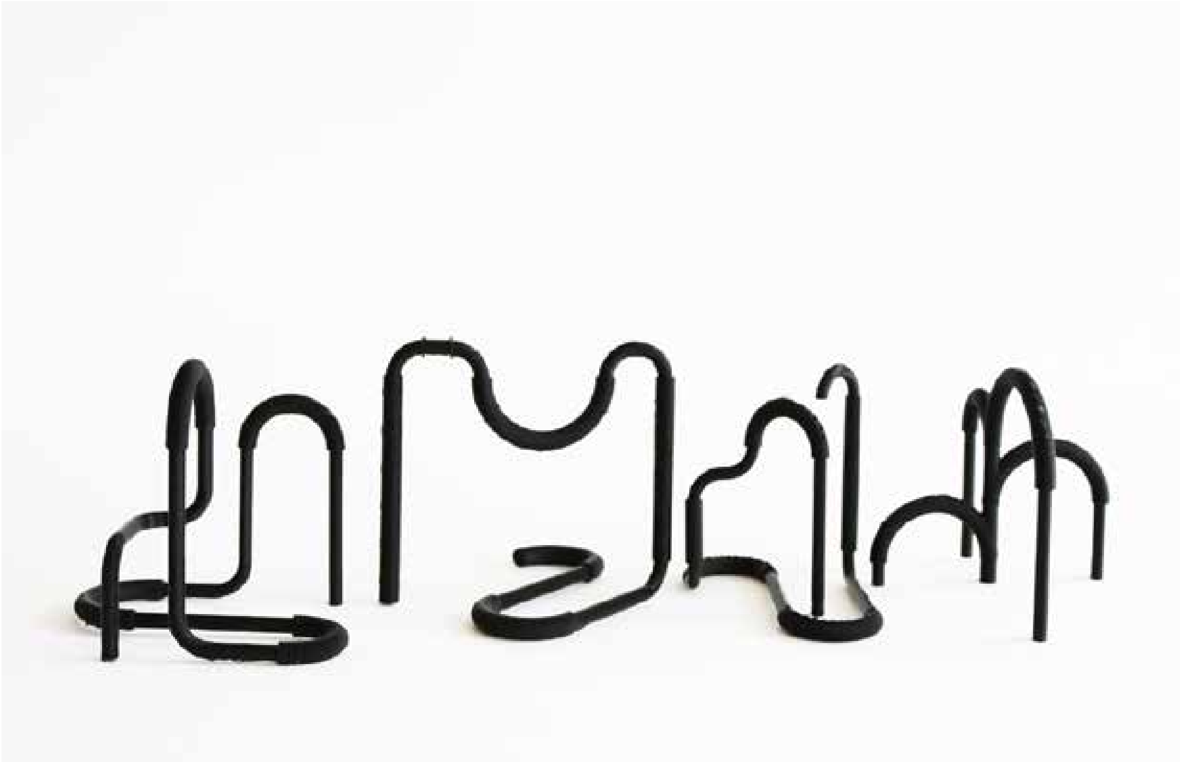


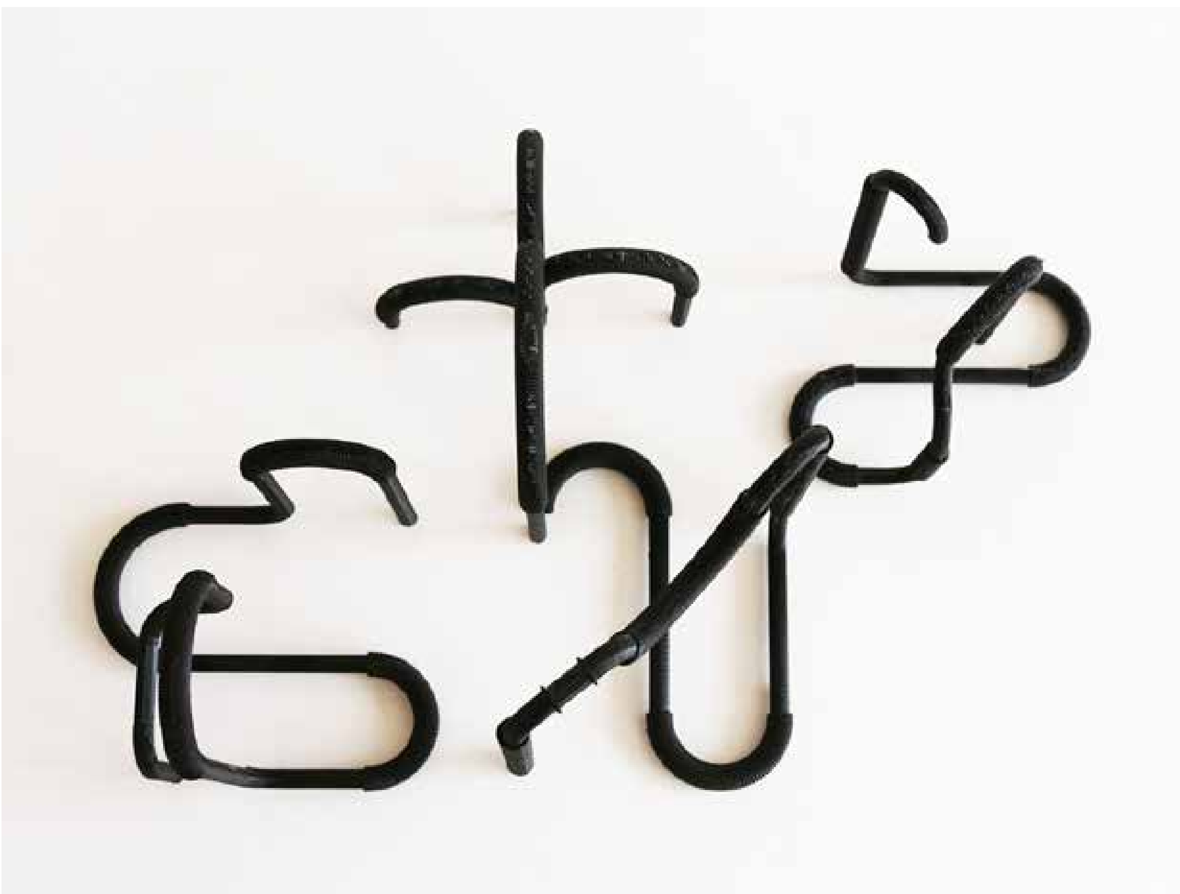
Figure 36–37 (opposite page): Speculative environment 002.d. Source: *authors.*

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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