TWINNED ASSEMBLAGE

Curating and Distilling Digital Doppelgangers

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Abstract. Recent developments in digital fabrication have made increasingly intelligent use of machine visioning and 3D scanning. These technologies enable ever-higher resolution digital models of physical material, and present opportunities for physical material to gain agency in the design process. Digital design workflows using such technologies require ever-greater computing power as the resolution of digitized models increases, and high-fidelity 3D scanning systems become cost-prohibitive, creating obstacles to widespread use. Twinned assemblage uses consumer-grade photogrammetry software, lowering the cost of equipment required, and presents a series of distillation methods that strategically reduce the fidelity of data digitally describing a physical object. Distillation methods discussed include reducing a mesh to a low-poly geometry, identifying the location and orientation of an object's largest faces, and creating 2D sections, among others. These methods can be designed intentionally to extract or highlight certain qualities in digital models, that in turn inform aggregation strategies generated through computational simulation. This paper presents several examples of such aggregations in a variety of materials, conveying benefits and challenges of the process. Such methods present opportunities for granting agency to physical materials in the design process, and for the democratized use of digitizing technologies.

Keywords. Authorship; Digitizing; Material Agency; Digital Design; Democratized Technology.

1. Introduction

Traditional authorship in architecture is exercised through a sequence in which the production of design documents precedes material acquisition and construction. Several recent projects including Tree Fork Truss at AA Hooke Park, Cyclopean Cannibalism at MIT, and elsewhere have reordered material's role within project delivery, beginning with raw logs and raw concrete fragments and shaping a designed form to fit and minimally reduce these inputs (Devadass et al, 2016; Clifford and McGee, 2018). Building on these developments, this paper examines how a physical collection of parts can be digitally documented, analyzed, indexed, and controlled, in particular how processes of distillation of the digital translation

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can grant objects agency within the design of an aggregate assembly – allowing parts to influence a whole in a dynamic give-and-take.

Found material collections are scanned and digitally aggregated using a series of low-cost, democratized simulation and modeling techniques. This methodology was performed by a group of collaborators working remotely, each of whom worked with a unique collection of found objects/materials. The workflow consists of curation and labeling of a physical collection, translation into a twinned collection of digital meshes using consumer-grade smartphone 3D scanning, distillation of digital meshes, and parametric aggregation strategies followed by physical assembly. Selective distillation of 3D scan data is employed as a principal strategy, allowing the designer to isolate characteristics of the objects that inform aggregation methodologies and develop parametric understandings of the meshes according to these biases.

Digitized collections were analyzed in Grasshopper using several methods to generate aggregations. Building on past scholarship using 3D scanning to optimize highly variable biomaterial parts, material eccentricity was embraced opportunistically (MacDonald et al, 2019). The aggregation strategies fell into three categories: 2D/3D packing, gravity physics simulation, and spring physics simulation, described in system diagrams that convey goals, techniques, and relationships. The methods are illustrated taxonomically in order to compare multiple variations of the approach. In all cases, the final physical aggregation was determined in part by the eccentricities of the collected objects.

2. Methods

The methods described herein lay out a series of steps in using twinned assemblage to generate digital aggregations that can be replicated physically. These steps include inventory curation, digitizing, distillation, aggregation through sorting and simulating, and physical assembly. Also discussed are the approach's implications on remote practices. Several example projects are described and shown, illustrating how the process can be adapted to different input materials and aggregation strategies.

2.1. INVENTORY CURATION

This research was developed and piloted through the serial curation of several collections of physical artifacts – found objects not created by the designer. Each collection ranges in selection criteria, from a common fabrication method to a shared biological or geological origin. Objects were inventoried with labels for referencing – a critical step to maintain a relationship between physical object and digital model, so that one can track where any single object is placed in an assembly.

The act of curation is viewed as a design problem and can be contextualized within a range of historical examples and precedents on collection. The late antiquity practice of spoliation, the sixteenth century *Wunderkammer*, and Sir John Soane's House collected and arranged architectural fragments and material objects, while the first open-air museum Skansen and a rich history of World's

Fairs collected and assembled entire buildings, both regionally and globally (Nilsson, 1906; Furján, 2004). Meanwhile, digital aesthetic culture has further seen the rise of collection, notably in James Bridle's New Aesthetic, which collected virtual tropes in a continually expanding Tumblr feed (Bridle, 2011). Within contemporary architecture, the collection and translation of digital objects into buildings is increasingly widespread: design leaders such as Mark Foster Gage kitbash digital models as a manifestation of Object-Oriented Ontology into architecture; in conventional professional practice, DIY open-source models on GitHub, ready-to-print models on Thingiverse, and product specification libraries in BIM packages such as Revit shape a built environment of assemblage (Gage, 2015).

The curation of a collection of materials to be digitized is important from a conceptual perspective, but also a practical one. The following distillation methods will be more accurate if the inventoried objects are of a similar form family, so that similar qualities can be extracted from the collection to inform aggregation methods.

2.2. DIGITIZING

Once each physical collection was curated and labeled, it was translated into a twinned collection of digital meshes using photogrammetry software (Figure 1). Professional 3D scanners (hardware and software systems that retail substantial sums) were tested but produced cumbersome data and large files that were difficult to share and open in Rhinoceros. Additionally, the high resolution produced was deemed unnecessary for this application. Instead, consumer-grade smartphone 3D scanning applications were found superior in meeting research objectives, with the authors settling on Qlone and Trnio for their efficiency, economy, and user-friendliness. Model resolution in scans produced using these apps was more than sufficient for current applications. Once scanned, digitized models were compiled into a single Rhino file, often arranged neatly in a grid with labels corresponding to the labels on the physical inventory.

2.3. DISTILLATION

Distillation methods are selected and implemented on a per-assembly basis and are aimed at two goals: reducing file size and computing time to use many digitized objects in a single file, and to analyze inputs to selectively isolate characteristics that inform aggregation methodologies and develop parametric understandings of the meshes according to these biases. These biases are constructed based on object properties and underlying orders such as geometry, volume, dimension, etc. and subsequently drive aggregation strategies. The term distillation is used here to describe both an act of reduction and a concentrating of certain qualities, building on Merriam-Webster's definition, 'to extract the essence of' (*Merriam-Webster*, 2020).

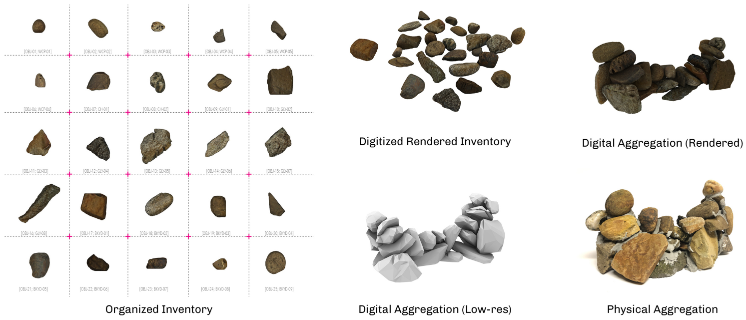

Figure 1. Physical and digital inventory data. Work by Kristin Pitts.

Distillation methods varied depending on which object qualities were needed to progress toward a certain aggregation strategy. Such methods were executed parametrically, and included simplifying a mesh to a low-resolution, low-poly geometry, identifying the location and orientation of the object's largest faces, reducing objects to critical 2D sections to use in packing simulations, and contouring models to interpolate centerlines, among others. If the number of undistilled models in a single Rhino file demanded too much computing power, models were distilled individually before being composed into an inventory within a single file.

Running physics simulations and evolutionary solvers with Grasshopper on one to two dozen 3D scanned meshes on average consumer-grade laptops often proved to be prohibitively slow, if not impossible. Distillation methods enable the creation and visualization of iterative results and allow the designer to control which qualities of the objects are primary factors in aggregation methods, described below.

2.4. AGGREGATION THROUGH SORTING AND SIMULATING

The distilled digital collections were analyzed in Rhinoceros using Grasshopper and a variety of plugins including Kangaroo, Galapagos, and Firefly, among others. Designers developed the methods for generating aggregations, but in all cases, the exact qualities of the final aggregation were determined in part by the irregularities of the collected objects – eccentricities highlighted through distillation.

Before objects were aggregated, they were computationally evaluated and sorted. Sorting criteria, like distillation methods, were assembly-specific and selected with a particular aggregation strategy in mind. Inventories were sorted according to qualities such as overall size (volume measurement), average circumference (section and area measurement), surface coloration (through scanned photographic data), or surface texture. Each sorting criteria was calculable using straightforward Grasshopper scripts. Objects were often positioned in 2D or 3D digital space according to sorting criteria before being aggregated through a digital simulation.

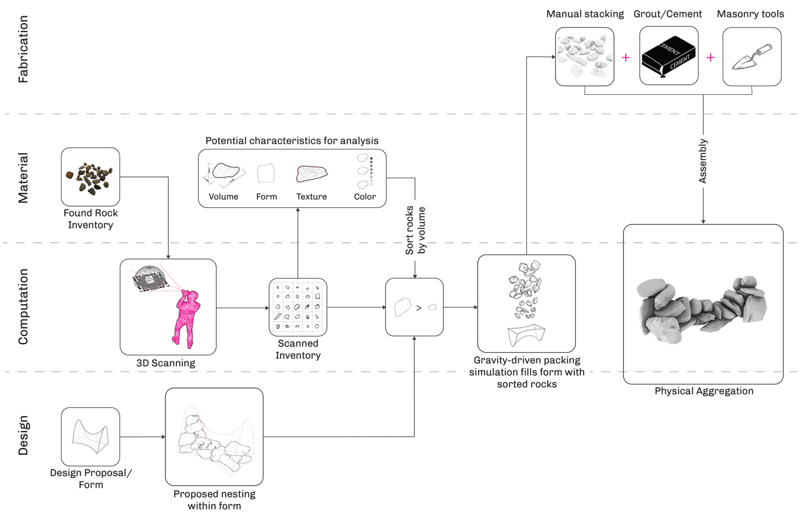

Figure 2. System diagram describes rocks scanned, sorted, and packed with a gravity simulation, that are then physically assembled with mortar. Work by Kristin Pitts.

Following in the vein of projects that use 3D scanning to optimize highly variable biomaterial parts, material eccentricity is viewed not as a barrier to aggregation but an opportunity (Devadass et al, 2016; Von Buelow et al, 2018). The aggregation strategies fell largely into three categories: object packing (2D or 3D), gravity physics simulation, and spring physics simulation. Aggregation strategies were described in relation to other steps in the process through system diagrams that outline contributors, relationships, processes, and negotiations (Figure 2). In each case, the aggregation strategy was enabled by and used data filtered or organized by the prior digitizing, distilling, and sorting techniques.

2.5. PHYSICAL ASSEMBLY

The final step in transitioning from computational model to physical aggregation is the design of the joinery between objects. For some, the objects themselves formed the joint – for example, the interlocking spines of pinecones, the tied laces of a collection of shoes, or the dry stacking of stones. In others, a secondary system of attachment was implemented – mortar, hot glue, melted wax, etc. The irregularity of each inventory and lack of a pre-defined method for joining objects posed the greatest challenge for implementing this approach. It was anticipated that distillation would produce discrepancies between physical objects and digital models, and the most successful assemblies took this into account when determining a joining strategy. Joinery method of the physical aggregation should be considered early in the digitizing process, so that decisions about distilling, sorting, and aggregating can be shaped accordingly. The use of a clear system diagram can aid in developing these relationships in different parts of the process simultaneously (Figure 2).

2.6. REMOTE PRACTICES

The methodology employed throughout was developed to allow multiple collections to be assembled remotely by designers during COVID-19, using consumer-grade technology rather than professional visioning and fabrication tools. Technology employed was limited to consumer-grade scanning and industry standard software, all run on personal laptops. The variety of collection types shows the adaptability of this approach. The leanness and distributed authorship of the resulting aggregations demonstrate how democratized visioning and parametric modeling can be deployed economically to produce bespoke physical assemblies of irregular parts.

Figure 3. Taxonomy of assemblies.

3. Results

Several distillation and assembly workflow examples are described. These and additional examples are illustrated taxonomically in order to compare multiple strands of a central approach – the orchestration of a complex group of physical objects via 3D scanning, distilling, parametric analysis, and simulation (Figure 3).

3.1. GRAVITY SIMULATION

A collection of round rocks was inventoried, sorted, and positioned in three-dimensional space based on size. Rock meshes were reduced by 50-75% to maintain formal definition but to reduce complexity for simulation. The digital collection was then packed into a form using a gravity and 3D object collision simulation with Kangaroo. The packing of rocks within the form was quickly iterated through many variations by editing the starting position of the rocks before being dropped (Figure 4).

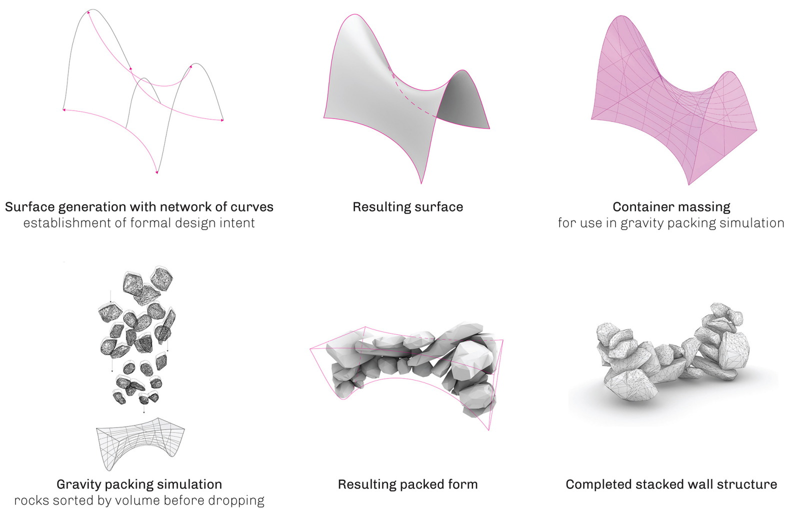

Figure 4. 3D packing with volume sorting and gravity simulation. Work by Kristin Pitts.

3.2. 2D SPRING SIMULATION

A collection of crushed aluminum cans was scanned and oriented uniformly within a grid in Rhino. Two longitudinal sections were cut through each can, each reducing the geometry to a single curve. These curves were aligned and pulled together into a stack using a 2D Kangaroo spring simulation. Iterations were developed by implementing a Galapagos evolutionary solver which attempted to create a stack of cans closely matching a goal curve drawn by the designer. Can stacking order was generated randomly, by cycling through the two different sections of each object to determine its rotation, and iterating through many possible combinations to approach the geometry of the goal curve.

3.3. 3D SPRING SIMULATION

A collection of angular coal fragments was scanned. These were distilled by reducing object meshes to an extremely low-poly count (over 90% reduction in face count). The reduced meshes were then analyzed by measuring and identifying the largest flat faces. The corners of these faces became the endpoints of spring lines for a Kangaroo spring simulation that pulled and twisted the objects into arched forms (Figure 5).

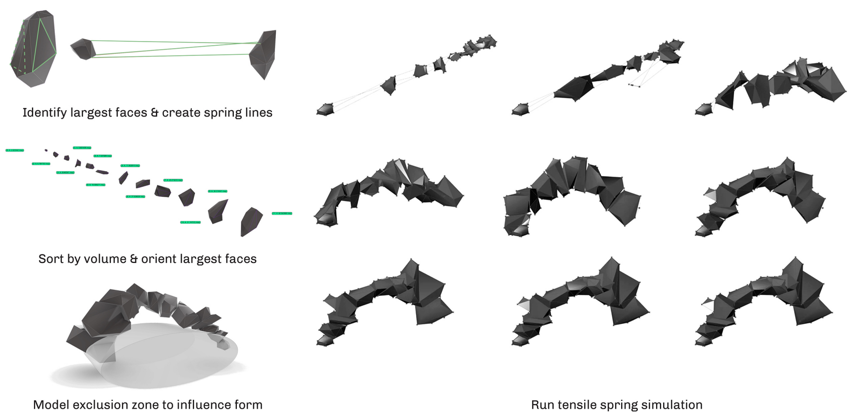

Figure 5. 3D assembly with face identification and tensile spring simulation. Work by John Michael Worsham.

3.4. PACKING AND FACE ALIGNMENT

A collection of slab-like rocks was scanned and inventoried. Each object in the inventory was relatively flat, allowing for the distillation process to reduce each rock to a simple straight extrusion using a section cut through the middle of each mesh. Distilled models were analyzed to measure the intersection angles of all edges, and the corners closest to 90 degrees were oriented together as the stones were stacked, forming a relatively consistent perpendicular corner within the stack.

4. Discussion

Techniques aimed at making digital copies of objects from the physical world have been underway for some time now – Mario Carpo describes the origins of digitizing methods: '[In the early nineties] several tools (some derived from medical instruments) were already available to scan and digitize all kinds of objects, regardless of their form, or formlessness. First, physical models had to be converted into their digital doppelgängers by scanning a sufficient number of their surface points. The digital process of design and manufacturing could then take over' (Carpo, 2011, p. 37). Carpo goes on to describe Frank Gehry's early digitizing practices as a 3D pantograph, in which points are located in three-dimensional space on a physical object and translated to a digital model. Until now, the emphasis of such efforts has been placed on increasing the accuracy, resolution, and overall fidelity of such doppelgangers. The progression of visioning technology toward more identical digital copies is unending and certainly has its applications in complex machining.

As an alternative approach, this paper identifies opportunities to reduce and abstract the information captured and stored in the digital model. It places a digital lens on the physical world and reduces the complexity of form to contours, centerlines, tones, etc. (much in the lineage of architectural drawings which reduce landscapes to topographic lines, stones to profiles, and materials to hatches). It argues for selective use of data; similar to Gehry's digitization, some points or edges are more critical than others in describing the essential qualities of a particular form.

For widespread 3D scanning of material inputs to inform digital fabrication methods, designers must refine strategies to oscillate between digital models and physical objects. The work presented here argues against focusing on increasing resolution and computing power, instead proposing that an intentional distilling – an abstraction – of the digital mesh allows the designer to control which qualities of the object affect a design. The work contributes to an expanded understanding of authorship in architecture: it is rooted in Michel Callon and Bruno Latour's Actor Network Theory, which understands objects to have agency – in this case, to shape an architectural whole in dialogue with the designer (Latour, 1988; Leach, 2016). Rather than design a form and use materials to make that form, this approach grants agency to the curator of parts and the parts themselves; it collects objects and reconciles their characteristics with a looser design intention, choreographed through the development of an open-ended parametric workflow.

High fidelity digitizing methods have proven useful in the fabrication of full-scale structural assemblies. Twinned assemblage contributes to this landscape of projects through a new approach to digitized data that intentionally distills computational models in order to extract specific qualities that inform an assembly. This inevitably produces a discrepancy between the digital model and physical object, which presents a challenge to scaling up the work and applying it to one-to-one constructs. Future work will explore methods of maintaining an acceptable tolerance between digital and physical dimensions and develop joining or attaching methods that can accommodate such discrepancies. In this sense, the approach may be more easily transferrable to masonry construction, where mortar can forgive a certain tolerance, than highly precise machined connections in lumber that demand a close fit. In the latter case, a design problem is presented wherein the design of such joinery must be able to accommodate a certain tolerance; the ethos of twinned assemblage advocates for viewing this not as a limitation, but an opportunity. The deployment of this approach in the construction of a structural assembly will also require a thorough understanding of the structural qualities of the physical inputs which populate the geometry, leveraging heuristic, form-searching methods of structural simulation (Carpo, 2017).

The approach defined in this paper responds to and seeks an alternative to the copy-paste aesthetics that result from specification using building information modeling – a tendency toward assembling products repetitively and with uniform means. It draws from a rich architectural history in which physical objects are collected and combined (spoliation, *Wunderkammer*, etc.) and the more recent development of the kitbashed digital object collection. The resulting workflow establishes and demonstrates a method for the aggregation of physical parts, using computational modeling as an analytical intermediary between the physical object and the physical assemblage.

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