From Curves to Aggregation: A Computational Toolset from a Broader Thesis on Geotechnical Urbanism

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Abstract: Within the architectural engineering and construction industry (AEC), we have developed diagrammatic representations and software translations of cultural patterns, extruded 2D cities, and built architecture of processed materials palettes (DEAMER & BERNSTEIN 2010). However, we are not yet able to diagrammatically compute the translation (intent to manifestation) of wild contexts and materials systems. This paper demonstrates a hybrid software approach to the bulk manipulations of aggregate, somewhere between that of a wild randomization and a refined aesthetic, at two scales: a residential garden and a regional waterfront.

Developing new software for aggregating "wild" (i. e. rock, soils and organic matter) rather than "cultured" (cast-in-place concrete, steel beams, and pre-fabricated urbanism) will result in new opportunities in the ecological landscape definition of the terms, and provide tooling for new forms of urban aggregate across more dynamic and less predictable cultural conditions – so-called geo-technical urbanism(s). This experimentation is applied conceptually to computationally replicate the manual processes which created a renowned residential garden; the experimentation also demonstrates its broader scalability in the contexts of sea-level rise and coastal urbanism.

Thesis question + use cases: How might new geotechnical approaches to computing aggregate + aggregations of other "wild" materials impact urban + landscape design systems?

Keywords: Wild, aggregate, aggregation, geotechnical urbanism

1 Introduction

The idea for this thesis was sparked by a desire to merge the speculative design and construction practices of a bespoke landscape with the broader built environment in a practical way. The results, ultimately, would address seemingly intractable challenges to the ubiquitous use of wild material in construction and, even more pressing, to the challenges posed to coastal urbanism and sea-level rise. I have compiled + modified toolsets from the civil engineering and gaming industries for applications to aggregate (wild and cultured) material systems within the broader design of built environment. These tools include Autodesk's Civil3D, Grasshopper, Rhino3D, Cinema4D, Houdini, and primarily the open-source entertainment industry software Blender.

The use, design, and construction of "wild" materials in landscape is more unpredictable and more difficult to control, document, and build with than their more common cultured and slick counterparts. The "cultured" or "unitized" approach to urbanization is easier to plan, more predictable, and therefore has existing software tools at its disposal. Thus, related professionals often relegate less predictable components of the landscape to the most manual or analog of approaches while the "cultured" components of our cities continue to be emphasized in the AEC market of innovation. In other words, our ability to work with large rocks,

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mud, soils (aggregate) and other common materials at the geotechnical foundations of our built environment remains in the early "diesel age" of construction, while "cultured" highly productized "thingy" or plasticized material aesthetics proliferate.

Fig. 1: Wild Stone (left), Cultured Stone (right). "Wild:" not of a manicured or predictable course (MERRIAM-WEBSTER n. d.: *Wild*). "Cultured:" grown or made under controlled conditions (MERRIAM-WEBSTER n. d.: *Cultured*).

This paper builds on skills and lessons learned from actual projects undertaken on affluent estates in Aspen, Colorado, a context of sensitive ecological landscapes, with large-scale construction of artificial streams, wetlands, and other seemingly wild landscapes, where individual boulders, amongst thousands to be placed, could take days to set. The budgets, levels of accuracy for location, and time scales of these projects necessitated and inspired technological innovations in 3D scanning, documenting, and scoring of a virtual model of these complex wild materials (MEKIES & TAL 2020).

As a code-using designer and adapting the level of care and precision of typical high-dollar landscapes ($250+/SF) to the public waterfront / sea-level rise, I have adapted several existing software functionalities to perform what does not yet exist broadly in current built-environment software engines.

Contemporary practices around the globe are working on similar material contexts of geotechnical infrastructure (SCAPE 2022). Visions and analysis of the intent for these "geotechnical urbanisms" abound in the work of contemporary urban design, engineering, and landscape architecture (RESILIENT BY DESIGN CHALLENGE 2022). However, the act of assembly, the scoring of how one gets from concept to a geotechnical ensemble lies primarily, for landscape, in PDF abstractions. These PDF two-dimensional static windows oversimplify what could be a dynamic geotechnical model. Through the scale of garden and city, software adaptations described in this paper, alter the "standard" practices, to be more accessible in simulating and deploying "wild materials systems."

A range of research tackling these applications has already contributing to our understanding of distributing sediment, plant material, and other materials computationaly. These include the Responsive Landscapes work by (CANTRELL & HOLZMAN 2015), the Harvard Graduate School of Design's Geomorphology modeling table originally by Steve Gough which focused on sediment and regional scale river applications (GOUGH 1995), Land Kit (Landau Design), a Grasshopper pluginset and online resources, and the "Groundhog.la" work in distributing and adapting planting design through computational means by Philip Belesky (BELESKY 2017).

The work lead by Christophe Girot / HEAP at ETH in their implementation at scale has set new bars to surpass (FAHMI 2020). Those applications, are not as accessible to the practicing landscape architect while tied to the autonomous hardware / robotics in-field. Their experiments remain costly and daunting to undertake. A hybrid of these applications and test-bed examples for other programs are beginning to surface in the Grasshopper Plugins and recent publication of Robotic Landscapes by Ilmar Hurkxkens (HURKXKENS 2022).

2 A Geotechnical Urbanism + Landscape Toolset

2.1 The Idea of Geotechnical Urbanism

Geotechnical urbanism rethinks the way the designed foundation of our urban cities (the ground beneath our feet) is composed and structured. It advocates for a physically and virtually connected hardware, software, and "wet-ware" of the city, one which organizes elements of urban design and landscape as aggregated to compose that cityscape through physics (LALLY 2022). These organizational principles expand on the current surface-based or "map-based" model of the city, allowing for the landscape of the city to be examined volumetrically through space, time, and at various levels of detail.

A rock's geometric complexity presents great challenges, particularly in dealing with many of these materially similar but geometrically unique aggregates in mass. Likewise, our world's informal settlements, favelas, or slums are built out of many seemingly chaotic but similar structures, each geometrically unique within a complex aggregation. Of course, differences exist in the cultural, economic, and human characteristics of the actors within each of these systems. In the complex geometry of these informal / kinetic settlements, they are comparable to the landscape aggregations from which their terrain and material pallets originate. Could similar software tools and geotechnical modes of inquiry be useful in both contexts of the built environment (KRENZ et al. 2016 & MEHROTRA 2021)?

There are critical needs for continued architectural solutions, modular housing approaches, and new technologies for efficient and comfortable enclosed habitats. How then can the toolset, presented here, help design, and construct the world outside of building walls and the foundational geomorphology on which our cities reside? This question is especially relevant in an increasingly technological world, potential new worlds on hybridized terrestrial, extra-terrestrial, and aquatic landscapes. Will our projected "Terran" futures continue to be hard-edged cultural solutions, or will they be embedded within the "wild" contexts they occupy.

"Terran" (in science fiction): relating to the planet Earth or its inhabitants (MERRIAM-WEBSTER n. d.: *Terran*).

The visual comparisons in Figure 3 illustrate an example material similarity of geometric patterning complexity in works of bespoke landscape architecture and informal settlement. Definitions of gradient, flow, and granular scale in response to geotechnical edges of the landscape are among just a few of the experimental lines of inquiry explored. The adapted software tools presented in this paper enable the transformation of a drawn curve to recreate the complex aggregation, gradation, and flows of a geotechnical aggregation (drift).

2.2 The Adapted Toolsets for Deploying Bulk Aggregate

The primary toolsets deploy through Rhino / Grasshopper the "bulk pile" locations along a "centerline" and Blender as an aggregate "crushing" and "delivery system" (dump truck, barge, or bulldozer blade thus far) within the simulation engine. The approach is built around the idea of a "score" or simply a set of relationships between curves the designer draws, and mathematically controlled boundaries and specifications of how the material is deployed.

"Score" – A system to visually describe and specify the virtual simulation and bulk placement of wild materials. Through Rhino, Grasshopper, Blender, and Civil3D the overall "score" of the site is defined. These files as of now take advantage of common import-export formats of OBJ and DWG; so, the system is not a fully linked at this point.

Within Rhino the designer draws the "Drift Centerlines" – A simple / diagrammatic set of notational curves (polylines or splines) which serve as the primary form giving input. The **"Domain"** – Physical limits of the resulting drift feature, determined from the centerline vertical (z-axis) difference from existing grade and bulk volume specification, are derived from the angle of repose using the **"Bulk System Specification"** – The larger programmatic requirements of a combined pile, stack, or drift assembly (i. e. is it an additive or subtractive centreline and what is the angle of repose for the specified aggregate material?). This **"Aggregate System Specification"** defines the individual aggregate properties, providing crush condition, angle of repose, source, and delivery / deposition within the overall pile, stack, or drift, which allows the Z-coordinates of the original drawn "Drift Centerline" to be compared to existing or pre-designed grade and the angle of repose as a volumetric calculation for each individual pile or "bulk unit" specified (see graphic below).

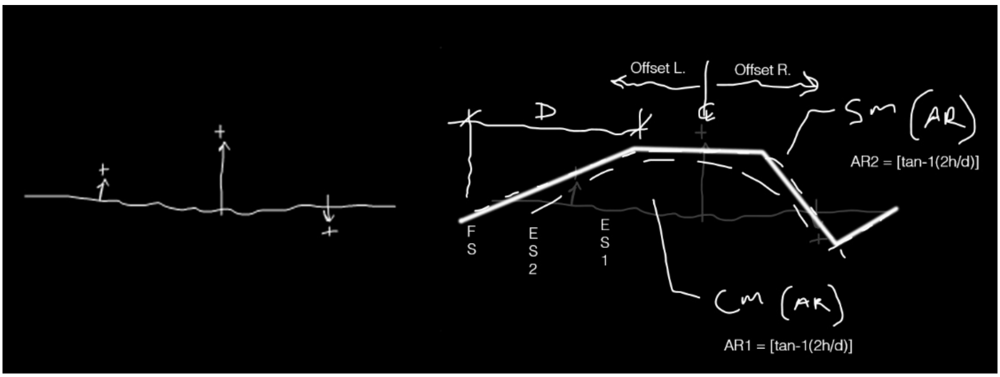

Fig. 2: With the "Centerline Curves" set to height the "Core Material (CM)" and "Shell Material (SM)" are deposited based on their respective specification and angle of repose

The terms above, used throughout the process are drawn from "RSVP Cycles" by Lawrence and Anna Halprin who refer to "resources" as anything that can be used in the process including time, physical materials, other people, ideas, limitations etc. They define "score" a bit more explicitly as "instructions for the work" (HALPRIN 1981).

Site preparation and coordinate system are defined in Civil3D and linked or 'referenced' to Rhino3D Software. Base material properties and any formwork or containment conditions in the grade are defined through Rhino geometry along with the centerline curves of the intended aggregate drifts through poly-line geometry. The domain or extents of the drift are defined through the Grasshopper script developed which is expressed in the section sketch (Figure 2 above). Bulk materials distributions are computed within the same Grasshopper script based on the volume of each material (shell or core respectively) now determined by the domain and angles of repose. The "bulk material locations" are the drop-sites, depending on the variable of dump-truck or barge, determined by the designer within the script at this early stage of the work. A solid mass is created by the script for each "drop-site" which, once crushed and deposited at the angle of repose, would compose the finished volume of the drift.

The Rhino model is "baked" and exported from Grasshopper and now an OBJ file is imported with the base terrain into the Blender interface. Within Blender, using re-defined parameters of the "Cell Fracture" function, the aggregate is crushed to the desired specification. This cell fracture function is breaking the delivery or bulk-volumes prior to their being dropped. This crushing process, if finer material is desired, is one of the most intensive computing processes. Once the material is crushed and bulk volumes arranged in their preliminary order of operations and, at the appropriate drop-height from truck or barge, the physics properties, within the native Blender interface, allow specific gravity, weight properties, and "bounce / stickiness (i. e. surface material condition to be set for the simulated drop)." The final step is a simulated "clean-up pass" through the bulldozer blade function or excavator condition; that would certainly be a next step to explore through more autonomous means of computational intervention.

Fig. 3: (Left) Old Quarry by Reed Hildebrand Landscape Architects (HILDEBRAND 2020); (Right) South African settlement patterns responding to context of the geotechnical nature of the site (UNEQUAL SCENES 2022)

2.3 Working with a "Less Predictable" Material Systems

Using the properties of physics engines rather than just geometric drafting software, complex geometries can be deployed by the designer in bulk, rather than having to draw or individually place each bespoke element (e. g. rocks, boulders, plant material).

Of all the components / materials we might control in the construction process, rocks are some of the most useful and abundant. They can be found everywhere, from deserts and cities to underwater, and even on faraway planets. Rock is one of the most common structural components of the universe, because it is essentially planet matter. Rocks are the geotechnical foundation of our world and other worlds we might explore. They have been the basic building block from ancient architecture, to science fiction design, to the parks we stroll through every day. The geometry of rock / aggregate is complicated; but if we can create tools to handle these complex components, perhaps we can also apply these tools to other complex built environments.

The traditional methods of documenting aggregate systems have been to first generalize an area, or "boundary," either in plan or section, and then apply a symbology and specification to that area. The information might describe the type of rock, size / gradation, compaction (if small aggregate), or provide specific directions on how to place the rock if representing larger boulders or stone materials. This process is in essence at the basis of low-resolution BIM / LIM technologies: such software creates a digital simplification / digital proxy and then attaches an informational tag providing the remaining information. However, this standardized approach works much better with materials that are culturally processed and consistent, leaving many aspects of the landscape as principal points of ambiguity, causing inefficiency in the construction of the built environment (RESCHKE 2018).

Rocks are organic and wild in nature; their shape, texture, gradation and material are directly linked to their context. Whether we encounter a steep ledge or a more malleable open delta, distinct differences exist in the aggregation of the materials which make up the underlying structure. These differences are based on physics (i. e. gravity, friction, etc.) and thus the computational engine or toolset for handling these types of materials is based on the natural state or angle of repose. The new software approach is simulating exactly what the material and physics would do in the real world. The designer only needs to place the bulk volume and assign a specification. Based on the specification, the simulated "crushed" or "individual" aggregate falls to its natural angle of repose. The designer can place the aggregate in their desired virtual bulk placement methodology (using dump trucks, bulldozers, barges, etc.) just as within the physical built environment.

2.4 Surface + Centerline (Control Through Flow Paths)

Modelling enables the designer to go beyond the exterior or" top-down" visible surface of the landscape, but inherently asks the designer for more input up-front to support the third dimension.

We can see in the sketch how most architectural software runs primarily off a vertical geometry, and then distributes program and information across the axial sections or "floor plans." Through civil engineering software the corridor or centerline-driven control of infrastructure in the landscape connects cross-sections along the profile.

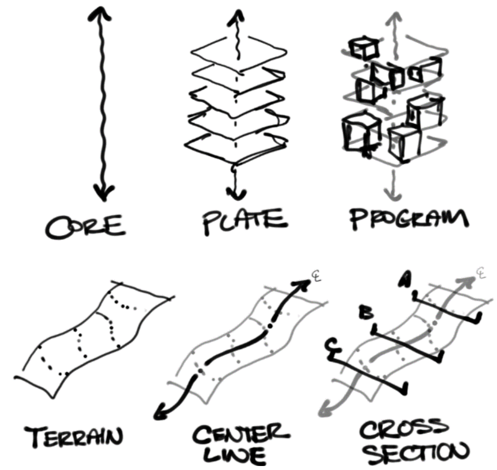

Fig. 4: Sketch comparing the foundational input / control curves or lines from architectural and civil engineering software

The physics or aggregated modeling approach taken in this paper allows blending to occur through the build-up of many objects, rather than the binary definition of "bounded surfaces".

2.5 Time + Digital Craft

We tend to assume that because a line is "in the computer" that that geometry must be resolved to its n^{th} degree. This is a fallacy. Unfortunately, we are forcing this requirement on digital media when we are more forgiving for a concept in printed or physical model form (MCCOLLOUGH 1998). Most 3D software commonly used for terrain modeling (Rhino, Civil3D, LandFX, Sketchup, etc.) can begin developing a surface terrain with as few as three points to triangulate. As additional information is fed into the system, the surface can evolve. In my experience we are falsely blaming digital surfaces for being "incorrect" or "unable to represent finesse" in the landscape when, in reality, we simply do not apply the time and craft to these surfaces that we do with our contours and spot-grading exercises. Good design takes time, whether digital, physical, 2D, 3D, or 4D.

So then why do we bother putting things into 3D, or virtual format? I would argue that if we focus on break lines, ridges, and flow-paths as the elements of calculation, input and design, then our virtual models will be much further resolved and thus be able to extract contour lines which actually represent a desired intent. Or will we need the contours at all? Ultimately, contractors using grading equipment are looking to a TIN (triangular integrated network) surface or point-based data as primary means of construction. If landscape architecture is going to remain relevant, the pedagogy in grading and drainage representation must begin to focus on a different set of inputs, a different shorthand for communicating and processing geotechnical formations.

2.6 Examples + Experiments of Centerline Landscape Models

The following example abstracts and attempts to recreate a portion of the Old Quarry project by Reed-Hilderbrand Landscape Architects (used with permission) (HILDEBRAND 2020). By sketching only a few centerline curves and computing or automating the rest of the model algorithmically, rather than getting a literal interpretation, we end up with an abstracted but reasonable approximation of the landscape. The volumetric calculations of the aggregate materials leverage algorithms developed in 2019 by Huang and Luo. However, due to the digital nature of the model in this case, the field-imaging component of their research is adapted to use visual renders or screen-captures from the software (HUANG et al. 2019).

The example builds on several years of work in landscape boulder manipulation and computation of individual 3D scanned aggregate objects described in the 2019 paper by Mekies and Tal (MEKIES & TAL 2020). An important question arises, however. Can landscape architects compute wild materials such as boulders or aggregate in bulk with enough intent to approximate the results of otherwise painstaking on-site manual feedback processes? And, returning to the thesis question, how might new geotechnical approaches to computing aggregate + aggregations of other "wild" materials impact urban design?

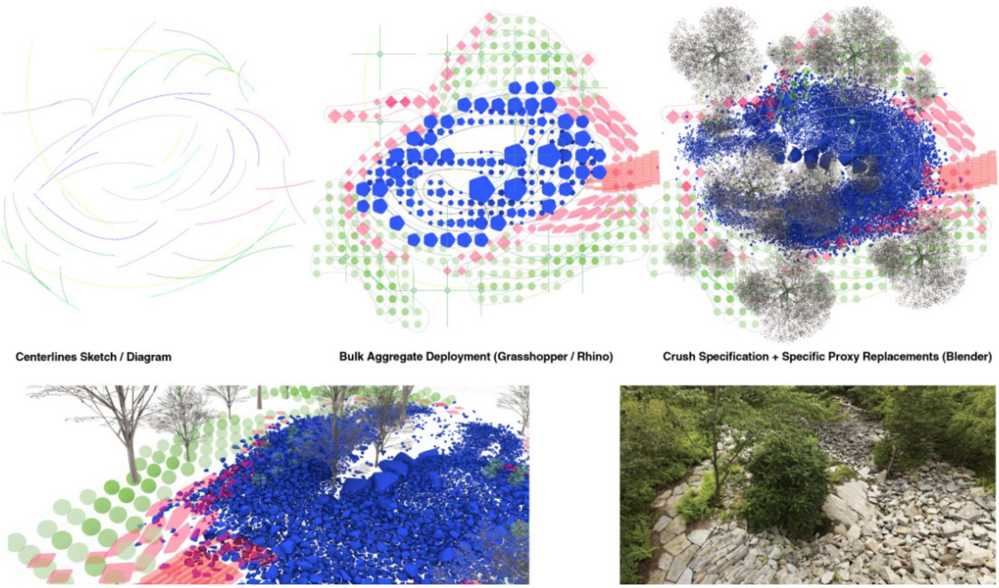

Fig. 5: Computational approximation of the Old Quarry Garden by Reed Hilderbrand Landscape Architects. Produced in Rhino, Grasshopper, and Blender with custom bulk aggregate distribution and physics deployment

The algorithms developed in this process allow for a simple curve or arcing gesture of a hand to represent an aggregated three-dimensional landscape. Many of the vector applications in mobile technology would be effective input devices if linked to this new toolset.

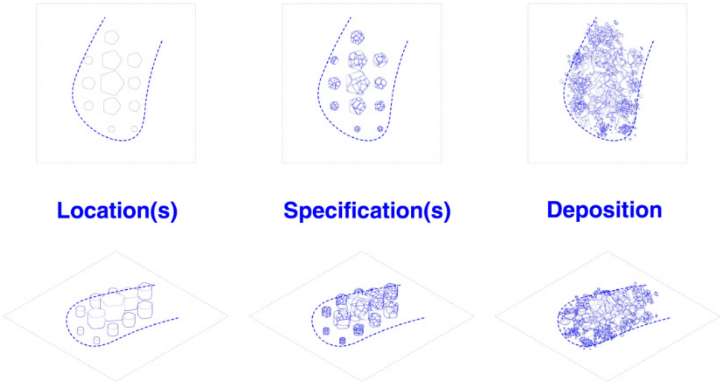

Fig. 6: Distribution of the bulk aggregate locations, crushing of the aggregate specification, and deposition of the aggregate through physics are shown in stages which composed the computed drift below

2.7 Input + Control Curves

In dealing primarily with rock as an aggregate system, the primary influencing geometries, from the designer's point of view, are often that of ridge or flow-line (i. e. high point and low point). These principles of control in the land-forming of a site act to either raise or depress a portion of the landscape. However, in the instances of a geotechnical urbanism approach, the control curves yield the bulk volumetric distribution of the specified materials which make up (build up) that landscape.

The input curves either push up or down on the terrain. Normally, landscape architecture simply documents the finished surface through contours in this drafting toolset. These software methods actually compose the volume within the surface, building that volume out of earth, sand, rock, or whatever material is specified. While working digitally in "wild" aggregate contexts is an emerging trend, as illustrated in particular by practices such as Scape SCAPE (2021), the work of Gunther Vogt (VOGT & KISSLING 2020), or the work of Bradley Cantrell (CANTRELL et al. 2017), the growing need to work with these materials is still a tremendously demanding and intensive design exercise.

The new software toolset does not apply to any one landscape process or function but to the broader set of materials and forms that landscape architecture, and its related disciplines, apply to solve the challenges presented. Rather than the landscape architects over-simplifying the aggregate they wish to draw, or spending days individually modeling each component, only a "centerline curve" needs to be drawn. The centerline curve is simply a control point or handle by which to ease the process of design.

Landscape architects are used to expressing their ideas by drawing curves, and these new tools simply make that one curve yield so much more: outer domain limits of the drift, bulk pile delivery locations, total volume of material, and final placement of the individual aggregate based on its angle of repose (i. e. a volumetric model) (LI & MOSHELL 1993).

3 Applications of the Toolset to Sea-Level Rise

Sea-level rise is the most salient use-case for applying these new technologies for two reasons: The materials and form-giving typologies of the software cater to the types of work and exploration in coastal resilience parks, wave breaks, and habitat creation. The amphibious landscapes of coastal resilience and sea-level rise mitigation have accepted a more "wild" aesthetic and looser tolerance for material placement.

As water levels rise throughout the world, more people are vulnerable to devastation. Among those are some of the poorest in the world, living in marginalized areas geographically prone to flooding and weather-related destruction. Time, money, and priority constraints are major obstacles. While modular construction, mass customization and systems automation are transforming building efficiency and the field of architecture itself, our exterior resilient infrastructure is being aggregated only one rock at a time.

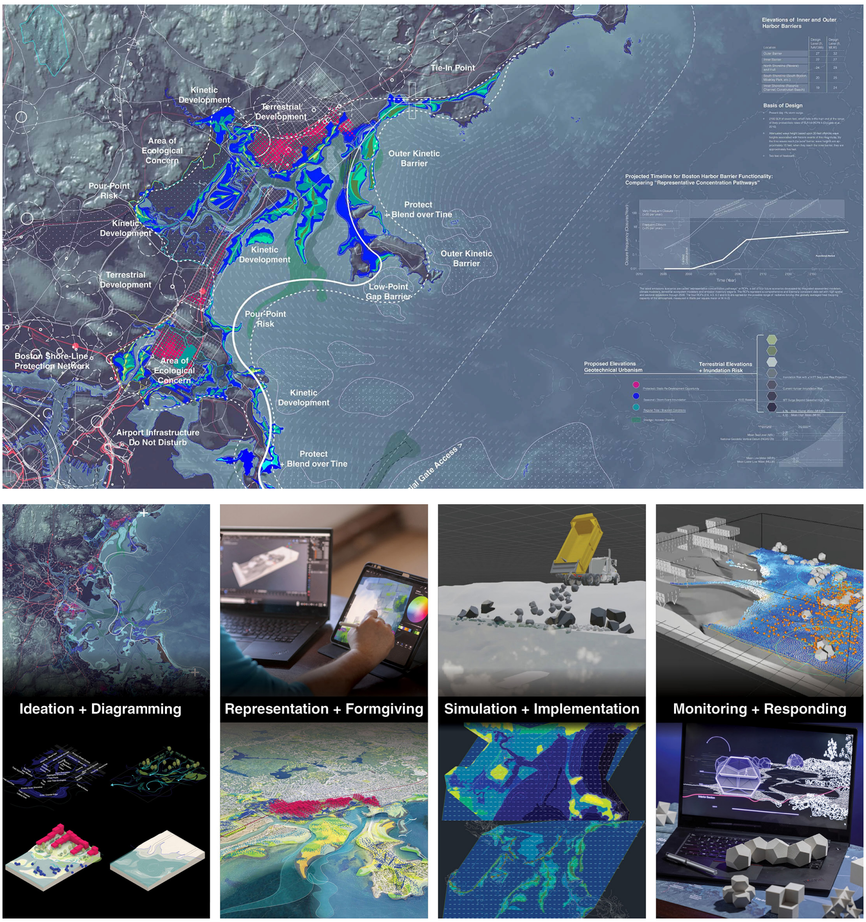

Fig. 7: Bulk aggregate scoring / deployment of a geotechnical infrastructure along the Saugus coastline north of Boston, MA

Without intervention, an estimated 300 million people around the world would be overcome by flooding by 2050 (KULP & STRAUSS 2019). Millions of stakeholders live along a million miles of coastline in vulnerable areas, all needing protection. This represents but one challenge to our built environment as we address the protracted debate between "cultured" and "wild" aggregate systems.

Software Trade-offs and Programs Considered

At the time of this research (2021), from a physics simulation of "crushing" and "distributing" perspective, the software platform Blender as the open-source engine worked well. However, in the fluid and suspended sediment simulations around coastal sea-level rise applications of testing the aggregate formations, Blender's capacity was not optimal. At the time, two software programs I knew about, could perform the same particle / fluid simulations quite effectively. Those tools were Houdini, and X-Particles for Cinema 4D. However, these were expensive programs and add-ons at the time, not software typical landscape architectural offices would have readily on file. Houdini is considered by many experts, to be one of the most powerful tool for complex 3D modelling and simulation. However, it is also one of the most difficult 3D software programs to learn and remains a work in progress for me as of this writing. Houdini is quite a departure from the programs in the standard landscape architect tool kit, but a powerful and potential next step in expanding this experimentation of adapting game engines to deploying landscape / wild material systems.

In the space of fluid simulation and mathematical modeling of geotechnical strata, a number of interfaces / toolsets from an engineering end of the spectrum exist (GAO 2018). These interfaces however are not geared for intuitive experimentation in a design office, they are much more technically driven. The purpose of this exercise and paper was to develop an intuitive interface accessible at reasonable cost / learning curve to the average landscape / urban design practice.

The immediate constraint is to process the complex geometries through mass physics simulation. That is certainly within sight given the fast-paced advances in technology and the drop in the cost of cloud computing cycles. The time frames involved in iterating design on a standard designer's workstation / laptop are onerous, for the moment, compared to the benefits of the open-source software availability of Blender and growing access to Rhino + Grasshopper across landscape architecture offices. Other ways of getting around the software challenge and addressing larger regional scales of sediment and geotechnical urbanist formations exist: (i. e. LIU & CANTRELL) at the University of Virginia (LIU & CANTRELL 2021). The approach involves training machine-learning algorithms toward prediction of these behaviors rather than calculating or simulating each aggregate instance at a site-scale physics interaction.

4 Conclusion

The results, ultimately, address seemingly intractable challenges to the ubiquitous use of wild material in landscape construction and, even more pressing, to the challenges posed to coastal urbanism and sea-level rise.

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