Grounding the Cloud or, Mapping a Digital Metabolism Through Art

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Notions of *cloud-based* data storage, *invisibly-ubiquitous* computing, and *cyberspace* Internet disembodiment have clouded (pun intended) the deep and heavy physical realities of our digital infrastructure. Situating networked digital systems such as the Internet as intangible, virtual phenomena promotes a series of misleading distancings: it removes the digital device from its embedded contexts; it hides the co-evolving, co-constituting nature of the digital's material and operational instantiation; and it excuses the digital from its geophysical implication. For artists, especially those working with and within digital media, these abstractions can provide a dynamic crux for material investigation.

Though the contributors to this issue were asked to reflect on the relationship *between* analogue and digital practices, this article looks at how hybrid digital artworks by such artists as Mitchell Whitelaw, Martin Howse, and Jonathan Kemp provoke a different configuration; it takes seriously the possibility that there is no between and suggests instead that we consider digital and analogue practices to be co-authors of a single project. To facilitate this reconfiguration, the article presents a material-based, process-focused experimental *digital metabology*: a theoretical framework that shifts, as do the artworks here, digital thinking away from terms like 'virtual' and 'immaterial' to remind us that The Cloud—that presumably nebulous space where our data is magically stored—is actually *very heavy*. The digital networks that maintain our cities, our wireless web searches, and our online social networks are in reality strictly tied to their tangible, thickly-wired substrates.[1] In parallel to the artworks presented, this

text attempts to close the analogue-digital distance by grounding the digital within its oft-ignored physical and ecological contexts.

If we understand theory to be a speculative creative practice, enacting and rehearsing its own ideas, the critical digital metabology developed here can be seen to work in partnership with the artworks. It seeks to expose the analogue materialities of *the digital*—a term here used, following established media-theoretical precedent, to signify the universe of digitally-based structures and operations—by following the currents of the digital's structural components, energy expenditures, and residual wastes.[2]

The notion of a digital metabolism is inspired by Peter Baccini and Paul Brunner's project to map a metabolism of the *anthroposphere* by way of analysing its stocks and flows,[3] and by Hannah Landecker's work on post-industrial metabolisms wherein she situates metabolism as 'both a conceptual domain and a set of experimental practices…understood to be constituted by a dynamic web of cellular signals, built by and responding to environmental information.'[4] The argument is not that the digital is biological, just as urban and industrial environments are not strictly biological, but that networked digital systems demonstrate a digitally-instantiated metabolism of their own. In concert with other systems, they operate in perpetual motion to sustain themselves by way of constant material exchange and metabolic transformation.

In order to understand this system and its processes, the digital metabology focuses on the full range of the digital's physical and relational constitution. This framework sees the miners who extract silicon and other potentially noxious minerals to produce digital components; it counts the steady supply of physical labour needed to construct, maintain, and destruct digital devices and infrastructure; it thinks on the level of the human data input required to feed the

system; and it considers how human biology is effected by the toxins and carcinogens released during digital processes. It sees the digital's implication in geophysical metabolisms, looking not only at how the digital's physical footprint—the globe-stretching visible infrastructure of components, devices, data centres, and wires that sit atop and within the Earth—affects the Earth, but also at how its consumption of natural materials—the digital requires rare-Earth minerals, fossil fuels, water, and massive amounts of energy—and its accumulating stocks of polluting waste alter the Earth's composition. By tracking such physical materials, the digital metabology exposes the flawed rhetoric of *immateriality* and reveals the deep ecological embeddedness of the digital network.

When applied to digital artworks, the metabolic framework indicates, following digital/ecological artist Jonathan Kemp, that 'materials are not ontologically independent of the way in which other things mediate them...'.[5] It highlights the importance of the parts and the complex acts and interactions they perform. As digital information specialist Jean-François Blanchette points out, 'however immaterial it might appear…[digital] computing [is] a material process through and through.'[6] Indeed, it is the material structure, Blanchette reminds us, 'that determines the base material conditions under which applications, services, and devices will perform.'[7] It is critical that we appreciate this when thinking about digital systems or we risk ignoring what Blanchette rightly points out are their 'essential dynamics':

> One can envision the difficulties that would arise in attempting to account for architecture without a working concept of the tensile strength of steel, of the durability of concrete, of the density of wood. Indeed, that these materials differ in their physical characteristic registers on the entire ecology of the field…and no meaningful analysis can ignore these differences…Without a basic understanding of the material constraints under which computing systems operate, essential dynamics that animate the built environment of the virtual will remain invisible and unaccounted for.[8]

The digital's materials are fundamentally implicated in the artistic process of making and of meaning-making, and they cannot go untreated. The artworks considered here respond to this—they manipulate the digital medium's speed, efficiency, interactivity, operational expressivity, and capacity for evolution and emergence—to make visible the digital's material contingencies.

Fifty Sisters (2012), by artist and computing researcher Jon McCormack, is a work that uses computational media to naturalise the digital and digitise the natural.[9] In *Fifty Sisters*, oil—a mineral resource derived from plants—is computationally returned to plant form by way of digital mediation.[10] Using digital technology, necessarily powered by electricity from the burning of fossil fuels such as oil, the project translates the corporate logos of the so-called Seven Sisters oil cartel into digital plants. The message is not just that organic raw materials are implicated in the digital's metabolic evolution but that so too are corporations and digital technologies enmeshed in the natural environment's metabolism.

McCormack's process works by way of generative evolution. He inputs a graphic logo into a digital program he designed to mimic evolutionary and biological processes. This program outputs pseudo-genetic digital DNA code, which is then read by a 3D renderer. The renderer then *cultivates* the logo seeds into code-based geometrical 3D offspring with photorealistic plant bodies. Following the digital metabology, these resulting plants are not 'immaterial' as one may be tempted to argue, but are digitally-constituted results of a generative digital breeding in a computational environment.

Figure 1: *Fifty Sisters*, exhibition image *Ars Electronica*, 2012. Image courtesy the artist.

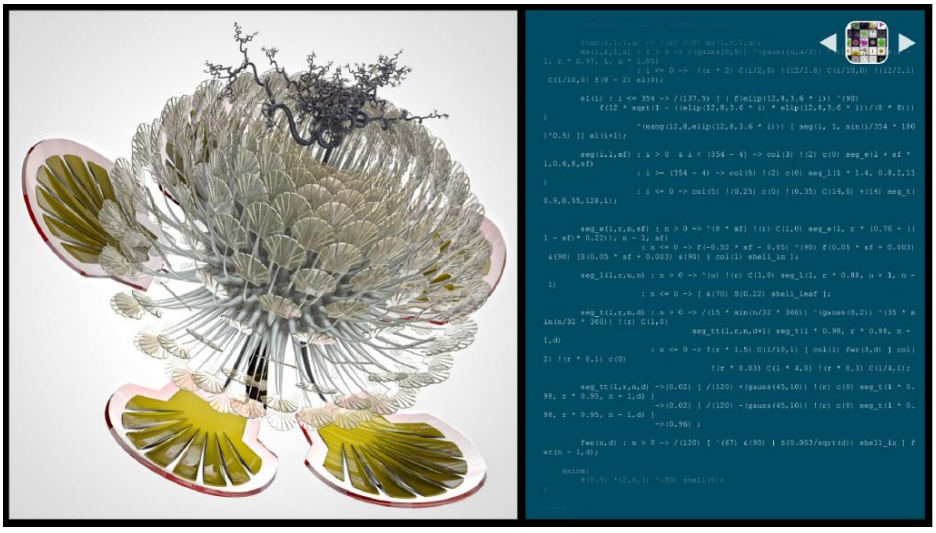


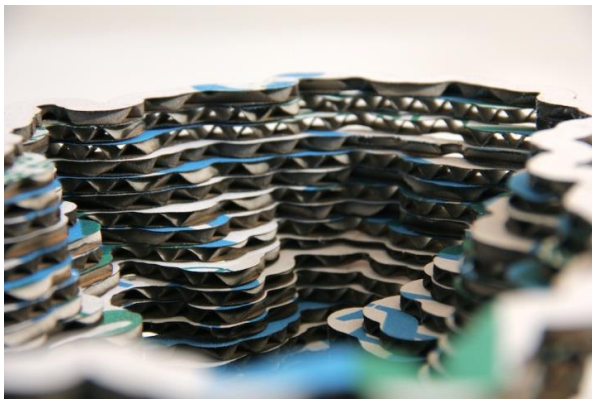
Figure 2: *Fifty Sisters*, exhibition image *Ars Electronica*, 2012. Image courtesy the artist.

As is evident in the exhibition images included here (Figures 1 and 2), the oil logo is sometimes prominently visible and other times entirely abstracted. The manifested differences are the result of an emergent co-authorship between the logo seeds, the programmed plant morphology protocols, the 3D renderer, the computational software, and the energies required to

power the process. Each element contributes properties and complexities, and each leaves traces on the final plant product.

By transplanting oil logos, quasi-representations of petrochemical extraction, into the digital environment and then into printed artefact, *Fifty Sisters* participates in the digital metabology by visualising, and in a sense reterritorialising, the digital within its natural ecological contexts. It artistically (re)embeds the material into the digital—and then the digital back to the material—to highlight the dynamic geological and biological metabolic entanglements that characterise the *nature* of the digital.

Local Colour (2011), by artist and academic Mitchell Whitelaw, plays with deeper dimensions of constructive relationality to interrogate the physical materialities of the digital. In his work, a trans(material)formation takes place: computational output is crafted into a physical structure through digital fabrication.



Figures 3 and 4: *Local Colour*, exhibition images *ISEA*, 2011. Images courtesy the artist.

Local Colour demonstrates Whitelaw's 'transmaterial' design process. This 'transmateriality', for Whitelaw, 'emphasizes the continuity between computation and material environment',[11] and his works explore this continuity—this erasure—of the boundaries between digital and analogue.

In *Local Colour*, a laser cutter, programmed using generative software, cuts terrace-like layers into reclaimed cardboard boxes to produce a bowl-shaped, digitally-incorporated physical structure. The bowls are designed through an interactive, iterative technique whereby the cardboard material, the fabrication software, and the algorithmic process coordinate to 'grow' the designs. He says:

> At times, material specificity 'reaches back' into the digital process. This tangles the simple causality that fabrication often implies, where matter is a passive thing to be formed. In this project the material feeds back to cause the digital form even as the digital form ultimately shapes the material. For example the dimensions of the bowls are constrained by the source boxes (as well as the laser cutter). The number of slices—and so the height of the bowl—is also constrained by the material available; again this reaches back to inform the algorithm generating the cutting instructions.[12]

The digital here enacts a co-dependent feedback loop with the physical material of the cardboard substrate; the digital algorithm responds to the box, and the box responds to the digitally-logical fabricator. Together, they engender an original sculptural form. It is perhaps no coincidence that the bowls resemble the quarries from which the minerals required to produce the digital are extracted. *Local Colour*'s metabolic transmateriality loops full circle, not just rhetorically, as is primarily the case with *Fifty Sisters*, but also materially as the work's physical parts and its meaning-making gestures cycle from Earth to digital to bowl to Earth again.

For Whitelaw, digital fabrication uncovers the already material nature of all things digital. Fabrication, he says, 'applies the functional logic of the digital to its materials…',[13] initiating a cycle whereby digital 'patterns traverse [physical] material [and] the embodied is dynamically re-embodied.'[14] Not only do digital works 'exist as a material pattern of voltages and magnetic flux inside [the] computer',[15] but the digital is also always embedded in a material substrate. The digital is embodied, for instance, as light travelling through optic fibres, as a magnetic charge on a disk, and as data traces on a drive. As such, it is not 'immaterial' but exists

as a material configuration, situated within larger material configurations of the physical ecologies of the anthroposphere. For Whitelaw, digital fabrication allows 'the specificity of digital media [to] emerge at human scale [as] the material patterns of computation congeal into objects we can wear, touch, or inhabit.'[16] The digital becomes tangible in an immediately perceptible way.

Where Whitelaw makes the digital physical, the interactive visual and sound work, *Khaos* (2012) by the Analema Group, performed and filmed live at London's Kinetica Art Fair, makes the physical body algorithmically digital. In the video recording of *Khaos*, a female dancer appears in person on a dimly lit stage, using expressive movements to interact with generative digital algorithms, and in turn, produce vivid, spiralling holographic fractal forms. These colour-changing, drape-like holographic images appear to be in sync with her body: as she moves, her actions alter the image's digital algorithms in real-time, forcing the hologram to undergo immediate transformation in response to her motion.[17] These dynamic holographic visuals, created through the algorithms that the dancer produces in her generative digital environment, are animate representations of a digitally coded human interaction. The dancer's body becomes, according to digital art critic Oliver Gingrich, 'a live form of digital code in an interactive performance of an intrinsically autonomous, code based art generation.'[18] The code and the dancer are entangled in the same dynamic *metabolic* system.

Local Colour and *Khaos* directly co-opt bodies and physical materials, inserting them into the digital apparatus, as they share one of the primary goals of the digital metabology: to use digital-analogue coupling as a platform for understanding our relation to (and implication in) the digitally networked environment. These artworks reproduce and make poignant the co-constitutive, *technogenetic*[19] environment we encounter in daily life, as we engage with countless

digital algorithms—including those involved in Google's search engine, in online dating matches, in quantitative biometric tracking, and in Facebook, YouTube, Amazon & Netflix preference predictors—that populate our networked digital systems. As such, these artworks give us a contact point for unpacking our participation with the digital network. As we interact with the Internet and other networked digital systems, our activity becomes data that is captured, processed into the digital network, and then endlessly fed back to us in recursive circulation. Media theorist Mark Hansen argues that this body-algorithm relationality is not only apparent, but is in fact coming to characterise modern sensibility:

> In our interactions with [twenty-first] century, atmospheric media, we can no longer conceive of ourselves as separate and quasi-autonomous subjects, facing off against distinct media objects; rather, we are ourselves composed as subjects through the operation of a host of multi-scalar processes, some of which seem more 'embodied' (like neural processing), and others more 'enworlded' (like rhythmic synchronization with material events).... Conscious experience of [twenty-first] century media increasingly occurs as the result of a complex… process involving digital techniques of data gathering… that facilitate the 'feeding-forward' of multiple experiential sources into a potential future synthesis within [our] consciousness...[20]

Just as in *Khaos*, in twenty-first century digital networked systems, our co-relation is not adjacent but contingent, and metabolically intermingled.

This contingency in the feed-forward nature of our data-based lives is investigated in a recent project, called *Manifest Data* (2014), created by myself and my colleagues in Hansen's Speculative Sensation (S-1) Lab at Duke University.[21] In an attempt to demonstrate the human's implication in the digital's metabolism, *Manifest Data* inverts the neo-Marxian stance—that the digital universe literally *melts all that is solid into air*—by translating digital human data into a tactile 3D-printed sculpture. With *Manifest Data*, the digital metabology becomes artistic intervention. S-1 Lab member David Rambo, in a forthcoming statement about the collaboration, suggests the project represents 'an analogy between the cultivation of online social relations and

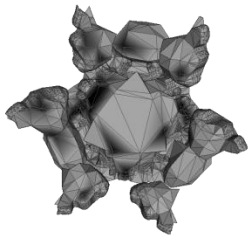
activities for profit and the real effects of western expansion driven by the 19th-century USA ideology of Manifest Destiny.'[22] Registering an important aspect of the project, Rambo's piece seeks to 'undercut the sanguine, egalitarian view of corporate Internet platforms by drawing our attention to a related history of violence, profit, and growth.'[23]

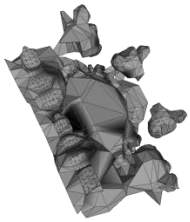
In *Manifest Data*, the S-1 Lab uses localized network analysis tools to capture the content and destination of user-scattered *cookie* crumbs dropped, most often unknowingly and unintentionally, during Internet browsing sessions. These data—the same data large firms like those mentioned above, Google, Amazon, YouTube, Facebook and Netflix, package and sell as data-based representations of the person who produces it—not only come to stand (in) for a user's physical form, but they also literally and financially fuel the web's metabolism. *Manifest Data* seeks to *incorporate* this personal user data in both senses of the term: it wants to re-body (gives body to) a user's personal digital identity data and wants too to transfer ownership of that data from corporations back to its original owner.

The S-1 data capture tools used, authored by Luke Caldwell, work to 'transform the protocological underpinnings of networking technologies—specifically IP addresses and port numbers—into points defining a vector field' that can be mapped using visual modelling software and then printed by a MakerBot 3D printer.[24] The product of this process is a three-dimensional digitally-rehabilitated personal-data sculpture. Human form is turned to data that is sculpted back to digitally-human form.

The material practice here is a collaboration of human and nonhuman, analogue and digital. The artists work, within the confines of the MakerBot's technical conditions and software programming in order for the printer to properly operate, to condense the digital representation back into a solid form. The mechanical constraints are meaningful as they represent decisions

made by the MakerBot in the process of collaboration. For *Manifest Data*, the MakerBot's primary contribution comes in the form of artistic translation from digital sketch (Figures 5 and 6) to printed sculpture (Figure 7). To successfully print an object, the MakerBot requires a solid form as its input. Unfortunately, it recognized our original data model (Figures 5 and 6) to have legible breaks. In order to correct this, our 3D printing artist Libi Striegl, overlayed a solid form atop the figure, in essence draping a solid blanket over the form's architecture, so as to make printing possible. Even once the model input is structurally sound, a secondary control is set by the printer in its idiosyncratic mechanical sensitivities. During our printing trials, we encountered glitches resulting in printing errors, unplanned MakerBot stoppages, and fragmented prints. Some we could explain—vibrations in the studio from a passing train caused one of our failed prints—and others seemed entirely MakerBot originated.





Figures 5 and 6: *Manifest Data,* Amanda Starling Gould's data model, rendered in Mesh Lab, 2014. Image courtesy Amanda Starling Gould and the Speculative Sensation S-1 Lab at Duke University.

Figure 7: *Manifest Data*, Amanda Starling Gould's data model, as printed by a MakerBot 3D printer, 2014. Image courtesy Amanda Starling Gould and the Speculative Sensation S-1 Lab at Duke University.

As also demonstrated by Whitelaw's laser printing, the practical and artistic aspects of the physical printing apparatus and its constitutive software programs contribute not only to the design but also to the message of the project.

Whereas the works above primarily ask how the digital might evolve (into) the natural, artists Martin Howse, Jonathan Kemp, and Ryan Jordan transpose this program, asking what it might mean if the Earth itself could evolve a computer. Their *The Crystal World* (2012) and *Earthcodes* (2012) projects speculatively reflect on the natural substances and (operating) systems of the Earth.

The Crystal World workshops, conducted in 2012, explored 'various bi-directional decrystallizations of the digital, returning to the earth redundant electronics, the poisonous support for a synthesized dystopic world, the pure mineral.'[25] *The Crystal World* investigations cut across two intersecting lines of experimentation: Howse, Kemp, and Jordan wanted first to extract minerals from defunct technologies and second to create working technologies from deep-earth mineral concoctions.[26] The premise of both is to reveal computation's minerality by way of showing that computation is mineral, and that minerals are the materials of computation.

> Inside every digital computer are wires, circuit boards, integrated circuits and other components. They are made from iron, copper, phosphorous, boron, tantalum and other rare earth elements. The central processing unit of a computer keeps time using a quartz crystal. The products of deep geological time are suddenly unearthed and set to pulsating millions of times a second... Computers are crystal engines. They are mineral fetishes that we use to manipulate powerful unseen forces that we believe we have mastered, like crystal healers working with a patient's energy grid. But they are so invisibly familiar to us as our smartphones and laptops and their use in logistics and media is so pervasive that it takes an effort for us to perceive their operation or their implications...[27]

Earthcodes is a subsequent series of projects by Howse that moves forward (or downward) from *The Crystal World*, to demonstrate the digital's implication in the geological

sphere. In *Earthcodes's Earthboot,* Howse 'plugs' his computer directly into the earth thus, as he says, 'sidestepping dirty mining actions, and the expensive refining and doping of raw minerals; thus avoiding environmentally wasteful production techniques for the construction of data bearing devices such as hard drives or USB memory sticks…'[28] He continues:

> The laptop, or PC, literally boots up directly from the specially designed, earthboot USB device pushed into the earth, running code which is totally dependent on small fluctuations in electric current within the local terrain….Quite often the earthboot operating system is not always fully functional as expected. Crashing is the price to pay for booting straight from the earth….[29]

Earthcodes's Sketches for an Earth Computer further demonstrates the physicality of the digital-analogue coupling by actually burying a computer system in the Earth, thus re-embedding it back into its originary mineral context. In *Sketches for an Earth Computer* various configurations of raw minerals were implanted within the Earth. Howse anticipates that over time these materials, when interacted on by both natural and synthetic flows of minerals, rainwater, and underground electric currents, would evolve into a functioning computer. It would be, he says, an 'earth computer; a machine without wires, without components and without abstractions, operating in the earth and proposing a negative ecology, a true earth animism.'[30] As such, this Earth computer, he says 'enters a feedback loop with the environment itself as geophysical, biological and electro-chemical elements can both encode and be modified by the computational structures.'[31] Howse's work demonstrates quite literally the material entanglement of the digital with the bio- and geo-logical spheres. His work renders the boundaries between digital, biological, and geophysical indistinct by closing the digital-analogue distance.

The works profiled here perform with and within various digital paradigms to collapse the gap separating digital from analogue. In so doing, in cooperation with the material metabolic

framework, they provide new patterns for (re)thinking the digital's rhetorically-established distancings. The metabolic framework believes a material intervention is not only necessary for understanding the particular physicalities of the digital universe, but is also critical for reterritorialising the digital system, as a force acting within the larger human-nonhuman-environmental ecosystem. Whitelaw suggests that 'if we think of media technologies as material from end to end, we can frame them readily as in and of the world'.[32] By focusing on the *trans*materiality of the digital through contemporary art and theoretical intervention, we are reminded of its many parts and pieces, and the misguided notion that our digital networks are composed of 'immaterial' 'clouds' of digital data that *melts into air*.

Notes:

1. Benjamin Bratton: ‘Let’s not forget that the realm of the imagination gets built on a very real backbone. The hard technical cabling of the cloud, its voracious energy appetite, its bizarre landscaping footprint, its water and coal requirements, etc, are central to what it is as a global project. It is dependent on the Earth layer for gigawatts of energy, and vulnerable to the vagaries of climate change. The Cloud is very heavy’ (Benjamin Bratton, ‘The Cloud, the State, and the Stack: Metahaven in Conversation with Benjamin Bratton’, Metahaven, April 2012, accessed 19 November 2014, http://mthvn.tumblr.com/post/38098461078/thecloudthestateandthestack).

2. *Digital*, as a noun, most generally put, refers to the full breadth of the apparatus containing digital networked systems. The term’s meaning as it is often used in media and digital arts theory is well captured by digital arts theorist Anna Munster who defines it thusly: ‘The digital is a flow of information, technologies, cultural and social deployments, potentialities, delimitations, and regulations…’ (Anna Munster, ‘Digital Embodiment/Digital Materiality’, in *Depletion Design: A Glossary of Network Ecologies*, eds. Carolin Wiedemann and Soenke Zehle (Amsterdam: Institute of Network Cultures, 2013), 36).

3. Baccini and Brunner define anthroposphere as ‘the network of urban, terrestrial, and aquatic ecosystems that constitute the Earth’s biosphere’ (Baccini, Peter and Paul H. Brunner, *Metabolism of the Anthroposphere* (Cambridge, MA: The MIT Press, 2012), 1).

4. Baccini and Brunner, resource and waste management experts, by way of using material flow analysis to study urban metabolisms, use the concept to ‘comprehend all the physical flows and stocks of matter and energy within the anthroposphere.’ For them, ‘the metabolism of the anthroposphere includes the uptake, transport, and storage of all substances, the total chemical transformation within the sphere, and the quantity and quality of all refuse’ (Hannah Landecker, ‘Post-Industrial Metabolism: Fat Knowledge’, *Public Culture* 25, no. 3 (2013): 1.

5. Jonathan Kemp, ‘The Crystal World: Executing a New Media Materialism’ (PhD diss., University of Westminster, 2013), 52.

6. Jean-François Blanchette, ‘A Material history of Bits’, *Journal of the American Society for Information Science and Technology* 62, no. 6 (2011): 1-2.

7. Ibid.

8. Ibid., 25-26.

9. McCormack in an interview: ‘I’ve been inspired by Hungarian biologist Aristid Lindenmayer, who in the 1960s devised a formal mathematical system to model the growth of plants and simple multicellular organisms. A book he co-authored, The Algorithmic Beauty of Plants [Springer, 1990], showed how simple replacement rules could give rise to complex forms. I used this idea as a basis to make early animations of imaginary plants. I used this idea as a basis to make early animations of imaginary plants. In 2006, I produced work for a large digital billboard on a freeway in Queensland. I made a series of still pictures of imaginary hybrids of plants that were once native to the region, but had been removed to make way for the road. At first people thought I was an incredible painter. They were disappointed to discover that these strange combinations were ‘grown’ in a computer. But I couldn’t have imagined those plants on my own’ (‘Species Futurologist: Q & A Jon McCormack, Interview with Jascha Hoffman’, *Nature* 488 (30 August 2012): 589).

10. Jon McCormack, ‘Representation and Mimesis in Generative Art: Creating Fifty Sisters’, in *xCoAx 2013: Proceedings of the first conference on Computation, Communication, Aesthetics and X*, eds. Mario Verdicchio and Miguel Carvalhais (Bergamo, Italy, 27-28 June 2013): 74.

11. Mitchell Whitelaw, ‘Data-Mysticism, Algorithmic Ecologies & the Human-Executable – Interview with Mitchell Whitelaw’, *Neural Magazine*, no. 40 (26 March 2013), accessed 19 November 2014, http://desktopmag.com.au/features/interview-mitchell-whitelaw-geoff-hinchcliffe-part-two/#.U8mAVbGTGW0.

12. Mitchell Whitelaw, ‘*Local Colour* and Networked Specificity’ (presented at ISEA 2011: 17th International Symposium on Electronic Art, Istanbul, Turkey, 14-21 September 2011), accessed 19 November 2014, http://isea2011.sabanciuniv.edu/paper/local-colour-and-networked-specificity.

13. Mitchell Whitelaw, ‘Transmateriality: Presence Aesthetics and the Media Arts’, in *Throughout: Art and Culture Emerging with Ubiquitous Computing*, ed, Ulrik Ekman (Cambridge, MA: The MIT Press, 2013): 223.

14. Whitelaw, *Local Colour* and Networked Specificity.

15. Ibid.

16. Whitelaw, 'Transmateriality: Presence Aesthetics and the Media Arts', 231.

17. Analema Group, 'Khaos at the MAMAs / Kinetica 2012', last modified 2 July 2012, accessed 7 August 2014, http://analemagroup.wordpress.com/2012/02/07/khaos-at-the-mamas-kinetica-2012/.

18. Oliver Gingrich and Alain Renaud, 'Generative Art - Interactive Art: Delineations, Crossovers and Differences', in *Generative Art 2012 Proceedings of XV Generative Art Conference* (Milan: Domus Argenia Publisher, 2012): 256.

19. Technogenesis is defined is 'the idea that humans and technics have coevolved together' (N. Katherine Hayles, *How We Think* (Chicago: University of Chicago Press, 2012): 10).

20. Mark Hansen, *Feed-Forward: On the Future of Twenty-First-Century Media* (Chicago: University of Chicago Press, 2014), 5, 46.

21. *Manifest Data* is a multipart, multi-authored speculative design collaboration owned and operated by the S-1 Lab. The S-1 Lab code was designed and coded by Duke University's Luke Caldwell. The Amanda Starling Gould data sculpture was printed with the help and expertise of Duke University's Libi Striegl.

22. Rambo, David. Interview with author. Personal Interview. Durham, NC, November 24, 2014.

23. Ibid.

24. Caldwell, Luke. Interview with author. Personal Interview. Durham, NC, November 24, 2014.

25. The Crystal World v.02. 'Publicity', accessed 1 November 2014, http://crystalworld.org.uk/wiki/doku.php?id=the_crystal_world:space:publicity#cw_lab_exhibition_index.

26. 'Mimicking the often dangerous processes undertaken in the extraction of rare and precious metals by the dispossessed, The Crystal World proposes to expand these world interventions through experimentation in the formation of novel crystal geologies aimed to etch unexpected psycho(geo)physical distortions and contingencies into our contemporary crystalline cycles' (The Crystal World v.02, '[[the_crystal_world:space:publicity]]', accessed 1 November 2014, http://crystalworld.org.uk/wiki/doku.php?id=the_crystal_world:space:publicity#cw_lab_exhibition_index.

27. Rob Myers, 'The Crystal World: Algorithms, Inhuman Speed and Complexity', Furtherfield, 18 October 2012, accessed 19 November 2014, http://www.furtherfield.org/features/reviews/crystal-world-algorithms-inhuman-speed-and-complexity.

28. Martin Howse, 'The Earthcodes Project: substrate/shifting the site of execution', accessed 1 November 2014, http://www.1010.co.uk/org/earthcode.html.

29. Ibid.

30. The Crystal World v.02, 'Post Description', accessed 1 November 2014, http://crystalworld.org.uk/wiki/doku.php?id=the_crystal_world:space:postdescription.

31. Régine Debatty, 'Sketches for an Earth Computer', We Make Money Not Art, 23 July 2014, accessed 19 November 2014, http://we-make-money-not-art.com/archives/2014/07/earth-computer.php#.VFwQh8mg-uN.

32. Whitelaw, 'Transmateriality: Presence Aesthetics and the Media Arts', 229.