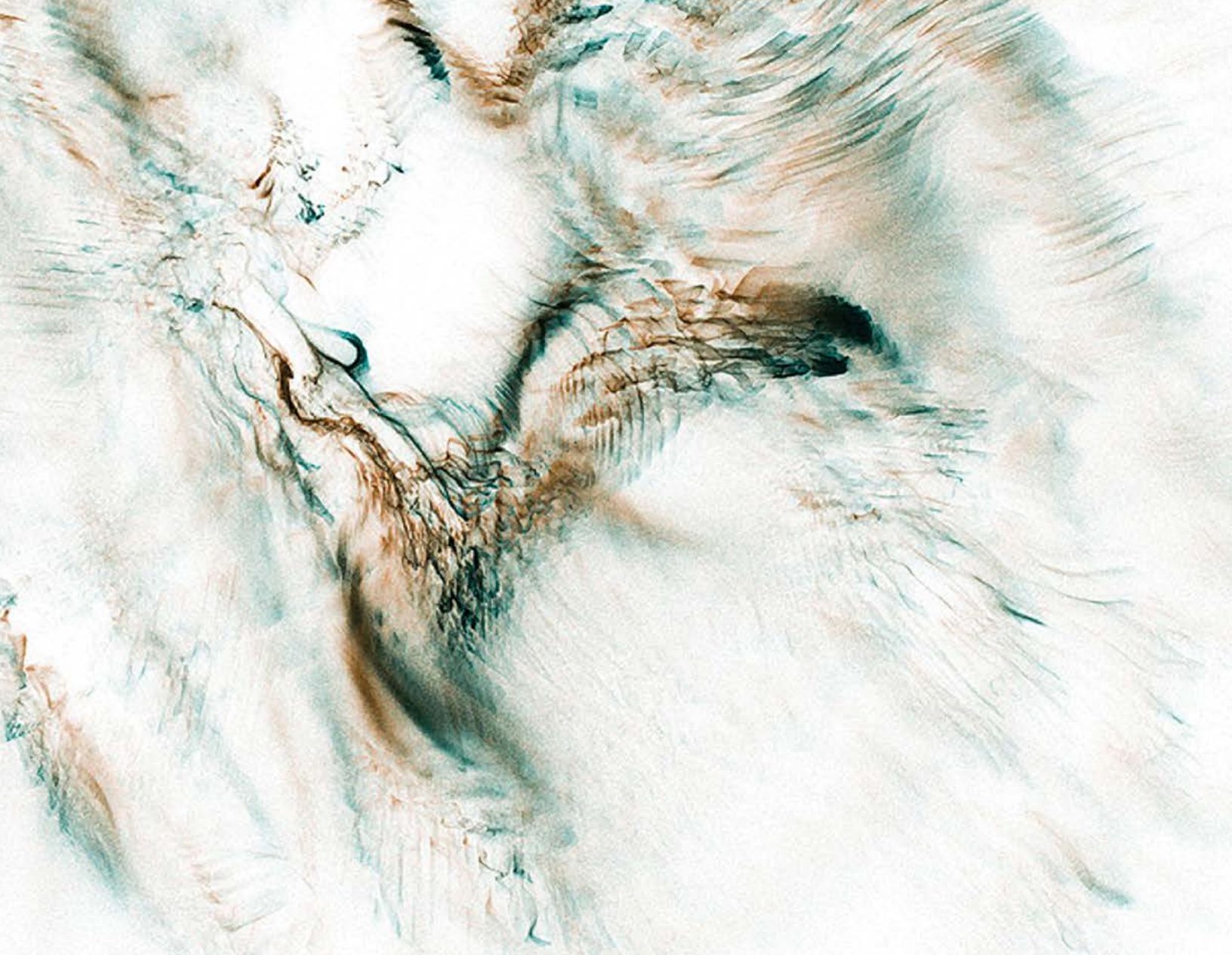


ACADIA // 2016

POSTHUMAN FRONTIERS:
DATA, DESIGNERS, AND COGNITIVE MACHINES

Proceedings of the 36th Annual Conference of the
Association for Computer Aided Design in Architecture

University of Michigan Taubman College of Architecture
and Urban Planning, Ann Arbor

Edited by Kathy Velikov, Sean Ahlquist,
Matias del Campo, Geoffrey Thün

TAUBMAN COLLEGE
architecture + urban planning
University of Michigan

POSTHUMAN FRONTIERS: Data, Designers, and Cognitive Machines:
Proceedings of the 36th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)

EDITORS
Kathy Velikov, Sean Ahlquist, Matias del Campo, Geoffrey Thün

COPY EDITING
Pascal Massinon, Mary O'Malley

GRAPHIC DESIGN
Rebekka Kuhn

PRINTER
IngramSpark

COVER IMAGE
Matias del Campo

© Copyright 2016
Association for Computer Aided Design in Architecture (ACADIA)

All rights reserved by individual project authors who are solely responsible for their content.

No part of this work covered by the copyright may be reproduced or used in any form by any means graphic, electronic, or mechanical, including recording, taping or information storage and retrieval systems without prior permission from the copyright owner.

Conference hosted by the University of Michigan, Taubman College of Architecture and Urban Planning,
Ann Arbor, Michigan.

Issued in print and electronic formats
ISBN 978-0-692-77095-5 (print)
ISBN 978-0-692-77096-2 (epub)

PROCEEDINGS

acadia // 2016

POSTHUMAN FRONTIERS:
DATA, DESIGNERS, AND COGNITIVE MACHINES

Proceedings of the 36th Annual Conference of the
Association for Computer Aided Design in Architecture

University of Michigan Taubman College of Architecture
and Urban Planning, Ann Arbor

Edited by Kathy Velikov, Sean Ahlquist,
Matias del Campo, Geoffrey Thün

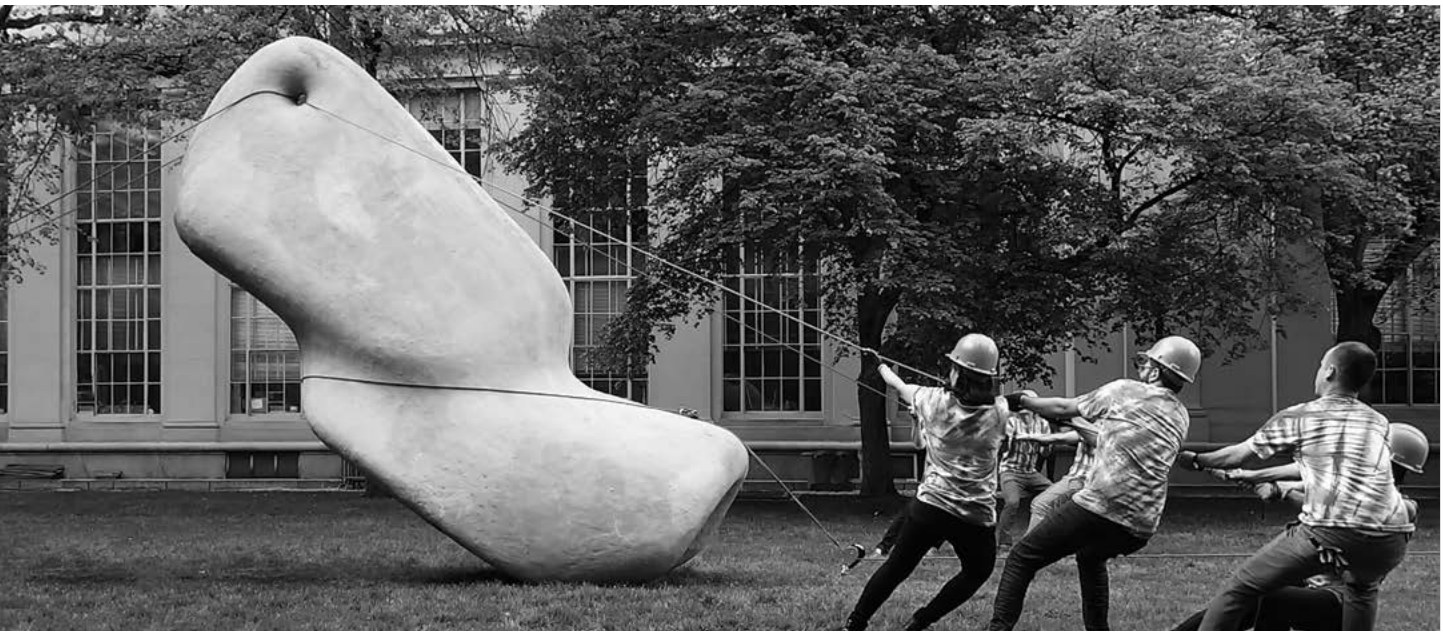
TAUBMAN COLLEGE
architecture + urban planning
University of Michigan

acadia

The McKnelly Megalith

A Method of Organic Modeling Feedback

Brandon Clifford
Massachusetts Institute of Technology / Matter Design



1

ABSTRACT

Megalithic civilizations held tremendous knowledge surrounding the deceivingly simple task of moving heavy objects. Much of this knowledge has been lost to us from the past. This paper mines, extracts, and experiments with this knowledge to test what applications and resonance it holds with contemporary digital practice. As an experiment, a sixteen-foot tall megalith is designed, computed, and constructed to walk horizontally and stand vertically with little effort. Testing this prototype raises many questions about the relationship between form and physics. In addition, it projects practical application of such reciprocity between architectural desires and the computation of an object's center of mass. This research contributes to ongoing efforts around the integration of physics-based solvers into the design process. It goes beyond the assumption of statics as a solution in order to ask questions about what potentials mass can contribute to the assembly and erecting of architectures to come. It engages a megalithic way of thinking which requires an intimate relationship between designer and center of mass. In doing so, it questions conventional disciplinary notions of stasis and efficiency.

1 Erecting, *McKnelly Megalith*, Killian Court: MIT, 2015.

INTRODUCTION

With carving starting around 1100 A.D., the Moai of Rapa Nui[1] weigh up to eighty tons apiece. Since the Dutch discovery of this Pacific island in 1722, visitors have wondered at these megalithic figures, asking the inhabitants how their ancestors possibly moved the statues from quarry to site. The Rapa Nui claim their ancestors never moved the Moai; rather, the Moai walked themselves. For centuries, this anthropomorphic explanation was considered superstitious poppycock by all but the islanders. It is this mystery that has fostered book titles by such as *The Mystery of Easter Island* (Routledge 1919) and *Aku-Aku: the Secret of Easter Island* (Heyerdahl 1958) by early researchers to the island. It wasn't until 2012 that Archaeologists Carl Lipo and Terry Hunt were able to prove the Moai were in fact transported in a vertical position (Lipo 2012;Hunt 2011). In a similar manner to how one might shimmy a refrigerator into place, the Moai were pulled back and forth by ropes employing momentum to transport these unwieldy megaliths. This (re)discovery brings new meaning to the assumed folklore that the statues 'walked themselves' from the quarry to the Ahu[2].

As with most megalithic sites, a feat of strength is challenged in order to produce a mystical spectacle. The challenge the Rapa Nui posed to themselves was to carve megaliths from a quarry in a horizontal position, dislodge these figures from the rock face and stand them vertically, then walk the Moai a considerable distance with relatively little energy. Once in position, they continued to carve and refine the statues in order to shift the center of mass back into a stable standing position. While the most common image of this ritual is the Moai lined up nicely on the Ahu, some (Hamilton 2008) have posited that the landscape of the quarry is equally calibrated, suggesting this wonder is larger than the objects. This ritual was a living process, not a design intended to result in a conclusion. In fact, a number of 'Road Moai'[3] are in a state of suspended animation. Carved to perform the act of walking, these Moai fell during transport and are still resting alongside the roads. The act of walking these massive Moai from quarry to Ahu must have been quite a spectacle.

In the digital era, architects and designers are employing computation to better inform their creations with concepts, principles, and constraints previously considered extra-disciplinary—structure, environmental conditions, physics, and material behaviors to name a few. When calibrating the center of mass to perform the movement behavior from quarry to site, the Rapa Nui were solving a multi-variable problem that bears similarities with the types of computation designers are working with today; however, the Moai are not the result of a problem-solving approach (engineering), nor an exclusively aesthetic concern (sculpture). Moai are a cultivated result of a conflated design practice that engenders practical concerns with cultural performance, which results in a marvel. This paper presents research into translating this ancient knowledge into contemporary computation methods. The result is a physical spectacle.

BACKGROUND

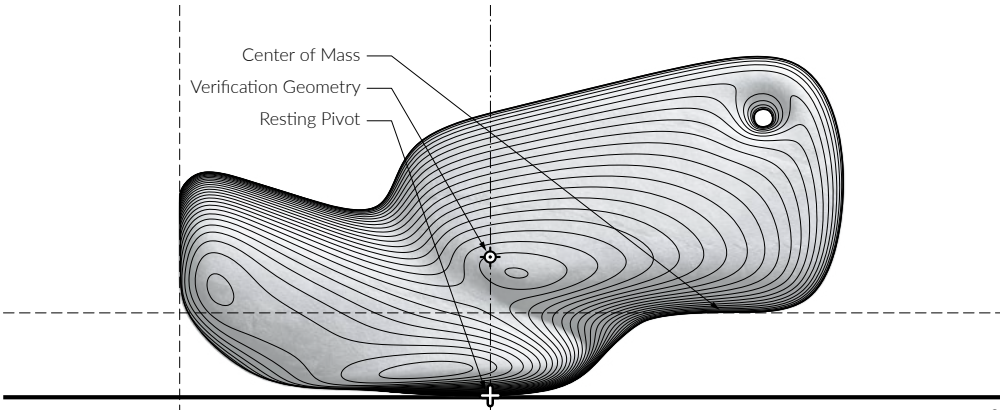
This research illuminates and exercises challenges of the megalithic era that become acutely problematic and hold resonance with contemporary practice. In proposing the act of transporting a large stone a distance and standing it vertically, the designer is required to become in tune with the center of mass relative to the desired actions and motions of the stone. This is not necessarily the case with heavy machinery, where one can overpower an uninformed geometry with a crane. In the world of the megalith, a failure to calibrate is a catastrophic event, but produces a different value set. Though commonly considered to be a hindrance today, mass is a tool for the presumably primitive civilizations that elected to work with megaliths. These stones are erected because of their mass, not in spite of their mass. This way of thinking is best described by Carolyn Dean in her influential book, *A Culture of Stone* (Dean 2010), which examines what is possible when a culture believes stone to be alive. While this challenge could be perceived irrelevant now that heavy equipment exists, there is a value in embedding topics such as mass into the design process in order to more intelligently assembly and erect architectures.

In developing reciprocity between center of mass and the figure's geometry, embodied computation allows the artifact to work for itself. One proof of this concept is the Gömböc, conceived of my mathematician Vladimir Arnold and later proven by Gábor Domokos and Péter Várkonyi (Domokos 2007). It has two states of equilibrium, one stable and the other unstable, explaining the mathematics behind how turtles right themselves. This delightful kinetic action builds a relationship between physics and form; a relationship that has entranced architects and engineers. For instance, recent work by John Ochsendorf (Ochsendorf 2010), Philip Block (Andriaenssens 2014), and others into compression-only structures is a contemporary expression of a time-honored tradition that includes Felix Candela, Antoni Gaudí, and Frei Otto (Rasch 1995). These works also deal with physics and the relationship with mass and form; however, they work under an assumption of singularity form-finding, or finding a form for a given constraint, often gravity. This motivation extends deeper through the compression-only structures of Gothic Master Masons, back to the megalithic eras where the immediate relationship is purposefully elusive. Why is this relationship largely absent from standard practice today? Perhaps the false assumption that architects should be relegated to producing representations of architectural intent has restricted the

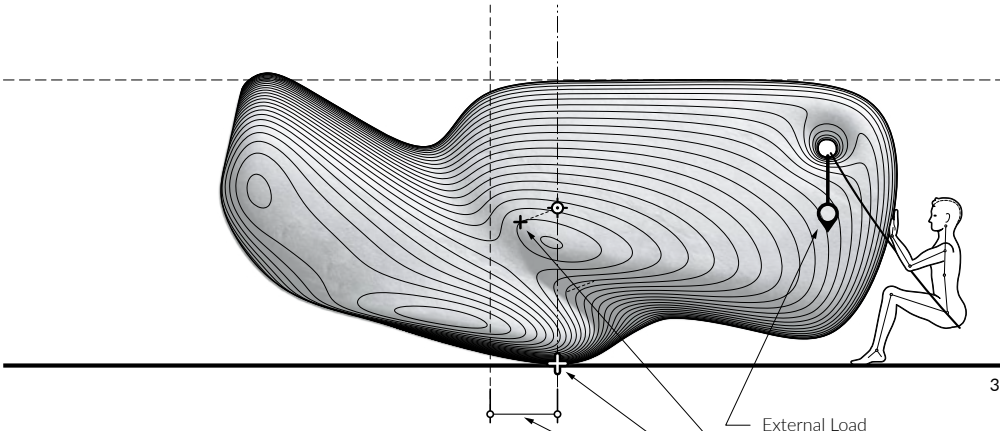
2 Resting Position – In this position, the center of mass is directly over the resting pivot, resulting in a stable equilibrium. Two verification geometries can be drawn from this position, the foot geometry is vertical to the ground and the chin is parallel.

3 Weighted Step Position – With the additional mass of one person to the eyehole geometry, the combined center of mass is disturbed, pulled closer to the head. This shifting of the COM results in a moment relative to the resting pivot rolling the megalith forward on the belly. Ultimately it finds a new stable position when the upper verification geometry strikes a horizontal.

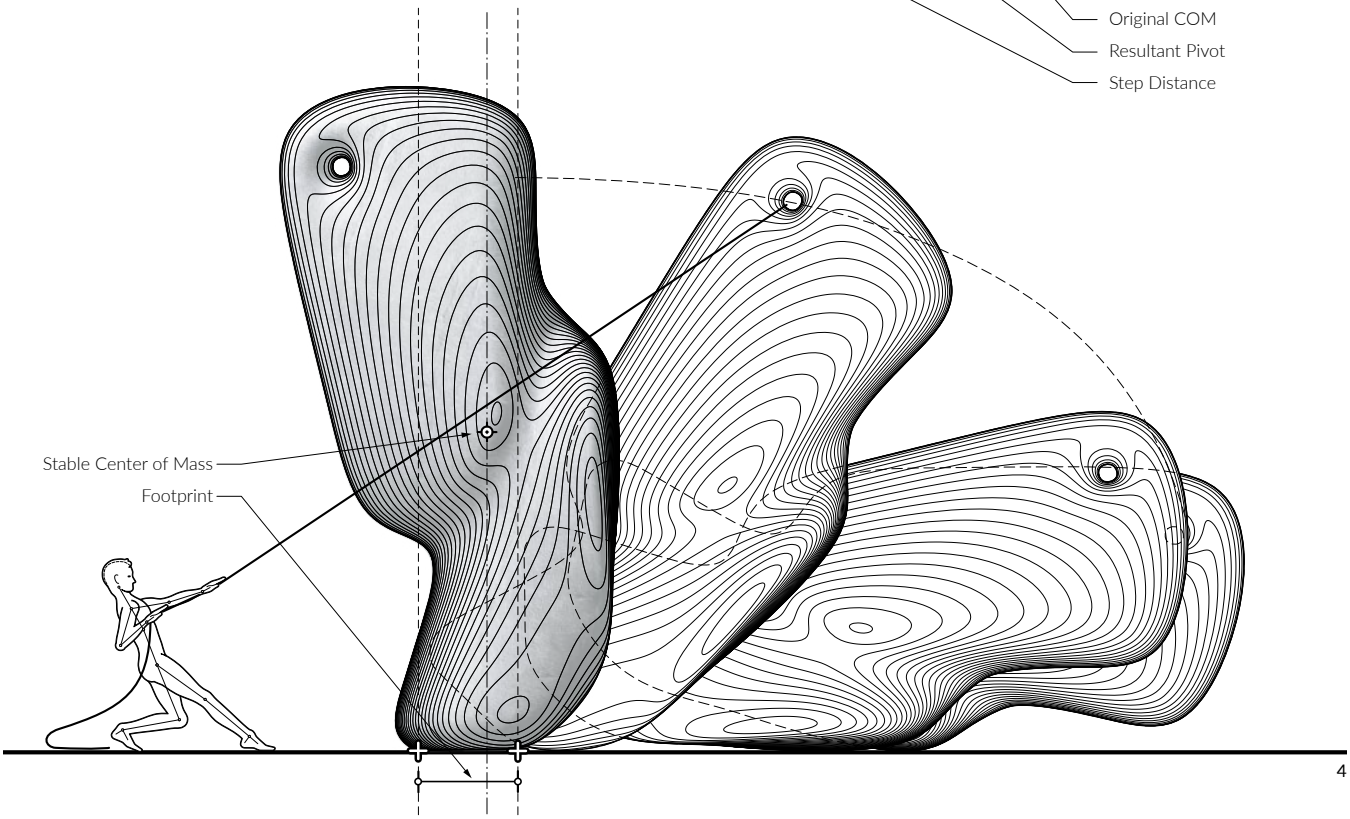
4 Standing Position – Once in the standing position, the original center of mass is above the 'C' shaped foot geometry, resulting in a stable condition.



2



3



4

profession to drawings, often uninformed by physical limitations, giving rise to the consultancy of architectural engineer. In spite of this false assumption, new research is developing design tools to re-integrate gravity with design, such as a paper by Axel Kilian on particle-spring systems for structural form-finding (Kilian 2005) and the recent work by Daniel Piker (Piker 2016) into building a physics engine titled 'Kangaroo.' As computation re-entangles our relationship with the physical world, topics from megalithic era knowledge are able to re-insert themselves.

A retired carpenter named Wally Wallington is dedicating his retirement to the problem of moving heavy things with little effort (Wallington 2016). While illuminating, his work operates under a similar assumption to those moving an Egyptian Obelisk (Dibner 1950)—that the form of the stone does not change, rather, the mechanism used to move it could be designed to be minimal. The research of this paper builds upon some of those findings, engaging them in a computation strategy for formal design, akin to the Moai of Rapa Nui.

The challenge of megalithic construction is to safely move a heavy object with little force. A vast majority of megalithic constructions evoke the mystery of transportation from quarry to site, and then the mystery around the erecting or assembly of the artifacts. These two mystical motivations exist in megalithic constructions, regardless of location or time-period—from Egyptian Obelisks, to Cairns and Henges of northern Europe, down to the Inca stonework, and over to Rapa Nui. The challenge proposed for this research is to design an artifact that intelligently transports horizontally and stands vertically. In doing so, it challenges the designer to create a single figure that resolves multiple stable conditions while simultaneously ensuring the forces required to transition between stable conditions can be safely accomplished within human abilities. The following paper illuminates this embodied computation process.

PROPOSED ACTIONS

Three positions are required to perform the action of walking horizontally and standing vertically. These three positions include the resting position, the weighted step position, and the standing position. While it is possible to design an artifact to perform any one of these positions, it is significantly more difficult to accommodate all three in a single object.

Resting Position

The resting position is a horizontal position where the megalith rests on the belly geometry. This position needs a base that is able to pivot, and therefore is required to balance on a point. In this position, the megalith needs to be able to spin, but should resist rolling over.

Weighted Step Position

By adding the mass of a single person to one end, the center of mass is shifted, allowing a new equilibrium position to be found. This new position should be far enough from the resting position to consider it a step. This weighted step position maintains the same program and constraints of the resting position, as the megalith will rotate 180 degrees in plan to release it back to the resting position—a second step has occurred.

Standing Position

The standing position is ninety degrees in elevation relative to the resting position. The challenge of reaching this standing position is significantly greater than the weighted step position, but only with respect to force. It does not have to deal with the pivot constraint. The participants should be able to erect the megalith from a 'safe' distance; defined by a radius around the object equal to height. Once in the standing position, the megalith should achieve a stable resting position able to resist wind-loads up to sixty miles per hour.

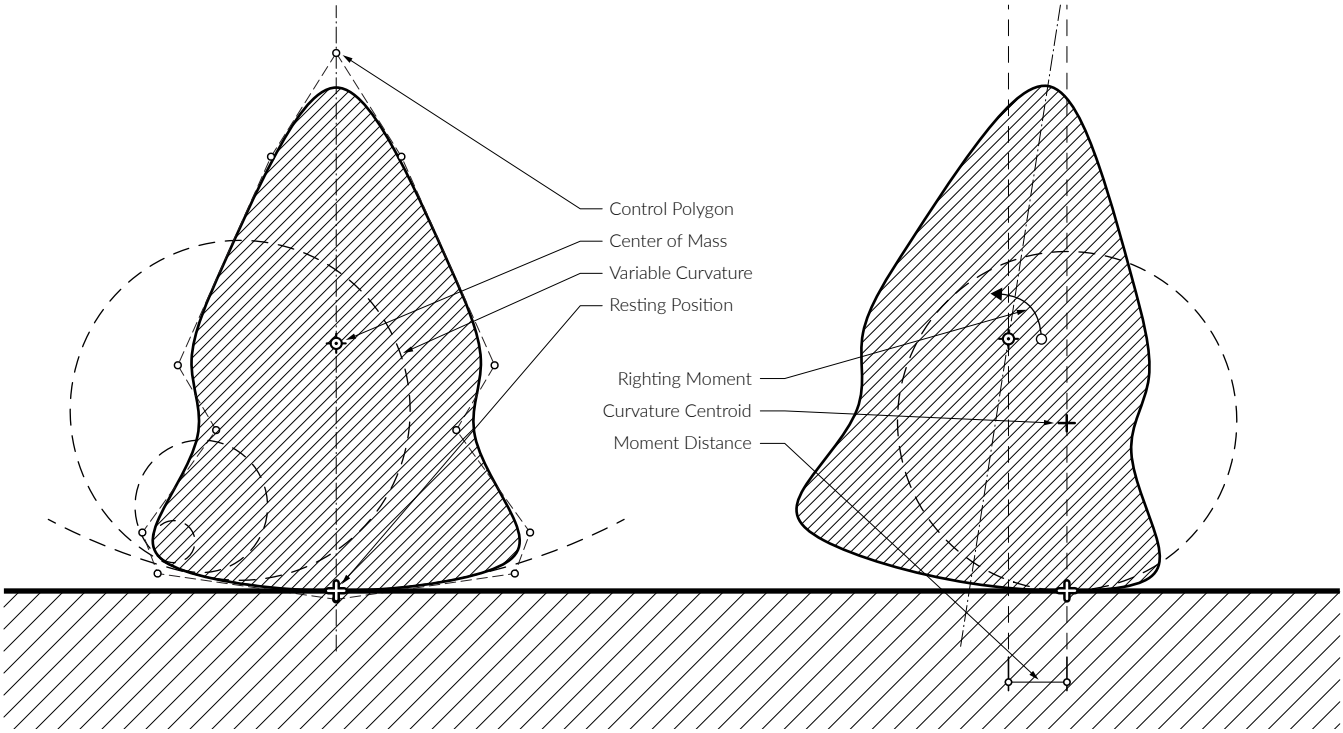
METHODS

The foundation of this method involves determining the location of the center of mass of an object and the effects it has on the object's form throughout the design process. This relatively simple calculation achieves its complication by adjusting the model to drive the center of mass where it is needed in order to resolve the three different scenarios. This method is broken down into geometries, computation, prototypes, and material methods.

Constant and Variable Geometries

The megalith is designed with a series of different conditions, some of which are fixed, and some variable. These conditions include the belly, rails, and feet, which determine how the megalith touches the ground. These also include an eyehole, which is a certain distance away from the resting point on the ground for maximum leverage. In addition, there are a number of verification and variable geometries.

Belly Geometry – The belly geometry is the lower surface that interacts with the ground in both the resting horizontal position and the weighted step position. This geometry needs to be able to allow the transition between the two positions as well as the ability for both to spin about a point. A perfect sphere would perform both of these tasks easily; however, the added constraint of stability is required. A cylinder would allow rolling in one direction and stability in the other, but does not allow rotation. To resolve this constraint, a bi-directional calculus geometry defines a variable curvature surface. This surface maintains an even curve between the two resting positions to ease this transition. The curvature in the opposite direction ensures that



5 Section describing the relationship between the curvature of the belly geometry and the height of the center of mass. When tipped to a side, a righting moment is produced resulting in a stable positioning on a single point to allow for rotation.

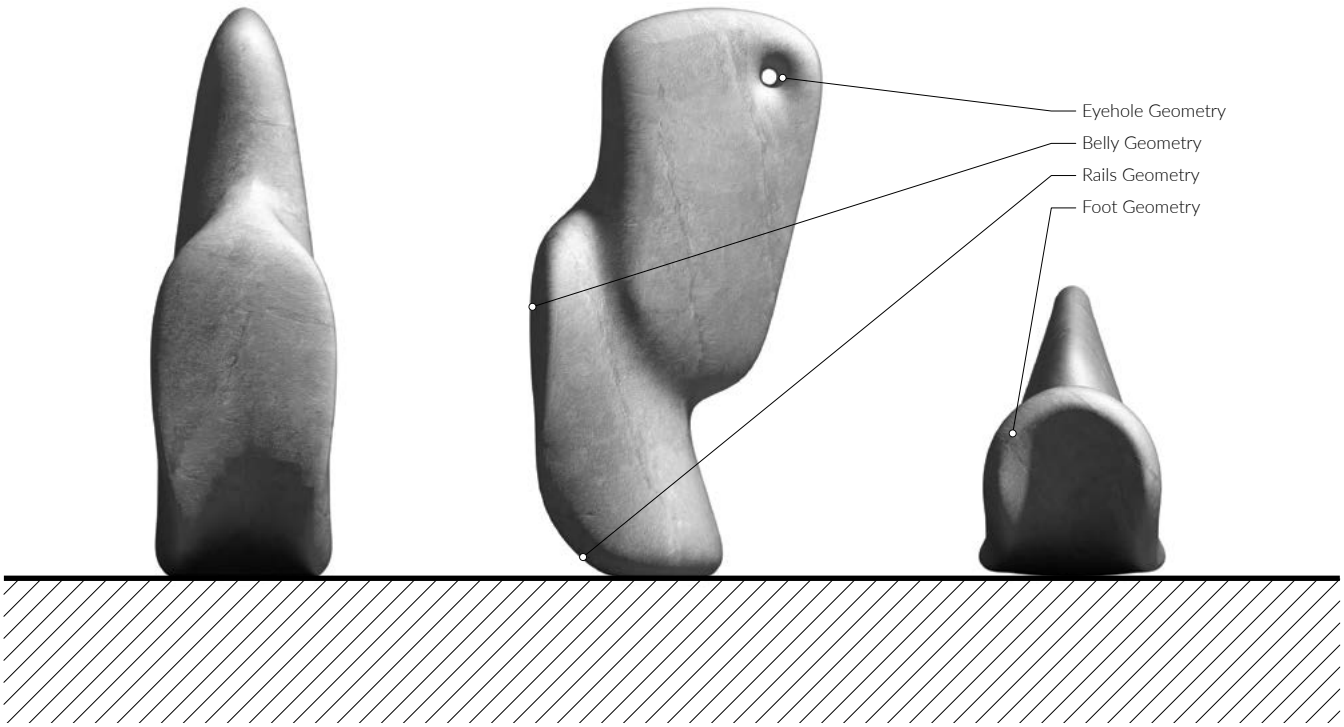
the megalith rests on a single point while resisting overturning. A constant curvature such as a circle allows a horizontal force to roll an object eternally because the center of mass is also the center of the radius. The geometry of the megalith has a large curvature at the resting position where the center of the geometry is well above the center of mass. This condition allows the object to roll easily, but the variable curvature rapidly transitions the radius from large to small, thus inverting this condition and transitioning the object from an unstable to a stable position. The result of this transition is a righting moment, which trusts from the resting pivot back to the center of mass until the object returns to the original resting position.

Rails Geometry – When the force is pulled down on the tail to erect the megalith into the standing position, the desire for being able to spin dissipates in favor of a stable and directional rolling up. Rail geometries emerge from the belly to provide the stability in the cross-axis, while the curvature of these rails attempt to alleviate the strain of standing the piece vertically. There is an unique moment of transition from a positive curvature of the resting belly to a negative curvature with two rails. This transition occurs seamlessly with curvature continuity derived from the calculus-based geometry.

Foot Geometry – Once in the standing position, the two rails transition into a 'C' shaped geometry where the rails are co-planar, providing a wide base for the megalith to stand upon. The center of mass is calibrated to stand within this 'C' shape, therefore ensuring stability. This 'C' geometry was favored over a flat base due to uncertainties about the flatness of the ground the megalith was performing on.

Eyehole Geometry – This aperture is employed twice, the first for the loaded step position, and the second to aid in the erection. For that reason, both of those forces gain the most leverage from being as far horizontal and vertical away from the center of mass. The eye is designed for a human arm to fit inside for the stepping position, where the most force is being placed. In this action, the entire mass of a human is pulling on this point, so a significant amount of material is placed under the hole to resist pullout. In the erection process, this concern is lessened as the ropes are mainly serving as stabilizers.

Verification Geometries – Because of difficulties in knowing the proper thickness of the Glass Fiber Reinforced Concrete (GFRC) coat, it was determined to provide a series of verification geometries in the megalith to verify whether it was performing as calculated when in these positions. For example, the chin is a curvature continuous with a horizontal line when in the resting position. This way, one might know right away if that is not striking a horizontal, whether something went wrong in the calculation, or in the application. The other verification geometry



6 Drawing locating the various geometric conditions.

is in the angle of the face. This angle is coincident with the angle of the weighted step to verify how far to pull the head down to make a proper step. In this project, these verification geometries are fixed as a design strategy; however, in future work, they could become dependent upon other constraints. For example, the angle of the face verification geometry could be derived from the distance of the eyehole from the pivot point. The further the distance, the easier it would be to pull the megalith into the step position, but the lesser the angle one could pull down before the chin hits the ground, thus relocating the eye hole and the face angle verification geometry.

Variable Geometries – While the previous geometries are variable throughout the design process, during the computation portion, those geometries become fixed and informed with parameters. Inside the computation loop, the variable geometry, which allows the center of mass to be driven where it is desired to be, are the cheek geometries. The cheeks are allowed to inflate or deflate to make the head heavier or lighter than the base, and they are also allowed to do this in the vertical dimension to lift or lower the center of mass, giving complete control over the location.

Computation

In order to properly compute this multi-variable problem, the computation is broken down in to deriving the center of mass of the object, operating on the object through recursive loops, and simulating the resting positions in order to validate those goals.

Center of Mass – In order to perform these three tasks, two different center of mass locations are required. The resting position and the standing position each share the same center of mass location. As there are no other forces acting on the megalith at those times, they are simply starting in two different positions and find different resting positions—horizontal and vertical. The loaded step position is not shared with the other two center of mass locations. It increases the mass of the megalith by the weight of a human. Given the form is produced of one lb/ft^3 density Expanded Polystyrene Foam (EPS) Foam and a half inch thick shell of GFRC (see materials), the calculation accepts a given geometry as input and parses these two materials by a volume and area calculation. The volume is assigned to the EPS foam, and the area to the GFRC. In previous iterations, the surface of the geometry offset the dimensional thickness of the proposed shell and calculated with that volume; however, the difference between the two was less than 0.001 inch, well under the tolerance threshold for this project. As a result, the area calculation was favored in order to increase the calculation speed. After the area is calculated, it is multiplied by the thickness of the coat to receive the proper mass of the GFRC shell. The resulting center of mass fulfills the requirements of the resting and standing position. In order to calculate the loaded step position, a point load of 160 lbs is added to the eyehole

geometry to represent the mass of a human. This pulls the global center of mass closer to the head, producing a new resting position on the belly geometry and thus making a twenty-four inch step. In calculating these centers of mass, the global mass without the point load needs to rest perpendicular above the belly in the horizontal position and needs to be low enough to maintain stability from rolling over. It also needs to be high enough to land within the footprint of the vertical position. This is a negotiation. The loaded step center of mass needs to pull forward enough to provide a step, but not so far forward that the head become top heavy, thus making the condition unstable. While the center of mass calculation can tell you where the COM is, it cannot drive the center of mass to where you would like it to be.

$$x_{cm} = \frac{\sum_i m_i x_i}{\sum_i m_i}$$

Variable Recursion – The input geometry is derived from a polygonal control point rig to produce a calculus-based curvature continuous surface with T-Splines in Rhinoceros. While a number of the control points are dedicated to creating the fixed geometries as described previously, within three points of those moments, a series of free points are variables to allow the center of mass to drive to the desired location. This calculation measures the distance between the current location of the center of mass and the desired location of the center of mass. As a fraction of this dimension, the variable points in the rig are scaled a proportional distance from the central axis, thus re-distributing the center of mass. This calculation is repeated until the COM distance difference is less than the tolerance (0.001 inches). As a result, the calculation adjusts the form to drive the center of mass to the desired location of the designer.

Resting Positions – While a significant amount of feedback is produced to ensure stability from curvature continuous surfaces, the simulation of resting positions is helpful for the designer to visualize what effects are being had when slight changes to the geometry are produced. For this calculation, a solver cuts a section through the model along the symmetric axis. Since this is a primarily directional calculation, the resting positions can be solved in section. From the center of mass of the object, the sectional curve through the artifact searches for perpendicular conditions between the curve and the center of mass. It then solves for the most likely resting position scenario by relaxing these angles relative to the given horizontal. These simulations do not animate the figure; they simply locate the likely resting position, or the point where the megalith interacts with the ground. These positions are then verified with prototypes and the verification geometries.

Prototypes

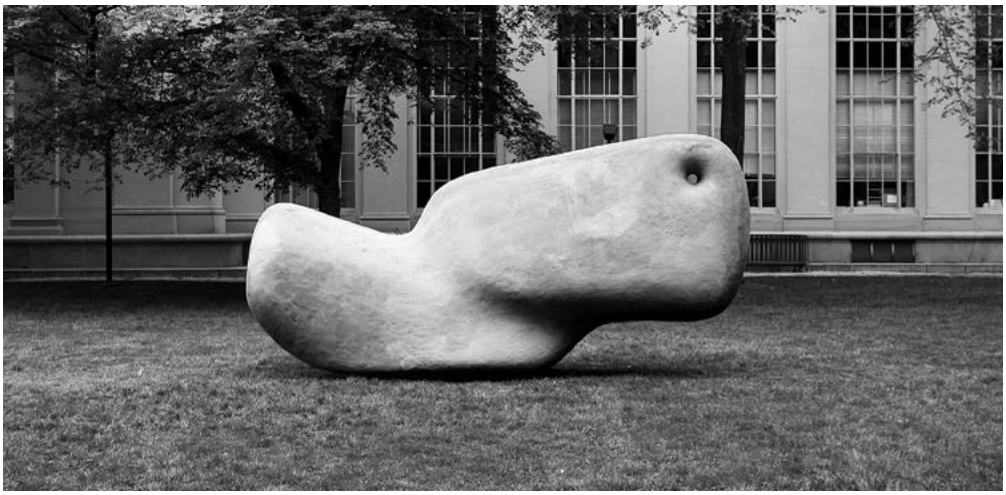
While the computation verifies the location of the center of mass relative to a geometry, it does not simulate the kinetic actions. In order to supplement this gap in the computation, physical prototypes are produced to validate claims. Powder rapid-prototypes served as an ideal form of prototyping. The final geometry is offset to produce a shell geometry, and the interior is hollowed out to re-locate the center of mass correctly. This is because a solid geometry volume centroid is not the same location as a surface area centroid. One can design a sphere with many wrinkles on one half and the area centroid would be pulled to that wrinkled half, while the volume centroid might not move. Once the ideal centroid matches the prototype centroid, the prints are tested. These prototypes served as incredible knowledge tests as they could withstand attempts to overturn, flip, re-right, and worst case scenarios before the final prototype was performed. They also served as devices to verify that geometries rock and roll at certain intervals when applied with forces from different angles, but return to the resting position in a repeatable manner. While an infinite number of geometries could balance the artifact in the computation, the physical prototypes allowed those geometries to become refined to better perform. For instance, the belly geometry is a difficult one to visualize in the computation, but in physicality, certain aspects become clear.

Materials and Methods

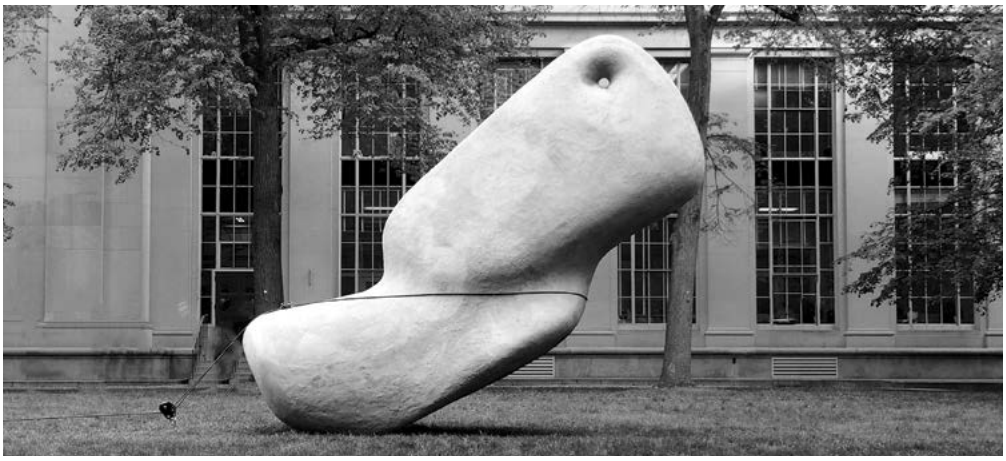
The megalith is composed of a solid core of Expanded Polystyrene Foam (EPS) and coated in a shell of Glass Fiber Reinforced Concrete (GFRC). This material method allowed the project to be constructed as a positive object coated in concrete to reduce the weight enough for safety and liability concerns, while providing a substantially heavy artifact to test. The difference in material density is appropriately calculated (see computation).

EPS foam core – The EPS foam core is subtractive machined on a 3-axis computer numerically controlled (CNC) machine in six-inch depths. These sub-units are then assembled with polyurethane glue in two halves. Once the two sub-assemblies have bonded, they are bonded to each other. Before this moment, the glue-up can be done on a flat surface with weights holding them in place, but when this bi-lateral glue-up happens, the two halves are ratchet clamped together.

GFRC Shell – The EPS foam positive is then covered in a woven mesh of glass fiber and turned on its side to receive a half-inch layer of GFRC. In order to ensure that the proper mass of concrete is applied, scales are used to give a live feedback and judge how many batches are required. Especially because the GFRC is sprayed onto the piece, some of the GFRC is atomized,



7



8

9

7 Resting Position, *McKnelly Megalith*, Killian Court: MIT, 2015. While perceived to be flat on the ground, this is the least stable of the three figures on this page. The belly geometry allows the megalith to teeter.

8 In the process of erection, *McKnelly Megalith*, Killian Court: MIT, 2015. From this position, one can see that a majority of the force employed to erect the megalith is forced down from the tail to a pulley which re-directs the rope. This allows the force to be at a forty-five degree angle at the height of the force, but also ensures once standing, the Megalith will not stand on top of it's own rigging.

9 Standing Position, *McKnelly Megalith*, Killian Court: MIT, 2015. This is a stable condition, with ropes running through the eyehole to stabilize the megalith during the erection process.

10

11

12

10 Image of the Belly Geometry while the *McKnelly Megalith* is in the standing position. Swirl stains from the grass can be seen from walking the megalith across Killian Court.

11 A bias view of the lower foot geometry demonstrating the 'C' shape which produces a flat foot.

12 A bias view from the front of the megalith, showing the tapper from the top of the head down to the chin, a result of the solver while trying to pull the center of mass lower.

or over-sprayed, making it difficult to judge based on the number of batches. This step is crucial, because the actual mass is important to know in order to determine whether humans can easily move it. Attempts were made to judge how thick the coats are with stand-offs, or depth gauges; however, these attempts fell short of their goal, as the EPS foam is softer than the concrete coat, making depth gauges unsure where they bottom out, and stand-off gauges got in the way and often lost in the process of spraying. The scales served as the primary judge of mass. Unfortunately, it is not possible to know where the shell might be thicker or thinner. Using this method, one may know the actual mass of the piece, but not the exact location of the center of mass. It isn't until the performance that we guarantee this with verification geometries.

The next step in the process is to complete the coat on the other side of the megalith. This process reveals two problems—the first being a cold-joint in the concrete, and the second being the complication of rolling this mass over. The cold-joint is resolved with the woven fiber mesh. Half of this mesh is embedded in the previous cast, and the other half is loose, awaiting the second coat. The problem of rolling the megalith over onto its other side is an interesting one, as it is not considered in the calculations. All the calculations consider a completed shell, but until the second half is coated, the center of mass is no longer down the central axis, but pulled to the side of the first coat. This means that in the act of rolling it over, the megalith rolled from its right side, up to its assumed 'stable' position of the final resting design, and continued over to land on its left side. As expected, but not as calculated, the megalith landed on spare blocks of foam to support it for the second coat. Once completed, the megalith is righted in a similar manner to the previous flip. This time, however, since the center of mass is re-distributed to the central axis, it did not flip completely over, but instead righted itself into the resting position. While these actions were not designed into the computation, future research could investigate these moments as part of the problematic.

RESULTS

The resulting *McKnelly Megalith* is sixteen feet long (or high in the standing position) by six feet of depth and eight feet of height. The EPS occupies 237 cubic feet, weighing 237 lbs. The half-inch thick GFRC shell occupies 268 square feet and weighs 1,763 pounds. In total the megalith weighs 2,000 pounds (1 Ton). While this mass is significantly lighter than the inspiration Moai, it is significantly heavier than one would expect a human to be able to maneuver. Each step travels two feet, allowing it to transport at 300 feet per hour.

CONCLUSIONS

This paper demonstrates a process whereby organic modeling can interact with physics-based information modeling in order to perform megalithic actions. It proves the ability to prototype, test, and manufacture at a large scale; however, this project asks more questions of the role of the architect and designer than it answers, thus a number of future works could test these questions. These future interventions could include dealing with significantly heavier masses, perhaps through the solid casting of concrete, or the carving of stone. It could also include other stability calculations such as buoyancy, which could incorporate counter masses and dynamic conditions. It could also be informed by wind-loads, and a host of other physics-based information. This method could inform architecture with information to aid in the erection and assembly of parts, or it could inform the stability of perceived unstable artifacts.

ACKNOWLEDGEMENTS

This research was conducted in the graduate options architecture studio titled 'Megalithic Robotics' at the *Massachusetts Institute of Technology* in the Spring of 2015 co-taught by Brandon Clifford and Mark Jarzombek (professors) with Carrie Lee McKnelly (Assistant Instructor). Students include Sam Ghantous, Anastasia Hiller, Karen Kitayama, Dan Li, Hui Li, Patrick Evan Little, Tengjia Liu, Ryan McLaughlin, Kaining Peng, Alexis Sablone, and Luisel Zayas. The computation employs *T-Splines* (www.tsplines.com) as the organic modeler to inform *Grasshopper* (www.grasshopper3d.com), a plugin developed by David Rutten for *Rhinoceros* (www.rhino3d.com), a program developed by Robert McNeil. The *McKnelly Megalith* is dedicated to the memory of Steve and Rendy McKnelly.

NOTES

1. Rapa Nui is commonly known as Easter Island.
2. Ahu /'ahú / *n.* Stone platforms upon which the Moai stand. There are over 300 known Ahu on Rapa Nui.
3. The term 'Road Moai' is coined in 'The Statues that Walked' (Hunt 2011)

REFERENCES

Andriaenssens, Sigrid, Philippe Block, Diederik Veenendaal, and Chris Williams, eds. 2014. *Shell Structures for Architecture: Form Finding and Optimization*. London: Routledge.

Dean, Carolyn. 2010. *A Culture of Stone: Inka Perspectives on Rock*. Durham, NC: Duke University Press.

Dibner, Bern. 1950. *Moving the Obelisks*. Norkwalk CT: Burndy Library.

Domokos, Gabor, Peter Varkonyi, and Vladimir Arnold. 2007. "Turtles, Eggs and the 'Gömböc.'" *Hungarian Quarterly* 48 (187): 43–47.

Hamilton, Sue, Susana N. Arellano, Colin Richards, and Francisco Torres. 2008. "Quarried Away: Thinking about Landscapes of Megalithic Construction on Rapa Nui (Easter Island)." In *Handbook of Landscape Archaeology*, edited by Bruno David and Julian Thomas. Walnut Creek: Left Coast Press. 176–186.

Heyerdahl, Thor. 1958. *Aku-Aku, the Secret of Easter Island*. Chicago: Rand McNally.

Hunt, Terry L., and Carl P. Lipo. 2011. *The Statues That Walked: Unraveling the Mystery of Easter Island*. New York: Free Press.

Kilian, Axel and John Ochsendorf. 2005. "Particle-Spring Systems for Structural Form Finding." *Journal of the International Association for Shell and Spatial Structures* 46 (2): 77–84.

Lipo, Carl P., Terry L. Hunt, and Sergio Rau Haoa. 2012. "The 'Walking' Megalithic Statues (Moai) of Easter Island." *Journal of Archaeological Science* 40 (6): 2859–2866.

Ochsendorf, John and Michael Freeman. 2010. *Guastavino Vaulting: The Art of Structural Tile*. Princeton: Princeton Architectural Press.

Piker, Daniel. "Kangaroo." Accessed July 6, 2016. www.grasshopper3d.com/group/kangaroo

Rasch, Bodo and Frei Otto. 1995. *Finding Form: Towards an Architecture of the Minimal*. Stuttgart: Edition Axel Menges.

Routledge, Katherine. 1919. *The Mystery of Easter Island*. London: Sifton, Praed.

Wallington, Wally. "The Forgotten Technology." Accessed July 6, 2016. www.theforgottentechnology.com

IMAGE CREDITS

Figure 1: *McKnelly Megalith* Erection (Kilian, 2015)
Figure 8: *McKnelly Megalith* Erecting (Ariza, 2015)
All others: *McKnelly Megalith* (Clifford, 2015 © Matter Design)

Brandon Clifford is an Assistant Professor at the Massachusetts Institute of Technology and Principal at Matter Design. Brandon received his Master of Architecture from Princeton University in 2011 and Bachelor of Science in Architecture from the Georgia Tech in 2006. He worked as project manager at Office dA from 2006–09, LeFevre Fellow at OSU from 2011–12, and Belluschi Lecturer at MIT from 2012–16. Brandon has been awarded the Design Biennial Boston Award, the Architectural League Prize, as well as the prestigious SOM Prize. Brandon's translation of past knowledge into contemporary practice continues to provoke new directions for digital design.