MESH AGENCY

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1a Typical Initial Formations (Jahn 2014)

ABSTRACT

This paper reflects on the role of computation in speculative design. It suggests that found, unexpected traces of computational processes can amplify designers' imagination. This theme is considered through a reflection on a practical workflow that pays close attention to the artifacts of algorithmically generated mesh geometries. The resulting interpretation of found artifacts as active participants in design processes is innovative in the field where computational objects (such as meshes) are typically thought of as neutral tools. Reconsideration of meshes as objects with agency can be extended to other computational entities, resulting in significant implications for design thinking and design craftsmanship.

INTRODUCTION
COMPUTER EXPERIMENTS IN ARCHITECTURE

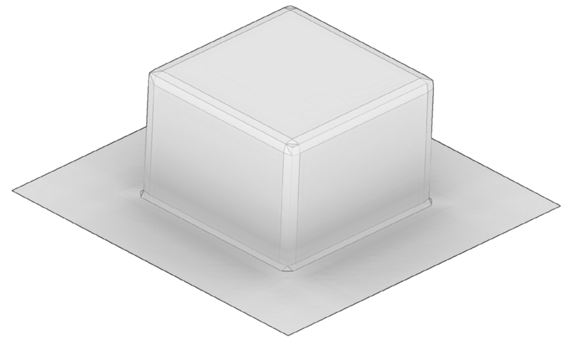
Thought experiments and practical props such as physical models or sketches are common in architecture and design. One could even argue that iterative, trial-and-error approaches are fundamental to design thinking. By extension, one could expect that digital tools should also amplify experimentation but this is not always so. Assuming that computation can contribute more than efficiency to existing approaches, this paper is motivated by an overarching research into methods through which computational simulation and dynamic modelling can contribute to speculative design (Dunne and Raby 2013).

In silico, or computer experiments, are increasingly used in science and engineering to simulate physical, chemical or biological phenomena. Many of these experiments are deterministic, with the same initial conditions leading to the same results. Other experiments use statistical approximations to overcome complexity or save computational expense. The experiments discussed in this paper do not aim to simulate existing or known systems but seek to multiply and make tangible futures that break away from the established momenta of thinking and doing. The concern of such experimentation is not with accuracy, but with poesies. When computer experiments generate unexpected phenomena, one can think of underlying models "as potentially exploring alternative modes of being and relation, telling stories but also literally toying with complex, dynamic systems, exploring them prospectively, and not (merely) as eye-candy machines, but as model worlds" (Whitelaw 2005, 152).

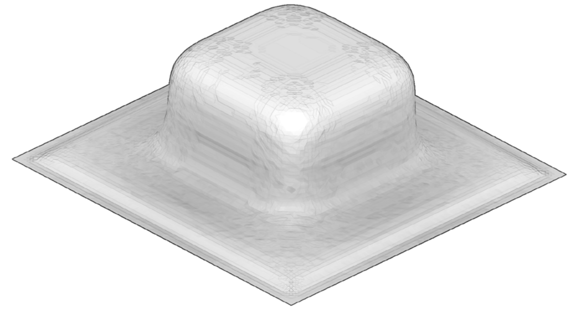
How can generative computational models gain voice and influence? What roles in this challenge can be played by common objects of computational geometry, such as meshes? Meshes can be conceived as descriptive (as in cartography) or suggestive (as in design drawings) but can they also function in other ways? Can they help to communicate subversive or critical meanings, or help to cultivate models that supersede, indeed, precede their reality? In response to these questions the sections below discuss: 1) design methods that are guided by computer experiments (*Can Meshes Talk?*) and 2) critical narratives that can be extracted from such experiments ((*What Can Meshes Say?*).

CAN MESHES TALK?
DORMANT MESHES

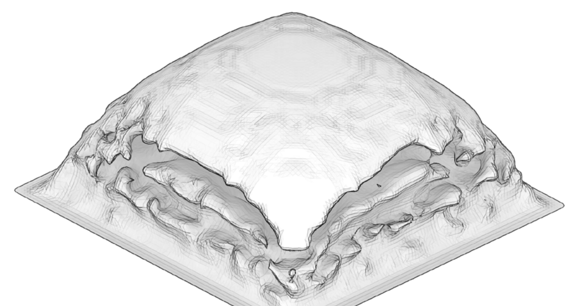
Polygonal or triangle meshes are a common concept in computational geometry. They are used to represent 3D objects in a broad variety of applications. Many data structures and algorithms for storing and manipulating meshes have been developed but the details and implications of these implementations are commonly hidden from end users of 3D modeling software. Their original purpose was to be compact (compressible) and static. Later developments allowed ascription of additional data to vertices (e.g. color) or areas (e.g. UV coordinates) and provided tools for manipulation (e.g. animation) and interpretation (e.g. normal averaging). More recently, coding of 3D video objects able to undergo topological transformations required development of dynamic meshes that can exist in separate groups with constant connectivity over set lengths of time. However, even such advanced implementations are intended as instruments for systems of representation. In such usages, the mesh itself remains mute or, to use Harman's metaphors, dormant (Harman 2011, 122) or withdrawn from view (Harman 2002, 60).



d) Cube Distribution

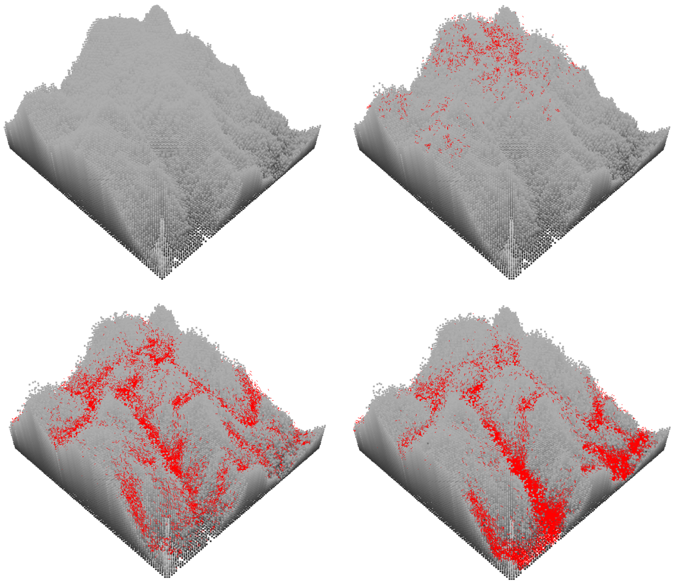


e) Diffusion (10 steps)



f) Diffusion+cellular automaton (100 Steps)

1b Typical Initial Formations (Jahn 2014)



2 Simulated Surface Flow (Jahn 2014)

This paper suggests that it is possible to shift the focus from the view of meshes as devices for describing and storing geometry to their roles as seeds, constraints and traces of processes. The voice amplified through such a shift in understanding is worth exploring because it can encourage designers to analyze and interact with otherwise hidden phenomena.

TALKING MESHES

Phenomena and the ensuing design potentials can be hidden for many reasons. They can be beyond designers' habitual imagination or drowned in hyper-dimensional possibility spaces. One type of potentials that we wish to discover has to do with morphological multiplicity and topological complexity. The discussion on the value of such characteristics is beyond the scope of this paper but briefly, an ability to understand and design complex structures and processes is important in many areas including systems and bio-inspired design, multi-performance architectures and aesthetic innovation. De Landa argues that complex formations emerge when material negotiates differences in intensity. When such negotiations take place in "far-from-equilibrium" conditions, they enable emergence of the "full variety of topological form" (De Landa 2000, 32). The design project discussed below utilizes innovative generative processes but the focus of this paper is not on the algorithmic rules of the processes themselves. Instead, the paper considers the roles that standard computational devices, such as meshes, can play in adapting innovative generative processes for the purposes of architectural design.

Meshes can develop voice in many ways. The approach discussed in this paper is to link mesh geometries to underlying emergent phenomena. As an example, this paper considers a project that simulates flows of material. This simulation consists of a bounded environment that includes an array of voxels and a collection of particles. Volumetric changes in such environments are represented by the states of individual voxels. A mesh representing a state of such a model can be obtained at any time through iso-surface extraction.

The following sections give two example implementations utilizing emergent patterns driven by gradients (De Landa 2011, 9):

1) smoothing and striation; and

2) redirection and reassignment.

The decision to work with gradients is driven by the team's previous experience with generative models. This experience demonstrated that experimental conditions sustained by gradients can amplify the discovery of features that cannot be predicted from the initial conditions by human designers.

GLOBAL GRADIENT: SMOOTHING AND STRIATION

The example of a gradient presented in this section operates at the level of the whole experiment. It utilizes 3D Gaussian diffusion to reduce noise across voxel values and enhance the effectiveness of behaviors that rely on an ability to identify features in the simulated environment (Basu 2002). Running the diffusion algorithm for ten steps on a randomly distributed grid of voxel values results in meshes with complex topology but little variation in scale or features (see (Figure 1b)). The same algorithm applied to voxel environments with some existing features (i.e., interpretable signals that stand out against the ground of noise) typically tends towards producing homogeneity. See (Figure 1), for example, the loss of hard edges in the transition from d) to e).

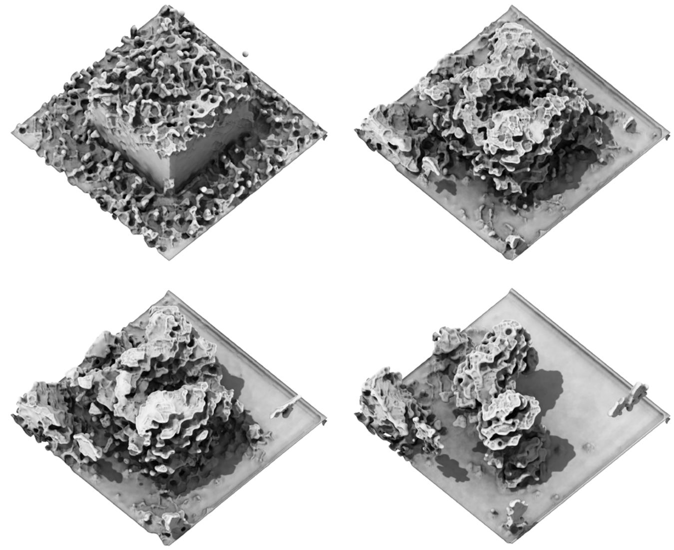
To resist this tendency, the project implemented an anisotropic cellular automaton that abstracts a process of striation. The meshes that are generated by iso-surfacing these striated congregations of cells (in our implementation called voxels, for uniformity) can be complex despite being generated by very simple rules (Wolfram 2006). A typical implementation of a cellular automaton is as an array of finite cells connected locally. These cells update their states simultaneously, in discrete time. In the implementation discussed here, stratification is achieved by limiting each voxel's awareness of its environment to the nine voxels on the preceding layer. Furthermore, each voxel's ability to modify those values is confined to the single voxel beneath it rather than affecting the states of all immediate neighbors.

The detailed discussion of the technical implementation is beyond the scope of this paper. The utilization of a different mechanism would not invalidate the design utility of this approach. If the stratification process is run on its own, it rapidly converges on stable, noisy forms. However, when it is juxtaposed by smoothing, the gradient between these two processes leads to topologically complex, legible features in the extracted meshes. In this example, meshes acquire voice through intensive interactions fueled by global, experiment-wide gradients

LOCAL GRADIENT: REDIRECTION AND REASSIGNMENT

Another type of gradient was established between particle behaviors and voxel values: particles reassign values of proximate voxels while voxels redirect the trajectories of nearby particles. The weight of these behaviors together with the frequency of interaction between particles and voxels determine the appearance of resulting meshes. A single behavior alone would rapidly converge on predictable outcomes. For example, when the behavior of voxels is given a greater weight than that of particles, the interaction is reduced. Consequently, the particles appear constrained to the surface of a predefined topography see (Figure 2).

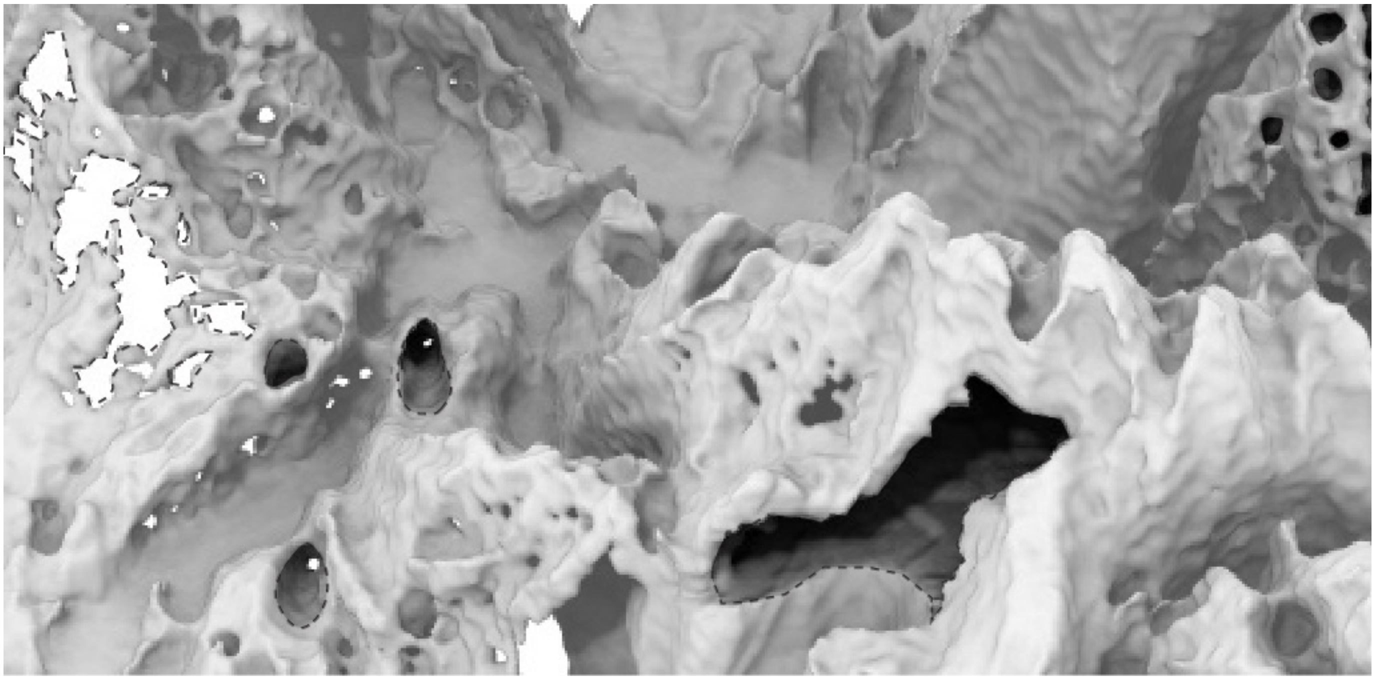
By contrast, the introduction of gradients between several behaviors results in a greater topological diversity, as per De Landa above. Generally, emergence-prone near-parity conditions ascribe meshes with greater agency by pushing the outcomes away from habitual intuitions of human designers. The initial variation in the environment (or, conversely, its homogeneity) also affects the capacity of the system to generate higher-order features. For example, (Figure 3) illustrates how the homogenous distribution of voxels in a cubic form is gradually transformed by competing processes. The cube is initially eroded by the reassignment of voxel values ((Figure 3), *top left*) resulting in significant noise across the surface of the cube. The homeostasis reached through continuous interaction between 1) particles and voxels and 2) smoothing and striation results in the diffusion of this noise. This diffusion can be interpreted as a deliberate redistribution of matter or designed change ((Figure 3), *top right*). Eventually, these features dissolve into newly homogenous distributions of voxel values that cannot be easily interpreted as architectonic phenomena (floating forms in (Figure 3), *bottom right*). Local gradients of this type can complement global gradients like the smoothing-striation examples discussed in the preceding paragraph.



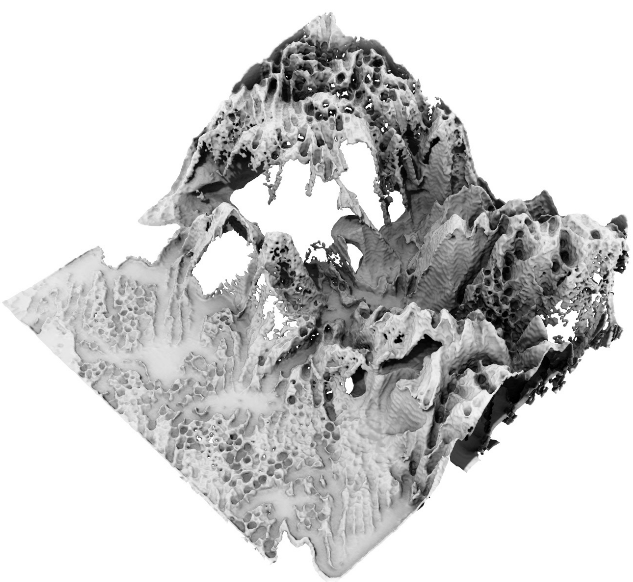
3 Sequence of generated meshes (Jahn 2014)

Examples of potential designerly interpretations can be seen in (Figure 4) and (Figure 5). (Figure 5) demonstrates mesh features produced while exploring local gradients of particle-voxel behaviors. For example, vertical (*top right*) or horizontal (*lower left*) fissures and circular cavities (for example, *top right*) appear when the influence of voxel values on particle behavior is reduced. Strata driven by the cellular automata implementation (for example, *middle top and elsewhere*) acquire occasional gaps (*white regions on the left*) when differences in values between stratified voxels and the volume beneath become sufficiently large. Feedback between particles and voxels results in small-scale features coalescing to form larger voids (*dark region at middle bottom*). These features can be interpreted as recognizable emergent formations and one way of utilizing such suggestive outcomes in design is considered below in section *What Can Meshes Say?*

The examples discussed in this section explored the hypothesis that *in silico* experiments with gradients can extend the agency of abstract computational geometry objects such as meshes. Using gradient interactions, these examples demonstrate that generative processes can give voice to meshes by supporting the discovery of features that cannot be created manually or predicted from initial conditions. The subsequent section will illustrate how these emergent pronouncements can be further deepened through the techniques of mesh analysis.



5 Detail of Emergent Features (Jahn 2014)



4 An Overview of Co-present Emergent Features (Jahn 2014)

MESH DIALOGUES

When a mesh is a result of an underlying complex process, it can assume the role of material evidence in physical or *in vitro* experiments. In such experiments, samples collected on site or in a lab are interrogated with a variety of analytical tools. Patterns are found, compared with theoretical predictions and integrated into explanatory narratives.

In architectural or urban design, it can be similarly productive to interrogate the experimental evidence, even when the experiments are conducted *in silico,* and even when they do not attempt to implement physical or social mechanisms of actual environments. Instead, purposeful interpretation or deliberate misreading of the discovered properties can be as useful. As before, these operations can employ meshes as active frames for further thought or design.

MESHPRINTS: TOPOLOGY ARTIFACTS

Topology can speak on behalf of implicit features of a mesh or for artifacts produced during its extraction. While these artifacts are typically ignored or avoided (Bischoff, Pavic, and Kobbelt 2005), this paper presents an approach for analyzing, exaggerating and translating these inherent features into expressive surface patterning and deformation. Topology artifacts are unique for each instance of extraction. As such, they can act as digital fingerprints that mark each mesh with an identity that is linked to but not determined by the processes of generation or the intentions of human designers.

For example, iso-surfaces typically exhibit triangulation artifacts that produce unique disparities in topology (for example, vertices with varying numbers of connected edges) and contain connectivity artifacts such as un-welded vertices or border edges. (Figure 6) illustrates how complex scalar attribute fields (Hoppe 1996) can be extracted from trivial geometry (a plane) because of triangulation artifacts. Here, vertices are given color values based on subdivision steps - white vertices are present in the initial mesh, while black vertices are the result of the subdivision. Since the process of subdivision is highly sensitive to mesh topologies, this process translates topological variation to specific vertex coloration. Such artifacts can be seen as problems or, as suggested above, be valued and used in subsequent transformation processes.

POLYPSYCHISM: ANALYSIS, INTERACTION AND FEEDBACK

Polypsychism (Harman 2011, 121) attributes modes of relation and being to all objects. According to Harman, objects have agency insofar as they relate to other objects. Exploring an approach that can also be conceptualized as polypsychism, this paper proposes a recursive method that couples implicit qualities of a mesh (discovered through mesh analysis tools) with subsequent selective deformations or colorizations. The deformed mesh can be used as the input to the next round of analysis and often produces complex patternations and deformations after several iterations. (Figure 7), *top*, exhibits a lack of formal legibility in a volumetric rendering of a low-resolution data set. However, despite the apparent absence of features, the subsequent articulation of extracted meshes through resampling and iso-surfacing allows discovery of, and interaction with, the hidden potentials. (Figure 7), *bottom*, demonstrates the discovered phenomena that suggest characteristics of scale, interiority and exteriority, thresholds and interfaces.

Mesh channels, such as vertex normal or color, act as containers for per-vertex properties of a mesh, for example local curvature, proximity (to boundaries, meshes, viewers or other objects), topology, self-shadowing, subdivision steps or other modeling operations. These properties are stored as vectors and can be considered as continuous or discrete values. (Figure 8a) demonstrates how local curvature vectors can be used to select faces in a mesh with greater than some threshold of curvature and consequently subdivide only those areas. After subdivision, the curvature of these faces is reduced, resulting in a new selection set when repeating the operation. (Figure 8b) demonstrates how the same curvature analysis can be used to interpolate between a mesh and a copy that has been deformed using a Laplacian smooth filter, producing a gradient between faceted, creased and smooth surfaces. (Figure 8c) demonstrates how curvature vectors can be mapped to vertex transformation vectors, exaggerating existing concave and convex features in the mesh.

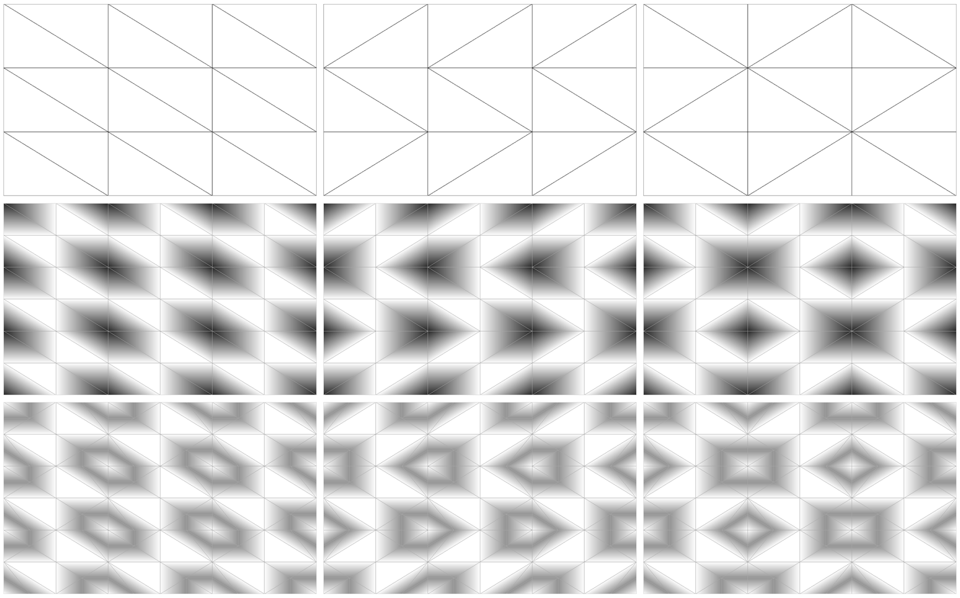
Following the process outlined above, the meshes extracted from the generative model carry meaning in two ways:
1) through the formal characteristics derived from iso-surfacing of voxel grids and 2) through subtle geometric features intrinsic to the processes of mesh extraction but hidden from unequipped human perception. By exaggerating these qualities through analysis-transformation feedback loops, designers can unlock new sources of creative potential that can be attributed to the mesh itself. Applying Harman (2011), this paper concludes that meshes themselves can be said to have agency expressed as their ability to interact with or relate to other objects: designers, designed elements or design contexts. The following section elaborates on how such implicit properties of a mesh can be mapped onto inhabited environments and interpreted as saline formations integrated into plausible (or deliberately provocative) design narratives.

WHAT CAN MESHES SAY? CRITICAL MESHES AS DESIGN AGENTS

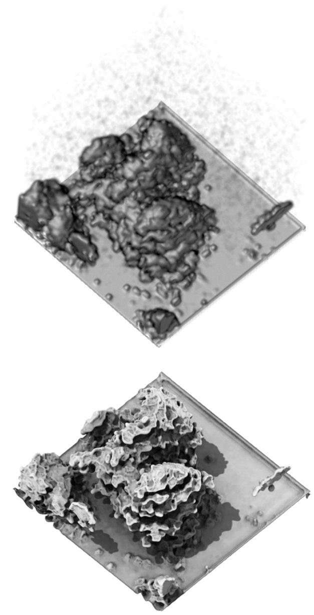
The agency of meshes as discussed above, has been tested in application to the Halophile project, a submission to the 2014 FuturArc urban design competition Water and the City.[1] The competition brief called for “a new vision of the water in the city” that “might manifest itself through new networks or infrastructure that deal with flows and loops” (Futurrc 2013).

The bulk of entries in previous years complied with common presumptions about existing economic and ecological structures. The design team perceived this as an approach that had “been shaped *reactively*, in response to industrial, technological and political parameters that are simply branded as ‘ecological’...” (Armstrong 2012) or “greened” (for example, see Fisher (2008, 5), Fry (2008, 54) or even Morton (2007, 109)). Responding to the unquestioning acceptance of green capitalism by the previous submissions, the team intended to use the competition as a venue for a meta-critique of ecological design.

To achieve such an objective, the design utilized a generative model to stage a computer experiment able to highlight possible destinations for the established vectors of urban development. This highlighting took form of model stories that “provide images of, or rather imaginations of, the (social, cultural, personal, material…) systems we live in” (Whitelaw 2005, 146).



6 Subdivision of a Planar Mesh (Jahn 2014)



7 Before and After Mesh Operations (Jahn 2014)

The experiment produced a vision for the future saline landscape of Perth, Australia. The scenario and resulting imagery aimed to capture the complex issues besetting this large, young, and profligate city: salinity, sprawl, climate change, cultural shifts. The intention was to communicate the notion that these "unit operations" (Bogost 2006) participated in a greater, systemic whole. This objective called for mesh topologies that could embody narratives about geological deposition and plastic deformation of salt diapirs, urban processes of accumulation and aggregation, architectonic processes of formal articulation and surface patternation. The resulting geometry needed the capacity to obscure deliberate design gestures to achieve "cognitive estrangement", a mode that exposes underlying patterns in existing systems and serves as an epistemological scaffold to examine deficiencies in the now. At the same time, this geometry had to be familiar because if a project "asserts its radical difference from what currently is [...,] it becomes, not merely unrealizable, but what is worse, unimaginable" (Jameson 2005, xv).

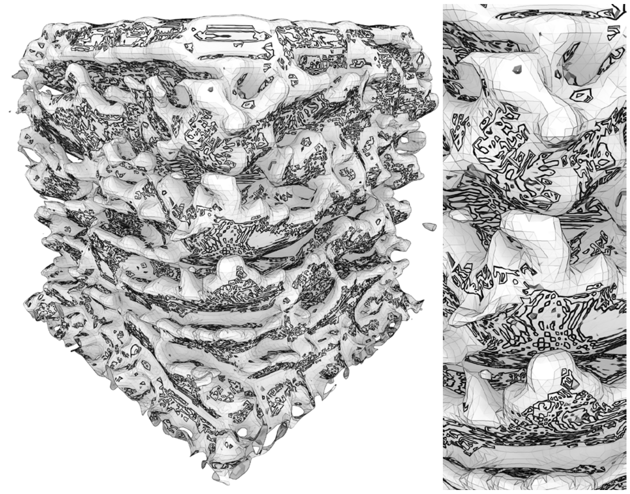
MESHES AS HALOPHILIC LANDSCAPES

This overarching narrative was developed through the emergent geometric variation in a series of test models. The particular model shown in (Figure 9) exhibits features that stress the totality and interconnectedness of the model and the scenario. These are perceived simultaneously as architectural, urban, or natural artifacts. For example, the articulation of forms within a single central mass suggests variable pressures of use at the scale of the dwellings or urban clusters; the threshold between the edge of the mass and a surrounding "landscape" suggests defensive maneuvers, the withdrawing of an occupant into a private space. Similarly, the layers and recesses of the envelope suggest elements at the human scale; they can be stacked floor-plates (addressing issues such as density, aspect, or solar access) or louvers arrayed around an isolated suburban dwelling. The model negotiates thresholds between different visible "features" in complex and unpredictable ways. Geometry of this type is hard to obtain through explicit modeling. For example, the threshold between the "roof" of the model, the periodically stacked blue recesses, and the formation of a courtyard or pool at the center of the mass exhibit a range of topological features – splitting, extruding, folding. Since all of these features are, in fact, exaggerations of underlying properties of the mesh, they maintain a cohesive model-story (Whitelaw 2005) despite these differentiated local transformations.

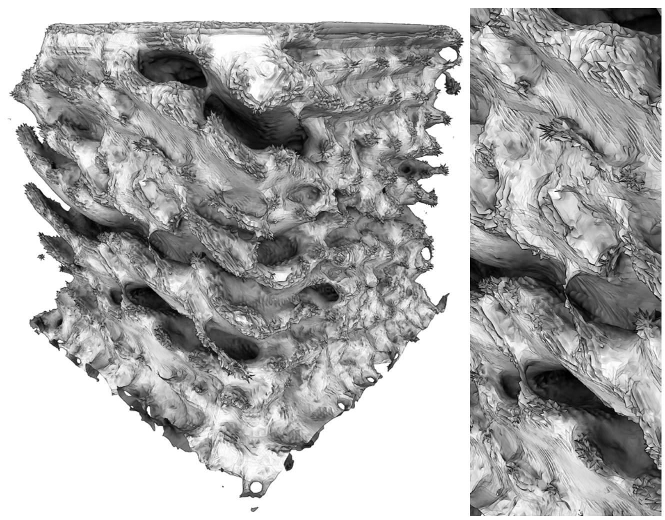
The features discussed above engage with the overarching model story, suggesting possible uses and locations of these socio-geological formations. For example, the banding and layered recesses present in (Figure 9) can be coaxed to preserve some of their characteristics while developing others; resulting in the emergence of territories that become readable as landscape (Figure 10). Coaxed by the designer, who continuously interacts with the resulting meshes, the model reorganizes into a network of deep cenotes or pools - potential sites for a new kind of halophilic agriculture - while the areas around the pools form multilevel bridges. The resulting organization is in continuous flux, with large mounds turning into cavities, bridges breaking into pools, and pools expanding to create overhanging geometry–all emerging from the repeated feedback between competing formation processes intensified through the mesh analysis and articulation procedures.

In these examples, the agency of the mesh is not in its ability to explicitly describe something that exists or is known (as typical in 3D scanning and 3D printing) or in its ability to suggest design directions (arguably, its main role in architectural drawings) but in its capacity to convey the familiar while evoking the alien. Both the mesh and its process of formation operate using their own fictional, "strange" internal ontologies, where existing models are "subverted and alternative models are played out" (Whitelaw, Guglielmetti, and Innocent 2009, 12). As traces of these underlying models shaped through guided interpretation of inherent artifacts, these meshes become the core constituents in the critique of ecological design; active players in Halophile's model stories.

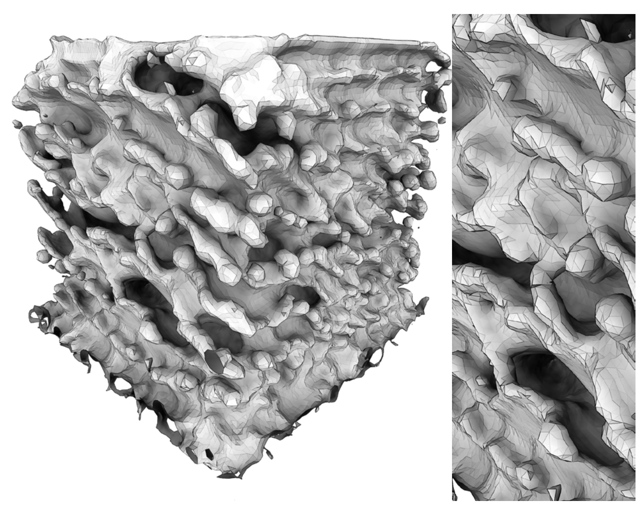
At the very least, such meshes can be seen as "props" (Dunne 2005, 92); objects that can, through a process of estrangement, "effectively transform the consciousness" of its audience and the way this audience understands the problems embodied in the work (Dunne 2005, 96). More radically, this capacity invokes a shift from the notion of the mesh as a mute or dormant object to that of the mesh as an active voice in a design narrative.



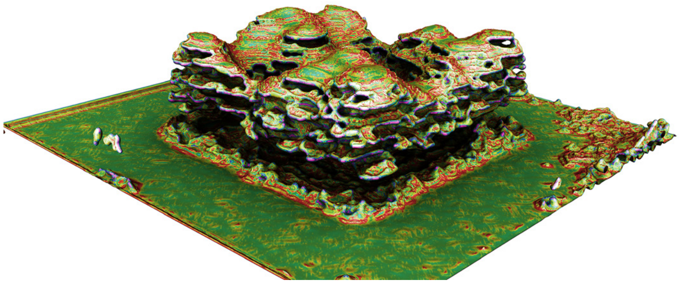
8a Pattern Differentiation (Jahn 2014)



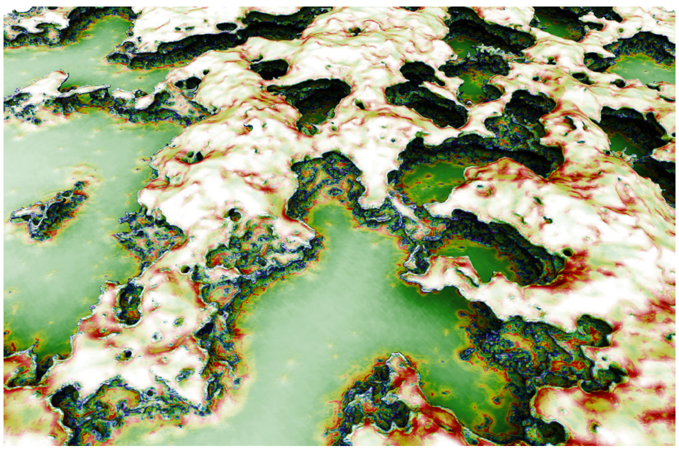
8b Smoothing Differentiation (Jahn 2014)



8c Concavity Differentiation (Jahn 2014)



9 Halophilic Dwelling (Jahn 2014)



10 Halophilic Topographies (Jahn 2014)

CONCLUSION: MESH CONTRIBUTIONS

This paper seeks to broaden the already extensive repertoire of complex mesh manipulations in architecture by focusing on the active agency of meshes as objects that can prompt designers to seed, analyze and interact with phenomena otherwise withdrawn from habitual human perception. Design work discussed in this paper suggests that meshes can have agency beyond that which is expected from predetermined representations because they can embody traces of generative behaviors. The focus on such behaviors can lead to greater morphological diversity, resulting in architectural geometries that are flexibly adaptable to diverse local conditions. When form-making is delegated to generative processes, another shift occurs. The designer's attention turns from the making of static objects to the making of dynamic systems. The effort to understand and direct change in such systems, *in vitro* or *in silico* is an important challenge facing architecture today. The practical experimentation discussed in this paper highlights computation's capacity to stage dynamic simulations and interact with their temporal and spatial states through mesh artifacts in a variety of ways.

Further, the paper suggests that mesh agencies emerging from computer experiments can productively model speculative design systems. In order to illustrate this conceptual stance, the paper described two generative techniques operating at the local and global levels of a voxel model. Meshes extracted from such processes are expressive of the underlying processes and can be studied as any other data obtained through an experiment, often with non-trivial and surprising outcomes.

Even when the generative processes are abstract, the resulting meshes can have useful design agency because they contain complex and organized features that cannot be invented by a human wishing to work alone. For example, topological artifacts that result from an abstract marching cubes algorithm can produce surface effects that suggest architectural and urban narratives. Similarly, rounding errors typical to the process of subdividing mesh geometries can lead to the emergence of local curvatures and opportunities to obtain complex and suggestive patterns from apparently featureless sources. Feedback between such properties as curvature and deformation can result in processes that exaggerate subtle features of a mesh or refine larger scale phenomena. As this feedback is applied locally, the surface of the mesh acquires differentiation suggestive of the complexities typically produced during such processes as geomorphism or habitation. Such suggestive patterns can drive narratives that integrate mesh geometries into designerly imagining of possible futures.

With adjustment, the generative models discussed in this paper could be used for realistic simulations that guide near-future practical decisions. However, they can also have other, longer term and more radical utility as critical devices. Employed as such, they engage with "the science of imaginary solutions" (Jarry 1996 [1911], 22), intended to question the habitual systems and logics. Experiments with such models are not optimized for a silently inherited set of constraints. Nor are they meant to converge on a single practical "solution". Instead, the topological and voxel transformation discussed above can become valued for their potential to demonstrate how things came to be, or could progress.

NOTES

1. The discussion of the context and the design outcomes of the project are outside the scope of this paper. Further materials and the full competition boards can be found here: http://elsewarecollective.com/project/halophile/

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IMAGE CREDITS

Figure 1. Jahn, Gwyllim (2014) Typical Initial Formations. Diagram

Figure 2. Jahn, Gwyllim (2014) Simulated Surface Flow. Diagram

Figure 3. Jahn, Gwyllim (2014) Sequence of Generated Meshes. Render

Figure 4. Jahn, Gwyllim (2014) Overview of Emergent Features. Render

Figure 5. Jahn, Gwyllim (2014) Detail of Emergent Features. Diagram

Figure 6. Jahn, Gwyllim (2014) Subdivision of a Planar Mesh. Diagram

Figure 7. Jahn, Gwyllim (2014) Before and After Mesh Operations. Diagram

Figure 8a. Jahn, Gwyllim (2014) Pattern Differentiation. Render

Figure 8b. Jahn, Gwyllim (2014) Curvature Differentiation. Render

Figure 8c. Jahn, Gwyllim (2014) Concavity Differentiation. Render

Figure 9. Jahn, Gwyllim (2014) Halophilic Dwelling. Render

Figure 10. Jahn, Gwyllim (2014) Halophilic Topographies. Render

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