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Drawing *Out* by Drawing *Into*: Representation and Partnership in a Design-Science Collaboration

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Abstract

“Synthetic Aesthetics” was a two-year experimental, interdisciplinary project that supported six partnerships between synthetic biologists and artists and designers. Each group sought to accomplish two tasks: build an interdisciplinary partnership and construct a joint representation. In this article, I explore the relationship between partnering and representing in one of the six partnerships: a collaboration between an architect and a synthetic biologist. I describe David Benjamin and Fernan Federici’s work on the self-organization and structural growth of xylem cells, and their pursuit of graphical and mathematical representations of so-called biological “logic.” I analyze the case study using two frameworks in unison. The first, from research in STS, explains representation as a social accomplishment with ontological consequences. The second, by pragmatist John Dewey, describes representation as drawing *out* and drawing *into*: selecting and extracting out of the world, and molding and installing into human artifice. I study Benjamin and Federici’s work as two acts of drawing *out* by drawing *into*: constructing and representing “logic” by forming a partnership to do so; and building a partnership by jointly forming a commitment to the existence of that “logic.” Doing so also involved ontological labor: making biological “logic” and rendering cells intelligible as products of rational mechanisms (as logical cells). Thus, representing and partnering are mutually enabling, mutually dependent and capable of ontological accomplishments. The lesson is useful to STS, a field increasingly concerned with art and design as topics of study and potential partners in work.

Keywords

STS; representation; art; design; synthetic biology; architecture

Introduction

In 2010 and 2011, I participated in “Synthetic Aesthetics,” an interdisciplinary, multinational project in art-design-science collaborations. “Synthetic Aesthetics” investigated design in synthetic biology—a young but prominent field in biological science and engineering—by organizing and supporting six partnerships between synthetic biologists and artists and

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designers. Each pair set out to build a distinctive team and to create correspondingly distinctive representations. Here I examine the relationship between partnering and representing, which I argue are mutually enabling and mutually dependent.

The team, their representations and the things represented come to be as interwoven social accomplishments. As evidence I present one collaboration from “Synthetic Aesthetics”: a partnership between the architect David Benjamin and the synthetic biologist Fernan Federici. The pair set out to represent what they came to term biological “logic.” Only through partnership did the team posit and represent “logic,” and only by committing to the existence of “logic” and representing it did they make possible and sustain their partnership.

I analyze Benjamin and Federici’s undertaking using two sets of theoretical tools. The first, compiled from writings in science and technology studies (STS), presents scientific representation as a social accomplishment with ontological consequences. The second, by pragmatist philosopher John Dewey, affords an understanding of artistic representation as an act of extraction and installation. Just as Benjamin’s artistry and Federici’s science worked in concert, so too each theory forms part of my analytic framework. Dewey’s work on art and aesthetics delivers a unique conceptualization of representation, new to STS. STS arguments lend greater sociological substance to Dewey’s pragmatism and supply crucial ideas about ontology.

I begin with an overview of Benjamin and Federici’s project. I then use the case study—in ever-increasing detail—to introduce STS arguments and Dewey’s philosophy. In the process, I employ those ideas to analyze the partnership. I conclude by considering the usefulness and relevance of my framework.

Benjamin and Federici

Synthetic biologists routinely use the term “design” and related tropes (such as “*rational design*”) to describe and champion their work. “Synthetic Aesthetics” enrolled other kinds of design practitioners to investigate what “design” means for the field, what it entails and how it may exist in practice (Ginsberg et al. 2014). We—the organizing team of two synthetic biologists, two social scientists and one critical designer—funded six partnership spanning diverse forms of art, design, science and engineering. Participants carried out reciprocal exchanges between lab and studio, and were afforded freedom to set their direction, craft their work and produce their choice of results. As one of two social scientists on the project I carried out ethnographic observations and conducted interviews with the partners. Jane Calvert, my fellow social scientist and STS researcher, did the same. My academic training and work in STS defined my methodology and analytic perspective, but I am also trained in drama and acting. I believe this artistic background greatly informed my understanding of the pairs’ work, particularly with regard to the process of group collaboration working toward a shared artistic accomplishment.

I focus on the partnership between David Benjamin, a New York City-based architect and Columbia University professor, and Fernan Federici, who at the time was a synthetic biology postdoctoral researcher at the University of Cambridge.

Benjamin directs the Living Architecture Lab at Columbia University, which explores innovative perspectives on technologies for architectural design. His work includes the use of genetic algorithms, evolutionary computing and experimental modeling tools (Benjamin 2012; Keough and Benjamin 2010). Broadly, he seeks to identify and harness useful computational processes for producing novel and compelling design permutations. Benjamin describes himself as always “trying to be a little bit of an outsider,” both philosophically and technically, and stresses his keen drive not to “become so technical and specialized that I lose the ability to re-imagine things completely.” His openness and enthusiasm for new and strange contributions to architecture greatly served the partnership, as did his willingness and excitement to learn.

Federici investigates plant morphogenesis and self-organizing biological systems (Rudge et al. 2013). He has worked extensively on microscopy and imaging technologies (Federici et al. 2012; Maizel et al. 2011), including those that Benjamin and he used in their collaboration. His considerable skill with these methods and instruments helps explain the widespread attention his images have gained both inside and outside the biological sciences (Osterrieder 2013; Parsons 2012).² Unlike other synthetic biologists Federici views the potential of the field expansively: “[synthetic biology] shouldn’t be just applied to like, engineering and science, it could be applied to many different things like art.” He also has a great passion for teaching and hopes to use lessons from his work with Benjamin to bring attention to synthetic biology in Argentina (his native country) and the rest of Latin America. Accordingly, he trained Benjamin enthusiastically in synthetic biology basics and devoted great energy to learning architecture from him.

Benjamin and Federici’s interdisciplinary work used imaging tools from biology and modeling tools from architecture to examine self-organization in plant cells. The two photographed the natural construction of plant cell structures and then developed graphical and mathematical models of that growth. At the heart of the work was the representation of biological “logic,” a concept specific to their partnership.³ Federici described this “logic” as “the underlying mechanism... rendering [plant cells’] shapes and these patterns.” That is, biological “logic” gives direction to the process by which certain plant cells grow structures. It also underlies the team’s views of cells as “direct problem solvers”: an ontology of “logical cells” (my term) (Benjamin and Federici 2014: 154).

The Project

Benjamin and Federici began at the Haseloff Laboratory in Cambridge, where the latter was carrying out his doctoral studies. The first challenge was to identify commonalities such as shared interests and abilities. Federici and Benjamin succeeded faster than the other five “Synthetic Aesthetics” teams. Federici argues that they enjoyed “a unique position” due to

² A sample of Federici’s work is available through his photostream:

<https://www.flickr.com/photos/anhedonias/>

³ Though the concept may appear similar to some found in philosophical and social scientific arguments about teleology, aetiology and mechanistic conceptualizations in the life sciences, the pair did not consult those arguments at all. Benjamin and Federici’s “logic” follows from their particular partnership; it belongs to them.

plainly clear similarities and mutual concerns. One shared interest was self-organizing systems, which both find compelling, study and employ in their individual work. Federici believes that synthetic biology aspires to find natural mechanisms of self-organization in biological systems; Benjamin engages with self-organization instrumentally, as something to harness for innovative design work. A second shared interest is computerized modeling. Although modeling in biology and in architecture differ in aims and practices, Federici argued that “it’s very similar in a way. So, I think the similarity and the overlapping is with the kind of tools that we use.” Benjamin found the possibilities for partnership to be “right in line with some of the things that I’ve been most excited about in my past research with you know, architectural systems and designing.”

The two chose to pursue instrumental links between synthetic biology and architecture (in the form of computerized modeling), and Benjamin began to learn key details about the laboratory’s work. Federici first provided him an overview of projects, procedures and instruments, starting with “all the visualization tools because for an architect it’s very important to see what kind of tools we use.” Federici demonstrated how the researchers:

... use visuals for communication, how we use visuals for hypothesis tests, how we use mathematical modeling for [developing] a framework where we can have a new hypothesis and test them and generate more like, prediction hypotheses.

Federici presented his work and his space by way of his instruments, and used those instruments to develop their common links. Months later Benjamin would do the same in New York. The architect also carried out basic “wet-work.” Federici believes that “it was very productive for David to do some pipetting,”⁴ in order to experience the transition from idea to process to product and to “see what equipment [synthetic biologists] use.” Again, instrumentation was vital.

Benjamin simultaneously worked to immerse himself in the laboratory community, using lectures and seminars about synthetic biology to learn more about the field. He sought anything that would “expand your mind and the way you might think about things.” Each talk gave Benjamin “so much food for thought” that he would “continue to think about it for several days.” Those thoughts and questions became part of the day-to-day work of the partnership because they led Benjamin to ask Federici things important to his understanding of the field. Benjamin also happened to be preparing teaching materials for an upcoming architecture class, which helped him to “translate a lot of what I had learned or maybe apply a lot of what I had learned to kind of my own way of describing things.”

Benjamin and Federici discussed at length ways to partner biology’s understanding of structure with architecture’s fundamental concern for structure. Conversations and collaborative

⁴ Pipetting is a commonplace laboratory practice, consisting of drawing a specific quantity of liquid from a container and transferring it to a different container. The instrument employed is called a “pipette” or “pipetter.” Federici is expressing his desire for Benjamin to carry out even very basic laboratory practice, and to get his hands “dirty.”

work at Cambridge produced a focus on the mechanisms controlling biological growth. Federici and Benjamin chose to observe xylem cells, which help construct and give structure to some plants' vascular system by producing a form of "exoskeleton." The cells' growth displays qualities of self-organization:

Xylem structures are rendered in characteristic patterns that seem to vary according to the size and shape of the cells. Thus, the process of pattern formation in xylem cells can be seen as a "morphogenetic" program—it renders form (structural support) in response to the physical conditions of its environment (Benjamin and Federici 2014: 144).

The team placed xylem cells on microfluidic plates and introduced artificial boundaries and envelopes around the cells. They then induced the cells to grow and form their "exoskeleton" structures within the boundaries constructed by the pair. In a sense the team posed a structural problem and watched the cells produce a solution. As the cells grew the residents used confocal microscopy and photography to document the process and its outcome.

The pair's time at Cambridge came to an end. Before moving their work to New York and carrying out the reciprocal visit, Benjamin and Federici took a short break. The latter returned to his native Argentina and took time to "barbeque, play football, go fly-fishing [and] stay in the mountains." He believes that his holiday enabled him to reflect on and make sense of their work at Cambridge. The pair maintained contact, and Benjamin sent Federici "web links to papers or precedent projects or photographs of architectural examples." He aimed to establish a "different mode of working together," one closer to architecture.

In New York, Benjamin set out to give Federici a "specific flavor" of things concerning architecture that he had mentioned in Cambridge. Most important was a sense of how architects "think about the design process." Benjamin demonstrated his understanding of architectural experimentation and the particular methods with which he makes decisions about design. He also involved Federici in some classwork in order to achieve the same end. Because his research and teaching focused more on process than they did on final form, those demonstrations fit well with the pair's concern with instruments and methodology. During this time, Benjamin recalled, they "were continuing negotiating and working through ways that our project ideas can be relevant and interesting to both of us." Teaching and learning again contributed to team building.

Benjamin also scheduled a series of meetings with different professionals involved in the design and construction of human structures, including material experts and structural engineers. He intended the meetings to help drive the team's project forward, but they also exposed Federici to "the type of moving a project forward that I would do."

The team had departed from Cambridge with a collection of images documenting the growth of xylem "exoskeletons." In New York, the two put computerized modeling to use. Just as Benjamin had experienced laboratory "wet-work," Federici was able to "play more with the software that David [uses]." He learned about and made use of *Catia* and *modeFRONTIER*, two software packages Benjamin employs in his architecture. The pair used their photographs to create computerized three-dimensional models of the xylem structures at different times. They

translated these first graphical models into point-vector models. These allowed the pair to derive datasets that represented the process of xylem growth numerically. That is, Benjamin and Federici quantified the structures' growth. The pair then ran the growth model dataset through *Eureka*, a computer program for deriving mathematical equations that describe a given dataset. Together those equations constituted a mathematical model of the process by which the xylem cells produced their structures.

At this point the team and its cells had traversed an extensive and heterogeneous chain of representations. In Cambridge, photographs recorded the xylem cell's growth. In New York, the photographs became a 3D graphical model, which became a network of points and vectors, which became a numerical dataset, which delivered a mathematical model. The end-result was a computerized representation of cellular problem solving: a series of equations and models that represent the underlying mechanisms of xylem structural formation. Put differently, the team created equations and models that capture the "biological logic" and describe the logical cells the two posited in partnership.

The Social Character of Benjamin-Federici

Many authors who identify with and contribute to STS have written extensively on representation in scientific and technological research. One reason is the importance of representation in such work. Michael Lynch writes:

... even the most "normal" of sciences continue to develop novel modes of representation and intervention. The daily struggle to achieve representational adequacy, to sort out signal from background, and to debug techniques and instruments, makes the natural science laboratory a particularly interesting place... (1991: 207).

As a result STS offers many useful perspectives on representation. Common to them is an understanding of representation as social practice and of representations as underdetermined, contingent and functional. Particular to some is the compelling and useful notion that representations give rise to that which is being represented. That is, they have ontological potential and effect. Such ideas do especially well in demonstrating the social character of Benjamin and Federici's work and products. I will not rehearse and reargue those ideas, but rather explain and employ them.

Representations are Underdetermined, Contingent and Functional

Representational practices and their products are underdetermined. There exists no self-evident or deterministic manner by which worldly entities and phenomena become representations, because things "out there" do not suffice to create those representations. Scientists and technologists must contribute something further to make representations work. That something further reflects the particularities of the field, its practitioners and their immediate research objectives. Researchers must purposefully make choices about what and how to represent.

The relationship between xylem cells in the laboratory and computerized models in architectural software is neither self-evident nor self-actuating. No satisfactory account of the pair's work can treat it as such because no straight path from xylem cells to computerized models exists. Benjamin and Federici's representations do not reflect simply the natural entities involved; they also embody social contingencies like the team's interests, goals, expertise and instrumental capacities.

Benjamin argued that the team's choice of focus followed from asking what "would be really interesting to both of us and potentially play on... the unique things that the two of us are bringing to the table." As I described above, instrumental commonalities became a prominent feature of the partnership. Benjamin said:

... the mathematical model and the computation, the use of a computer to simulate things is a real, is a really natural common ground for us, based on our interests and also relations to our different fields at the time.

Benjamin recalled that the crucial connections were "the confocal photographs that Fernan has... and my experience with optimization and basically genetic programming." The choice of representations followed from their attempt to forge a collaboration, and from Federici's decision to teach Benjamin about synthetic biology through instrumentation. It did not develop in a deterministic manner, but rather through an involved process of partnership.

As something underdetermined, a representation's content is shaped by physical and social contingencies. Clearly there exist material limits on what can form part of any particular representation. A photograph doesn't capture all visual characteristics of an object from all possible perspectives, and it doesn't capture the feel or smell or sound of that object at all. Every representational instrument has limited capacities because of inexorable physical constraints and intentional design choices. A lens's angle of view and the design of the imaging sensor limit the representational capacity of a camera. Social contingencies also shape content. For instance, practitioners do not use all things captured in representational practice when making their final representational product. Lynch argues that diagrams based on photographs "exhibit a limited range of visible qualities in comparison to the photographs. Unused visibility is simply discarded" (Lynch 1988: 209). Practitioners exclude some things captured through representational practice and emphasize others following the epistemic task at hand. Certain elements may be present in one context and collective and not another, in service of one goal and not another because capturing the totality is not only impossible but also most often unnecessary and frequently counterproductive.

In New York, Benjamin and Federici pondered how to translate their Cambridge photographs into a computerized model. Benjamin noted:

... we're trying to figure out what are the essential characteristics that we want to represent in this computer model, which will be maybe metaphorical but also an actual wire-frame version of reality, not just the [xylem structure] which is honed down to its essence.

Choices about what facets of the xylem cell photographs to include in the computer models and which to discard followed from their commitment to biological “logic” and their desire to harness it. The computer models are partial representations because not all elements of the cells are photographable, and not all things photographed were used to make the models. Only certain quantifiable components of the models are represented in the numerical dataset: those relevant to “logic.” The dataset exists only to enable developing the equations. The xylem cells themselves did not determine what was excised, emphasized or added to the various representations. Benjamin and Federici together made those choices within the context of a shared project.

Representations are representational only within systems of social relations, practices and knowledge. Morana Alač argues:

... the features of fMRI images become perceivable in terms of the work, structured by the disciplinary expectations and the routine practices that have developed for the accomplishment of the task... (2008: 495).

Representations’ adequacy is similarly contingent, because “‘reality’ is not an entirely independent standard of reference separate from representational work” (Lynch 1991: 208). Practitioners evaluate representations in a manner consistent with the conventional practices of their particular collective. Representations that one group may consider satisfactory, another group in different circumstances may think inadequate.

For Benjamin a satisfactory model would capture the performance criteria of xylem cell structures; it would also be accessible to and useful for architects. He said:

From my point of view as an architect, it will be helpful if that software can be legible to architects, can be usable, maybe even can be file formats that are exported from these synthetic biology software models, could be able to be imported into an architecture software.

The quality of the pair’s representations was contingent on the practices, expertise and instruments of a specific community, and not how close they came to replicating reality.

Finally, STS authors argue convincingly that scientific and technological representations always serve functions; they exist as “constituents of a work process. They are *used*” (Lynch 1991: 211). Intended functions and the overarching venture shape choices in representation. For example:

[Brain scans] reify the brain as a locus of control and as a site of neurological, neuropharmacological, and neurosurgical intervention, or even self-improvement (de Rijcke and Beaulieu 2014: 131).

Brain scan representations situate human brains within a series of work processes and enable intervention for purposes like diagnosis and treatment.

Benjamin and Federici envisioned particular functions for their images, models and quantitative data. Having developed a way to represent biological “logic” using architectural modeling, they could present scientists with new instruments for biological research. Federici said:

If we can plug-in our design process, some kind of genetic programming or genetic algorithms where we, you know, you want to say, “I need to create a system that could communicate with these plants,” so I define my objectives and say, “OK, tell me what will be the best solution given the parts or whatever I have.” I think that’s something that could be really, really interesting for synthetic biology.

Many synthetic biologists seek new tools and processes for building genetic constructs with predictable and reliable functionality. Federici argued that by employing the computational instruments that Benjamin uses in his architectural practice, synthetic biologists may improve their capacities for biological design. Importantly, representations can function to coordinate practitioners and their activities. Annamaria Carusi argues that visualizations in computational biology work at:

... establishing shared modes of seeing, both literally and figuratively, which would go a long way to building an intersubjectively shared framework for trust on the basis of which subjects can exchange reasons in support of claims, demonstrate trustworthiness and give their testimony authority (2008: 248).

A representation and the practices that produced it may enable the building and shaping of social relationships.

The concept and representations of biological “logic” helped enable and drive the interdisciplinary partnership responsible for the existence that such logic ultimately achieved in the context of the partnership. Benjamin summarized the pair’s starting point as a desire to explore “the way that architects could start to really use synthetic biology as part of a design tool.” As I described, they identified shared aims, challenges, tools and practices. For example, Federici argued:

... in science you are trying to create models to describe and describe a problem that allows you to predict or generate new hypotheses and test them in, and David uses computers to like, solve problems.

Benjamin and Federici used representations of “logic” to develop familiarity, collegiality, shared understanding and a common end-goal. One function of the team’s representations—perhaps the first function—was to make their share of “Synthetic Aesthetics” truly collaborative. “Logic” functioned as an interdisciplinary junction.

Representations Create the “Out-There”

Everyday ideas about representation carry the assumption of “the antecedent existence of something (some person, object, or entity) that is being represented” (Woolgar 2014: 329). On that line of reasoning, although humans develop and employ representational tools, that which they represent exists as a standalone actuality. However, some authors challenge this common assumption and argue that representational practices play a key role in giving rise to the thing “out there”: “to make things visible is to make them real, or to try to” (Wise 2006: 81).

Consider first that representations often “capture” entities and phenomena not otherwise accessible to human perception. Lynch argues:

Biologists’ representations are not transparent windows on an independent reality since in many fields of biology, visual and other form of representation are the only way phenomena can become materially witnessable (1991: 208).

One cannot circumvent representational practices and tools used to make things “picturable, graphable, mappable, or measurable,” (ibid.) because absent them there exists in effect no “out there, real thing” to perceive. Put otherwise, representation has ontological capacity; by representing, one can create being.

Xylem cells are not visible to the human eye; we cannot see them in the common sense of “seeing.” Benjamin and Federici employed techniques and instruments like confocal microscopy to image the cells, and then used computer modeling software to develop three-dimensional graphical models. In New York, the team even used a 3D-printer to build physical models of the xylem structures, enabling a form of tactile perception. Moreover, biological “logic” does not exist in space and time; there is nothing to perceive in the first place.

Second, and more interestingly, social institutions play necessary roles in making entities and phenomena “witnessable.” The common notion that representation captures an antecedent reality carries with it the assumption that the transfer of reality to representation is “untouched by human hands and uncontaminated by preconceived ideas” (Lynch 1991: 213). However, scientific and technological representations invariably rely on conventions. For example, a choice to image an expanse of ice may follow from consensus about increasing global temperatures and shared beliefs that particular images of particular objects can represent that phenomenon and make desired interventions possible.

Benjamin and Federici’s representations created something entirely new and wholly dependent on the partnership and its work: biological “logic.” While others may have posited comparable ideas, the pair’s “logic” is theirs alone. So too is their understanding of xylem cells as logical cells.

First, biological “logic” depends on a belief—unique to Benjamin and Federici’s joint work—that biological “logic” exists. Without this shared commitment, searching for that “logic” would be nonsensical. The commitment belongs uniquely to this partnership in the sense that it served to answer their particular ambition for building a collaboration using shared tools. In working to establish their links, Benjamin and Federici developed a strong and shared opposition

to what they term “bio-mimicry.” The two define “bio-mimicry” as the copying of biological shapes for architectural projects with no regard for the biological processes underlying the forms. Federici said:

... if we just take the cells, the shape of the cells and go all the way to create a building, solving, even if we solve the scaling-up problems, like saying what material we will use that has the same kind of properties in a bigger scale, similar to what cellulose is doing... it's not very interesting...

In addition to lacking appeal for this reason, “bio-mimicry” is a form of dishonesty, argued the pair. Architectural replication of biological form can suggest some type of thorough link to the unique qualities of living things, but if the design of a building makes no use of the biological past shape it fails to engage with biology in a meaningful way. That is, it fails to accomplish the partners’ core ambition: unveiling and appreciating the processes behind the biological end-product.

Second, Benjamin and Federici defined “logic” using experiments unique to the team. Their shared conviction regarding “bio-mimicry” informed not just the driving motivation to seek biological “logic,” but also how Benjamin and Federici engaged the xylem cells: as logical cells. Their choice to pose structural problems using artificial boundaries followed from their concern for self-organizing structures and their shared belief that those structures are products of a “logic.” Accordingly, they did not end their work with the first graphical models (which captured only form) but pushed forward to datasets and equations (which captured process and therefore “logic”). Those representations gave “logic” existence, and made xylem cells “witnessable” as logical cells. That is, Benjamin and Federici’s representations gave being to their “logic” and new being to their xylem cells.

John Dewey, *Drawing Out and Drawing Into*

In *Art as Experience*, the pragmatist philosopher John Dewey explains artistic representation as a venture in drawing *out* from the world and drawing *into* a system of human artifice. In making their work artists select, extract, shape and install things of the world:

... objective material becomes the matter of art only as it is transformed by entering into relations of doing and being undergone by an individual person with all his characteristics of temperament, special manner of vision, and unique experiences (Dewey 2005 [1934]: 299).

Representation is *by* the artist and *of* the artist, and involves real-world materials and practices. For instance, a painter employs brushes and colors in lived physical action to deliver something of her creation. In pragmatist fashion, Dewey rejects abstract conceptualizations of art and aesthetics in favor of explanations grounded in human experience. The position is one

similar to that of STS with regard to science and scientific knowledge. This initial similarity suggests potential for partnering ideas from the two fields.

Dewey introduces “drawing *out*” and “drawing *into*” as concepts and actions that tie together representational practice and representational artifact:

[Drawing] is not a means of assisting recognition by means of exact outline and definite shading. Drawing is drawing *out*; it is extraction of what the subject matter has to say in particular to the painter in his [sic] integrated experience. Because the painting is a unity of interrelated parts, every designation of a particular figure has, more over, to be drawn *into* a relation of mutual reënforcement with all other plastic means—color, light, the spatial planes and the placing of other parts (2005 [1934]: 96).

An artistic representation is not a signpost directing the viewer to something standing in the world, nor is representation an imperfect replication of that something. Instead representation is a situated practice of transfer and transformation. Artists concurrently take from the world and implant into a product of human artifice. Both constitute acts of human practice and products of “the ordinary forces and conditions of experience” (2005 [1934]: 2). As such, representation is open to empirical study of the kind I employed throughout “Synthetic Aesthetics.”

Dewey’s drawing *out* and drawing *into* help form a useful framework with which to interpret Benjamin and Federici’s joint work. The pair chose to draw *out* aspects of the cells’ behavior and structures that served their project. Rather than attempt to copy what they saw, the two recast it selectively for the purposes of their partnership. The overarching aim was to draw *out* “logic,” which they did by selecting and extracting things such as the geometry of the cells’ exoskeleton and its change over time. Those were then drawn *into* “products of human artifice”: models, data and equations, all tied through various relationships of mutual-dependence. In doing so, Benjamin and Federici brought into being “logic,” and gave new being to their cells—both ontological accomplishments.

Seemingly simple as Dewey’s “drawing *out*” and “drawing *into*” may be, they form a useful perspective on representation, one enriched by sociological ideas from STS authors. *Art as Experience* does not neglect the social and cultural. Dewey argues that aesthetic study of an artistic artifact demands concern for “what the people into whose lives it entered had in common” (2005 [1934]: 3). Art, like architecture, sits inside, is molded by and conveys tradition, the “enduring values of collective human life” (ibid.: 230). Nonetheless, Dewey’s conceptualization of art and artistry ultimately hinges on the individual. He writes:

A work of art no matter how old and classic is actually, not just potentially, a work of art only when it lives in some individualized experience (ibid: 113).

Social tradition matters, but only insofar as it is channeled through the artist and “the alembic of personal experience” (ibid.: 86). While artists are most certainly shaped by “the cultures in which they participate,” (ibid.: 339) the “human contribution” to art and artistry is

“those aspects and elements of esthetic experience that are usually called psychological” (ibid.: 255). Dewey even explicitly notes that his concern for the collective is not that of a “sociologist in search for material relevant to his purpose” (ibid.: 3). Rather, he introduces and develops drawing *out* as actions by a single artist, whose individual experiences and “individuality of vision” (ibid.: 85) influence her choice of things to select and extract. Drawing *into* involves an arrangement of interdependent and mutually-reinforcing “plastic” parts and no other kind. Analytic tools developed by authors in STS offer a “missing social” in Dewey, and demonstrate how Dewey’s drawing *out* and drawing *into* can tie together not just representational practice and representational artifact, but also representational *group*.

Drawing Out “Logic”

“Drawing *out*” involves selection and an extraction. The artist locates “potencies in things” that have “significance and value” (2005 [1934]: 192); she then pulls those from the world to produce artwork. Importantly, drawing *out* is neither blind nor generic. It reflects and follows particularities specific to the artist such as her interests, tradition, methods and context. Dewey writes:

The painter did not approach the scene with an empty mind, but with a background of experiences long ago funded into capacities and likes, or with a commotion due to more recent experiences. He comes with a mind waiting, patient, willing to be impressed and yet not without bias and tendency in vision (2005 [1934]: 91).

The artist selects and extracts things particular to her and to her work. The artist draws *out* in her way for her ends.

STS authors argue that representational practices are responsible for making particular things “witnessable” in particular ways, including things not otherwise perceptible. The world presents us with a barrage of empirical experience. Constituting an entity or phenomenon from that barrage involves acts of selection and extraction: acts of drawing *out*. This drawing *out* occurs within a particular community, enrolled in a particular undertaking, employing particular knowledges and methodologies, and working within particular times and material spaces. Scientists draw *out* the thing in representation in accordance with shared commitments, beliefs, practices and instruments. Drawing *out* is a coordinated social practice.

Only in partnership did Benjamin and Federici’s seek to draw *out* “logic” and only collaboratively did they develop the mechanisms for doing so. The end-result had a character specific to the particularities of this interaction. Drawing *out* “logic” was a process of socially constructing “out-there.” Benjamin and Federici shared a belief that there exists such a thing as biological “logic,” and together portrayed xylem cells as products of such a “logic.” The pair gave being to “logic” and logical cells as a central part of their efforts to build a partnership. The “potencies in things” of “significance and value,” such as xylem self-organization, were selected and extracted collectively, not individually.

Having posited the existence of “logic,” Benjamin and Federici drew it *out* with tools and methods particular to their collaboration. The two developed a system for presenting xylem cells with structural challenges in order to encourage behavior driven by biological “logic.” The method followed from the team’s shared concern for self-organizing structures. Moreover, Benjamin and Federici used microscopic imaging and computerized modeling as representational instruments, both because these were tools and expertise each brought to the project and because they served to construct the instrumental links fundamental to the partnership. Tools for drawing *out* both reflected the team’s intention to build a partnership and served to execute that intention.

Lastly, Benjamin and Federici molded the product of their drawing *out* in accordance with their shared work. The two represented “logic” as a series of computer models and mathematical equations, and cast xylem cells as products of that “logic,” because these had meaning within the scope of the team’s project. Just as Dewey argues that the selection and extraction of things during artistic representation has meaning only within the artist’s “integrated experience,” drawing *out* “logic” had meaning only within the integrated experience of a biologist concerned with self-organization and biological structure and an architect concerned with computer-assisted architectural design.

Drawing into a Partnership

“Drawing *into*” is a shaping and an installation of the drawn *out*. When drawing *into* the artist shapes what she draws *out* to fit a system of interdependent material parts. Indeed, only by such shaping does something of the world become “the matter of art” in the first place (Dewey 2005 [1939]: 299). Crucially, the artist shapes the parts and builds the system in a way particular to her and to her work. As with drawing *out* she draws *into* in her way for her ends.

STS authors argue that representations represent only insofar as they possess a particular social standing in a particular collective. Practitioners first draw them *into* a system of social relations that enables and sustains those representations’ intelligibility. Thus, representations consist of entangled material *and social* components. Drawing *into* involves a process and a product, both of which belong to the collective.

Benjamin and Federici drew *out* biological “logic” by drawing *into* their partnership. Their collaboration was not simply that of a group but of a *particular* group whose processes and products were of *this* architect, *this* biologist and *this* partnership. Drawing *into* the collective involved drawing *into* the collective’s particularities, such as their precepts, aims, practices and tools. Benjamin and Federici built and shared a system of ontological premises (biological “logic” exists; xylem cells are logical cells), epistemic commitments (learning about self-organizing structures), methodological persuasions (using computerized modeling) and functional targets (building an architecture-biology partnership; advancing synthetic biology and architecture). What the two drew *out* was shaped to fit and installed within this system of social relations.

Importantly, Benjamin and Federici did not intend their representations of “logic” and logical xylem cells to be ends in themselves. The pair sought to embed those representations in ambitions specific to their partnership. As such, drawing *out* “logic” involved drawing *into* a set of broader enterprises, such as: the interdisciplinary collaboration itself; the transfer of

knowledge, practices and instruments between biology and architecture; the pursuit of biological knowledge; and the practices of architectural design. For Benjamin and Federici, mathematical renderings of “logic” are one part of an effort to make knowledge and further design. They drew “logic” *into* utilitarian commitments specific to this partnership.

For Dewey, the result of drawing *into* is a construct of interdependent, mutually reinforcing material parts working in concert. Benjamin and Federici’s project demonstrates that the represented—here “logic” and logical cells—is a unity of material *and social* parts, also working in concert. Only within an appropriate partnership does “logic” gain and retain intelligibility. Benjamin and Federici’s graphics, models, datasets, and equations rely on the social relations specific to the pair’s collaboration. For example, the pair’s shared belief that computational tools can serve the study of cellular self-organization, or their commitment to shared instruments and expertise. In turn, the graphics, models, datasets, and equations lent support to the team’s belief in “logic,” their understanding of how it ought to be represented, their choice of practices and tools, and their confidence in the success and value of their collaboration. The material and social parts constitutive of the representation depended upon and reinforce each other.

Drawing Out by Drawing Into

All six collaborations in “Synthetic Aesthetics” undertook to create a team and create a representation. David Benjamin’s and Fernan Federici’s project demonstrates that the architect and biologist’s partnership and representing were mutually-enabling, mutually-dependent and involved ontological work. That is, the team, representations, and things represented were brought into being together. Dewey’s work and ideas drawn from STS together explain the dynamics of these social accomplishments. Drawing *out* and drawing *into* illuminate important ideas offered by the latter, which in turn offer better conceptualization of the social and of ontology.

To Represent “Logic” Benjamin and Federici Built a Partnership

Benjamin and Federici’s “logic,” and everything the pair employed to render it, belong to and reflect the particularities of their partnership. Only by drawing *into* their interdisciplinary partnership did the pair draw *out* their “logic.” “Logic” was ultimately a collective good *by* the team and *of* the team. *To build a partnership, Benjamin and Federici represented “logic.”* The pair posited biological “logic” early in their efforts to establish a working partnership and enable true collaboration. “Logic” served as a node between disciplines and a foundation for the partnership’s subsequent work. Put otherwise, Benjamin and Federici drew *out* their partnership by drawing *into* the concept of biological “logic.”

Thus, the team’s project involved two types of “drawing *out* by drawing *into*.” Benjamin and Federici drew *out* “logic” by establishing a team, and drew *out* the team by committing themselves to the existence of that “logic.” “Drawing *out* by drawing *into*” is a phrasing but the ideas that give substance to that phrasing offer curious and effective tools with which to study

the relationships between building collectives and producing representations. Most important is the notion that the two are mutually enabling and mutually dependent.

Drawing Out and Into Ontologies

“Drawing out by drawing into” also offers insight into ontology. Woolgar and Lezaun argue that the STS “turn to ontology” is a re-purposing of the field’s “longstanding core slogan—‘it could be otherwise’—this time to the realm of the ontological” (2013: 322). Much as earlier work conceptualized knowledge claims as underdetermined by the material world, lacking absolute status and fundamentally conventional, research on ontology understands the being of entities as underdetermined and contingent on social practices. According to scholars Law and Lien (2013), there is no fixed and non-contingent way that things “are”; instead, particular activities of particular groups generate things with particular being. Ontologies “could be otherwise” because contingencies can be and routinely *are* otherwise. My case study and the theoretical framework I have detailed contribute to this branch of STS research. Namely, by illustrating that mutually enabling and mutually dependent “drawing *out*” and “drawing *into*” involve ontological exercises and accomplishments. My argument also expands the analytic potential of Dewey’s work by adding ontological action to his understanding of art and artistry as lived experience.

Benjamin and Federici gave being both to biological “logic” and logical cells. “Logic” exists only in the partnership. Xylem cells and their “exoskeletons” exist in space and time but exist as logical cells as a result of specific ontological labor. As Haraway argues, they are not a “ghostly fantasy” but neither are they ontologically singular (1991: 209). For Benjamin and Federici xylem cells are products of a mechanism called biological “logic.” It was only once the two had interpreted xylem growth in microfluidic channels as governed by “a ‘morphogenetic’ program” (2014: 144) that they were able to give birth and lend substance to the notion of biological “logic.” Representations of “logic” were enabled by an ontology of xylem cells as things governed by rational mechanism. Those representations in turn made the cells “witnessable” in a manner consistent with that ontology. In a sense, ontological construction (of logical cells) and drawing *out* (of “logic”) supported each other iteratively. Drawing *out* has ontological necessities and ontological consequences. And so does drawing *into*.

In *Vibrant Matter* (2010), Jane Bennett uses the example of food to point out that things (even material things) become what they are in engagement, much as Dewey argues that art exists only in experience. The eaten becomes food because it relates to the eater in a certain way. Concurrently, the person becomes an eater because she engages with the eaten in a certain way. In the case of Benjamin and Federici, xylem cells gained their ontology as logical cells because they became engaged with this particular team: a team that chose to study and engage with cells as products of “a ‘morphogenetic’ program.” At the same time, the team came to be what it is by bringing “logic” and logical cells into being. Drawing *into* has ontological necessities and ontological consequences.

Drawing *out* by drawing *into* is ontological. The concept, built from Dewey and STS, gives to the field a novel way of making sense of ontology.

STS, Art and Design

Bringing Dewey and STS together contributes conceptual and analytic tools. It also constructs a tool for self-reflection. In "Synthetic Aesthetics," we social scientists collaborated with various critical and speculative designers (Dunne 2008; Dunne and Raby 2013), even becoming objects of their study and work ourselves. Others in STS have concerned themselves with how we might establish new, fruitful partnerships with art and design for things such as methodological innovation (Born and Barry 2010; Michael 2012a and 2012b). We continue to explore ways to partner with art and design, and to construct shared outputs. We are drawing *out* and drawing *into*. By asking why, how and what we will partner and represent we can carry out this work more deliberately and with greater cognizance (Calvert and Schyfter, in press).

Coole argues that art and design help undermine conventional assumptions about meaning and ontology "by encouraging us to observe the very 'fabric of brute meaning' as it takes shape" (2010: 104). Observing our (ever more numerous and substantial) partnerships with artists and designers as we choose to draw *into* them and as we draw *out* products forces vital self-reflection, and demands well-considered choices about what role art and design might and ought to play in STS.

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