Back to Mass: Terra Cotta's Redefinition of the Performing Envelope

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Keywords: terra cotta, mass, porosity, grotto/cave, bioclimatic

Building lighter and thinner has conceptually targeted the reduction of energy and labor in processes of construction and material production. However, this thinning does not always mean a reduction in energy use as shown by the expenditure of energy required to control a thin envelope's ambient sequestration or the production of the preferred materials for the thin envelope. Despite these considerations, architectural production has evolved from thick enclosures to thin solutions. The pattern that is predicated on minimum material envelopes and energy-dependent standardized ambient conditioning requirements has produced an energy-hungry building stock. Reversing the typical constructive paradigm from thinness to thickness poses reversals of norms, with the potential to manage carbon emissions through production, maintenance, and conditioning. The preferred ratio of thin enclosure and large interior volume is redefined in favor of a performative thick boundary layer and a less energy-hungry interior. Terra Cotta Grotto proposes a return to mass in architecture, redefined through the contemporary lens of thermodynamic and ambient processes that, at certain scales, dematerializes the very solid boundary layer and provokes a critical discussion around how thickness can redefine our carbon footprint.

BIOCLIMATICS IN MASSIVE TERRA COTTA

A traditional grotto displays an interior that results from the expression of the mass that surrounds it. The moisture in the pores of the grotto's soil provides cooling, the surrounding earth mass maintains a constant interior temperature, and the encrusted surfaces create specular light effects. Terra Cotta Grotto is a porous mass formed by waterjet cut terra cotta rainscreen panels. The cuts that define the space of Terra Cotta Grotto reveal a set of formal and material qualities that produce ambient phenomena like those of a traditional grotto. The design recreates the grottos' earthy material, as well as spatial, experiential, and bioclimatic conditions by cutting the stack of panels to display multiple degrees of porosity. By exposing the rainscreen panels' underlying structure through an exuberant cut, the prototype offers a pattern of open channels and ribs that displays an underexplored aesthetic and environmental conditioning potential.

Terra Cotta Grotto is a design research project that addresses carbon reduction in contemporary architecture through its thermodynamic qualities and its material production.[1] This design addresses energy consumption for fabrication and predefined standards of thermal comfort, both of which are responsible for producing the majority of architectural industry's contribution to world carbon emissions. Building lighter and thinner has conceptually targeted the reduction of energy and labor in the process of construction and material production. However, it is acknowledged that this thinning does not always mean a reduction in energy use as shown by the expenditure of energy required to control a thin envelope's ambient sequestration or the production of the thin envelope's preferred materials. Despite these considerations, architectural production has evolved from thick enclosures to thin solutions.[2] Predicated on minimum material envelopes and energy-dependent standardized ambient conditioning requirements, this pattern has produced an energy-hungry building stock. Through the design and development of a thick thermodynamic environmental enclosure, the project Terra Cotta Grotto explores an alternative to the more hermetic contemporary thin envelope models that prevail in the architectural field. While not intentionally a predictive model, the project proposes to raise awareness and promote questioning of these standards.

THE GROTTO: ONTOLOGY OF LIGHT AND HEAVY

"The grotto is the ultimate architectural interior. [It] has continued to exert a fascination that has secretly run through modernity, always vying with the supremacy of the idea of exteriority. […] In fact, the grotto represents the very core of architecture, the need for inner force, an obscure, atavistic center that refuses, opposes and counters transparency, visibility and lightness." Iñaki Ábalos[3]

Drawing inspiration from the pre-modern use of mass in construction, the traditional grotto provides lessons for responsive architecture that is generally answered with lightweight systems. In the US, engaging climate and environment as a basis for design has been tied to both vernacular tectonics and a construction paradigm of lightness and ephemerality.

Figure 1. The prototype shows the tactile and ambient attributes of the porous aggregate mass.

Both apply to construction systems that maintain a distinction between systems, skin, and structure.

Addressing this distinction, Reyner Banham framed the theoretical understanding of the shelter as a choice of how resources are used. In a parable where Banham describes the hesitation as to whether to use the available wood for a campfire or a structure, the forest is either consumed by a fire or cut down to make an envelope.[4] Such vision had an underlying material bias: in both cases, it implied the forest and its abundance of wood as the germinator of architecture. Banham's vision on the origin of architecture follows Marc-Antoine Laugier's 1753 theory of the primitive hut as a tectonic structure[5] and leads to an ontology of shelter as a skin and bone with the hope for integration of systems.

In *The Architecture of the Well-Tempered Environment*, Banham described the properties of long-lasting construction systems based on mass. The book was a timely response to this type of architecture based on the integrated skin and bone model, which had become economically and pragmatically out of step with the advanced construction and the innovative implementation of integrated ambient control systems. Banham defined mass as the "conservative mode" of environmental control, since its thermodynamic properties collect and hold heat energy.[6] The recent paradigm shift in design focus toward resilience in architecture, in addition to sustainability, has reawakened an interest in mass. Terra cotta, as an earth-based material, is exemplary of the thermodynamic properties of mass that make it coveted in passive design. This leads us to contemplate this weighty alternative, and perhaps go deeper and further back than the hut – to the cave.

The cave offered the first known shelter to humankind, taking place earlier in history than the theoretical primitive hut presented in the eighteenth century.[7] As opposed to the primitive hut explored by Laugier based on Vitruvious' *Ten Books of Architecture*, the cave presents the other end of the spectrum from the drive towards light efficient construction. Moving beyond the cave's sheltering purpose, the grotto can be considered a specific case within cave formations that provides a space for a somatic, tactile ecology that emerges from the conjoined work of the natural phenomena of its mass with human physiology and psychology. The cave was likely the first interior to be used by humankind, and it continues to exert and influence what could be described as a primordial somatic drive. In the text "Grotesque Somatic," Iñaki Ábalos explains the somatic thermodynamics behind the alignment of the body and interior spaces such as the grotto. He describes the relational transformation of an occupant "from an irradiated into a radiating body. [As] electromagnetic waves circulate in the opposite direction[8] [...] giving us the characteristic sensation of cold that is always more than the thermometer registers; our body and our somatic terminals activate a dialogue with earthy matter, humidity, and geomorphologic darkness of an intensity that is unknown."[9]

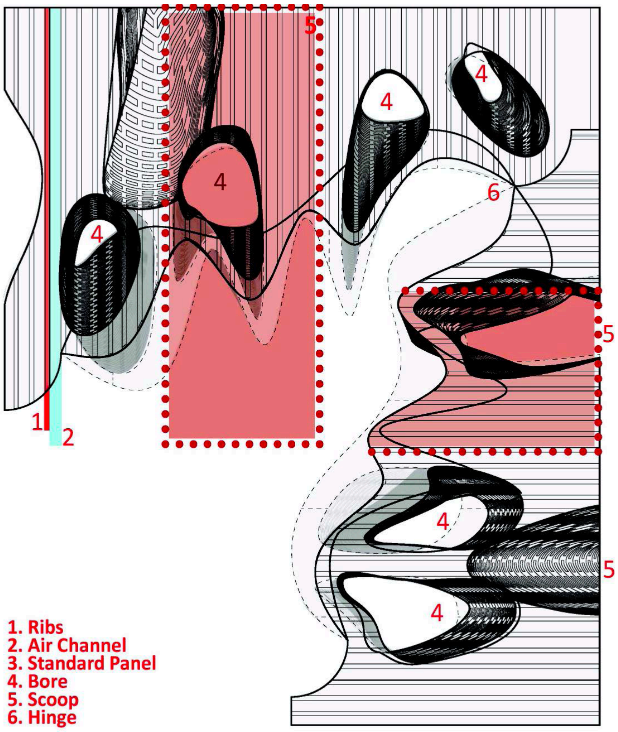


Figure 2. Corner unit prototype plan.

Due to the escalation of thermal comfort standardization in the late 19th century and the 20th century, space conditioning was married to a tight envelope. A layered system consisting of either glazing or a weather envelope, insulation, and interior liners make a taunt skin and provides a good net to gross ratio, maximizing space by placing mechanics in the plenum. Those hidden mechanical systems call for the sequestration of interior space that severs a haptic connection with local ecology. Dependent on technological products this "optimally" conditioned environment does not need either rely or inform architectural form.

Contemporary sustainable construction has moved from the thin skin, (but not from transparency and lightness), by expanding the green house model into the engineered double skin envelope, which works with sun and wind to manage interior conditions. The thick skin becomes part of the environmental control system. These spaces are oftentimes large enough to walk in for maintenance in more controlled systems, and for seasonal occupation in more domestic programs. These spaces take away from the square footage but return in energy costs, both monetarily and ecologically. These thick boundaries form a mass of combined passive/active heating and cooling solutions. They extend horizontally into the buildings through another poché space hidden in the plenum or the floor.[10] These thermodynamic pochés generally preserve the independence of skin and structure, emblematic of the Modern, and maintain a well-controlled interior environment.

In these cases, the skin assumes a role in the expression of architectural form.

Stefan Behlig, of Foster & Partners, proposed a focus on passive conditioning systems to favor their performance under their thermodynamic behavior. Such new focus would give a primacy to the architectural form rather than to the mechanical system, an attitude that Sanford Kwinter has identified as defining a "thermodynamic approach to architecture."[11] In contrast to the thin envelopes, these thickened skins can indicate the formal development of the building, as they communicate their performative function and passive potential. A thicker enclosure system as thermally active as that of a double skin façade is found in the earthen mass that engulfs a cave or a grotto.

Climate conditions once drove users to occupy the grotto, as its mass was itself a conditioning system. Constructed grottos were used to cool off in hot summers in Renaissance gardens, while natural caves or grottos provided shelter in ancient and prehistoric times. Earth is a pervious gradient that creates an alternative ambient condition within it. Below the frost line, its mass maintains a constant temperature of 58 to 62 degrees. This mass is not a solid, but a combination of solid materials with air and water, which occupy the spaces between soil particles. Thus, the mass constitutes a filter that manages thermal and hydrological systems by mediating but never sequestering, air, water, and light that travels into the earthbound space.

The traditional model posed by the grotto is based on form and distribution of material rather than mechanical systems. This design imperative has the potential to create an "integrative spatial design [where] conductive and/or convective channels of thermal gain [...] are integral to the architectural concept but tied to the creation of space (interior) rather than form (exterior)."[12] Such consideration promotes a design process where the ambient conditioning and material properties work in tandem to redefine a "synthetic idea of architectural beauty" where mass and materiality are formal drivers.[13]

MASS, CLIMATE, AND COMFORT

Bioclimatic variances have been a basis for design of architectural form since shelter was first conceived. Material responses to these forces have prompted historical and theoretical formulations of primordial models of shelter. These shelters informed societies with attitudes toward the ecology that were consistent with the same historical and theoretical formulations. For a time, comfort-seeking control parameters created a disjunction between architecture and environment. Architecture has conceded that engagement with material properties, ambient flows, and ecological context allows us to live with rather than against our microclimate. As cited in Alberti's *On The Art of Building,*[14] the combinatorial responsiveness of form, material, and ecology is to-day consciously changing architecture into a manifestation of "natureculture."[15] Greater responsiveness is

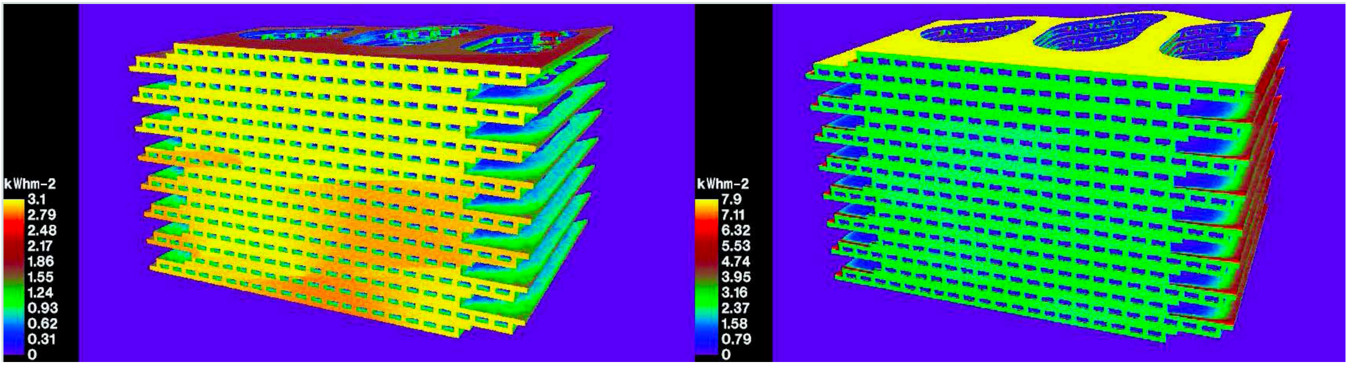


Figure 3. DIVA radiance maps supported the temperature readings showing where to expect thermal heat gain.

sought, as hermetic seals are replaced with filters, and architectural enclosures are redefined to form a gradient rather than perform a cut with the exterior.

The project Terra Cotta Grotto contends that such responsiveness can be explored through a heavy material assembly. Its terra cotta poché wraps an interior that awakens the senses as it collects and redistributes the flows of light, water, and air. The project explores the bioclimatic and experiential qualities of mass by figuratively carving out space from an initial volume created by stacking standard terra cotta rainscreen panels. In doing so, the prototype seeks to bring forth the earthy material and spatial, experiential, and bioclimatic conditions of a traditional grotto.

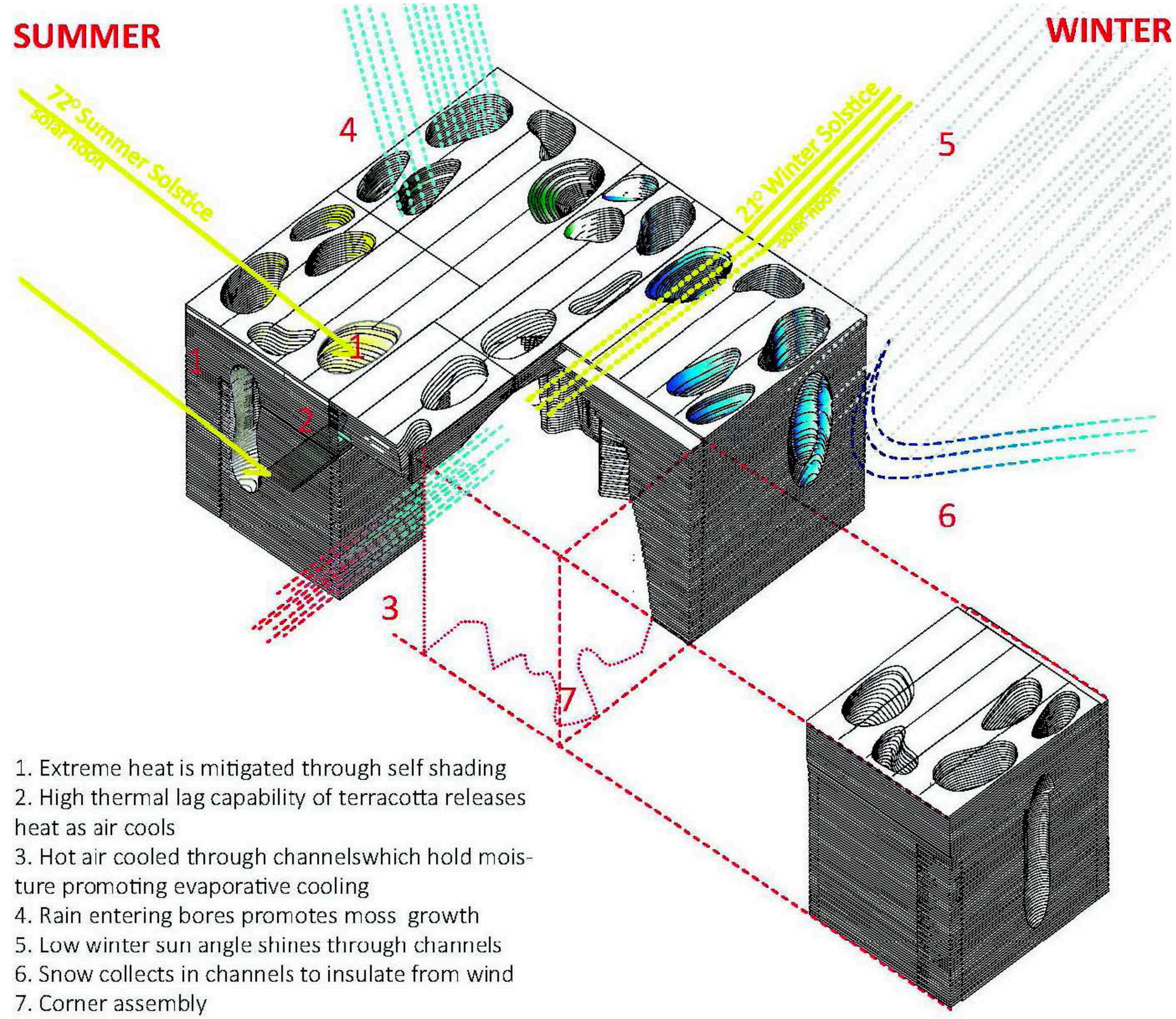
ENVIRONMENTAL IMPACT OF ARCHITECTURAL TERRA COTTA

Architectural terra cotta has a lower emission coefficient than more commonly used construction materials.[16] Its processing presents a significant reduction of environmental impact compared to concrete, steel, foams or glass. Fired at temperatures ranging between 1000 ºC to 1200 ºC, terra cotta is considered a low-fired ceramic as opposed to stoneware and porcelain. Although it takes significant energy to fire, the use of high-efficiency kilns is a matter of cost effectiveness that is driving manufacturers toward a more environmentally friendly practice. In fact, terra cotta has a lower embodied energy than glass, steel, aluminum, and even paint when factoring in the environmental cost of procuring the raw material and the heat required for manufacturing.[17]

Terra cotta is a resilient and eco-friendly material when compared to other contemporary construction stock. It is produced from naturally occurring clay and other inorganic materials that are widely available. Although most manufacturers no longer source materials from their own backyards, the wide distribution and abundance of appropriate clays makes it possible to source materials within a modest distance from a site of fabrication, further reducing its carbon footprint. Unlike aluminum alloy or the sand needed to make glass and concrete, terra cotta is not a dwindling resource. Wood is of course renewable and available, but time for reforestation is an issue, and there is a pressing need for forests for carbon sequestration.

Terra cotta can last for centuries, even under continuous exposure to the elements. The firing temperature and material makeup engineer a combination that makes its molecules align to create a non-permeable clay body when it is sintered. Consequently, architectural terra cotta absorbs 1/3 the moisture that concrete absorbs, but it can be fully water repellent. The waterproofing does not need an additional layer, such as glaze, but it is inherent to the terra cotta body, which is made water-tight to withstand freeze-thaw cycles that buildings are exposed to in northern US. Firing also makes terra cotta corrosion resistant. Architectural terra cotta is produced from widely available naturally occurring clays and minerals that give it a variety of properties. Most of these components become oxidized in the firing process rendering the finished product corrosion resistant. The additional benefit of having no color or texture change when exposed to chemical tests gives contemporary architectural terra cotta products a standard 50-year manufacturer's guarantee.

To complete the material's life-cycle efficiency, terra cotta is 100% recyclable. Recycled ceramics, in the feorm of grog, are in fact a necessary part of terra cotta production, contributing to control shrinkage and adding strength and texture. Coupled with its thermodynamic qualities, terra cotta's very composition expresses the low environmental impact of this ancient material and makes it an appropriate partner when seeking to reduce architectural carbon emissions.[18] These carbon-reducing solutions are predicated on the material's intrinsic qualities, but it is through a counterintuitive aspect of its production that the application of architectural terra cotta becomes a key factor. Reversing the typical constructive paradigm from thinness to thickness poses reversals of norms, with the potential to manage carbon emissions through production, maintenance, and conditioning. The preferred ratio of thin enclosure and large interior volume is redefined in favor of a performative thick boundary layer and a less energy-hungry interior. Terra Cotta Grotto provokes



1. Extreme heat is mitigated through self shading
2. High thermal lag capability of terracotta releases heat as air cools
3. Hot air cooled through channelswhich hold moisture promoting evaporative cooling
4. Rain entering bores promotes moss growth
5. Low winter sun angle shines through channels
6. Snow collects in channels to insulate from wind
7. Corner assembly

Figure 4. Bioclimatic performance of terra cotta assembly.

a critical discussion around how thickness can redefine our carbon footprint.

TERRA COTTA GROTTO: EXPERIENCING POROUS MASS

The space of the grotto is carved from the earth, which is itself composed of solids and voids. Its porosity simultaneously configures the expression of its form, the manifestation of its structure, and the basis of its environmental system.[19] The force of expression is fully internal, where the space is mediated through mass. Access, illumination, ventilation, and thermal conditioning are all indirect and encompassing inside. Terra Cotta Grotto models itself on these conditions. Intended for a temperate climate with hot summers and snowy winters, it does not seek to create a homeostatic environment but one that affords a degree of comfort, like a warming hut in the winter or the moist sheltering earth of the cave in the summer.

Terra Cotta Grotto's structural envelope consists of a porous poché made of standard extruded terra cotta rainscreen panels that are stacked to create the enclosure. The 1.50 inch-deep panels are internally striated by a pattern of open channels and vertical ribs (0.75 inches) to reduce weight and maintain a homogeneous surface thickness that prevents fractures due to potential uneven drying and firing processes. The continuity of the extrusion ribs and channels between the unfinished face and the cut face creates the haptic, visual, and ambient expression of the Grotto.

The porosity allows for the passage of air and water, as surfaces play with borrowed light, and maintain the heat of the sun. The terra cotta stack is carved out with specific voids that respond to the placement of the inner surfaces and solar orientations. Two types of cuts manipulate the volume: the bore channels cut from the top plane, whilst the scoop cuts slice the mass into its sides. The east and west faces receive more lateral scoop cuts so that the setting and rising sun fill the horizontal channels directly. On the south side, the high summer sun is controlled through self-shading, while the low winter sun is able to light up the channels inside. The north side opens overhead to expose its inner surface to the sun. The geometry of the bores and scoops allows water to fall inside the mass but not into the grotto's interior. Bores are parametrically defined by a top and bottom curve like the central cut. Once the central cut is chosen, each bore is set with its central point aligning the center of one panel and bound by the cut and the edges of the panels. Elongation and displacement of the sides is manipulated by solar and water access into the bore. Specific conditions relating to solar orientation that define the scoops can be adjusted with sliders in the script to control the amount of solar access in a winter condition. The parametric nature of the cuts, bores, and scoops allow the Grotto to be made site specific once its location is set as it relates to the four cardinal directions.

Terra Cotta Grotto replicates earth-like conditions creating its own microclimate. Solar access simulations defined the placement, depth, and excavation of the prototype's mass. Simulations during design development affected the location and size of cuts in the mass. Thermal testing in a controlled environment supported expectations of the material's thermodynamic performance for cooling and heating. Structural analysis of the drystack system is currently underway for a long-term outdoor installation. Further testing will be done in the coming months in this venue.

Ventilation and radiant properties result from the material and formal structure of the terra cotta panel. Thermal analysis tests show the surface temperature differential between the irradiated surface and the inner (shaded) surface in mid-August at solar noon. This was tested using a digital infrared thermometer pointed at the terra cotta surface made up of a group of 10 panels, and calibrated for its emissivity. The readings were done in two sections, the channel and the rib, and compiled. The air temperature in the outdoor testing area was 84 degrees. This test shows that the deeper part of the surface, averaging between 4' and 2' in depth, has a greater differential than the narrower part that ranges between 1' and 6". The insulated side was an average of 10 degrees warmer than the shaded (inner) side. But even the thinnest portions show a 5º differential. The laser accuracy of the measuring device allowed us to measure the temperature within the channels as well. Since the sun, being at its zenith, did not penetrate into the channels due to the self-shading property of the rib and channel structure, the surface was an average of 7 degrees cooler 12" into the channel in both thick and thin parts of the wall. We speculate that the air temperature around the object may have affected the thermal reading making the inside of the channels cooler than the inner wall. This lower temperature may cool the air further as it passes through the structure, and allows us to speculate that the air temperature within the full construction would maintain relatively constant despite fluctuations of external air temperature. DIVA radiance maps supported the temperature readings showing where to expect thermal heat gain. The DIVA model performance closely approximated the measured performance.

The material's thermal lag allows it to absorb heat while maintaining a cool interior. It releases heat when the air has cooled in the night due to its diurnal lag; the longer the path that the energy travels, the more effectively it is dispersed within the wall. The material's thermal lag maximizes thermal capacity and minimizes thermal conductivity. The bores and scoops contribute to reduce the lag or allow the heat to dissipate into the internal voids before reaching the interior. Such parametric variation allows the design to fit into either zones where diurnal temperatures shift and those where nights remain hot. In the first case, this happens by transferring the heat inward, whereas in the second case, this happens by releasing heat through a chimney effect within the walls. Energy stored in thermal mass goes through reaches a maximum value but decreases slightly after the wall gets too thick. This would be the case if the walls were solid. Thermal energy storage would be reduced. However, the Terra Cotta Grotto presents a web of open and closed cells. The air channels allow air to flow through the mass, performing like a mechanical heat exchanger, but instead of utilizing energy from active systems of production, the terra cotta porous mass provides the temperature variation by radiating or absorbing heat.

RhinoCFD (Computational Fluid Dynamics) models were run on a 2'x2'x2.5' portion of the prototype to analyze airflow through the horizontal channels. It was assumed that airflow would be slowed down by passing through the screen but could be manipulated by redefining the openings within the walls and placing an oculus in the roof of the interior. Cross-currents of air were fluid when facing the wind direction because the openings line up across the interior. Expectations of accelerated air-flow through the smaller channels (Bernouilli effect) were not realized as expected, and further study is required. The poché behaves more like a sieve, creating a gentler flow within even in a strong wind condition.

The prototype can also work through evaporative cooling as the channels hold water on their inner surface while air moves through them and cools further. Since rain enters the mass through the bores as well as from the outer surface, the channels can remain in shade for long periods allowing a thin sheet of water to collect on their surface. Inspired by the micro pores of the botijo, an ancient terra cotta cooling vessel the Terra Cotta Grotto uses the vertical bores to collect water and cool the air flowing through its walls and roof. Porosity is good for heat retention and for evaporative cooling properties of terra cotta, but it is problematic for applications in freeze-thaw prone areas. Our response was to increase the scale of the pores, by turning the rib-channel morphology into linear pores. This maintained the engineered watertight surface of a rainscreen panel designed for northern climates, but maximized the potential for thermal retention and evaporative cooling. Preliminary tests suggest that air moving through the wet terracotta channels will result in an air temperature reduction of 15 ºF. If located in a cold wet climate, it was expected that the channels would fill with snow and create a problem with breaking due to expansion of ice in a closed volume, so a portion of the prototype was set outdoors to study this potential problem. The form of the surface proved to prevent snow from collecting in the openings eliminating this concern.

CONCLUSIONS. FROM MASS TO BODY

The model of a traditional grotto, as translated into the proposed pavilion prototype, is not earthbound, so it provides conceptually transferable lessons for the exploration of a thickened boundary condition. The proposed boundary differs from ancient mass structures in that the former highlights an interior haptic articulation rather than external formal expression. It proposes that to achieve carbon reduction, before we lean into the construction of testable objectives, we need to imagine the potential of alternative models of architectural production that speak to the qualifiable aspects of the architectural object and the space it defines. The social construction of the technologies to be explored needs to be established to support, or to question, the techniques and technologies to be employed in this endeavor.[20] Proposing diverse habits of haptic engagement with a sheltered space becomes a driver in the pursuit of alternative carbon futures.

Terra Cotta Grotto proposes a return to mass in architecture, but redefined under the contemporary lens of thermodynamic and ambient processes which, at certain scales, dematerialize the very solid boundary layer.[21] Modeled on the performative natures of an earth-bound architecture, the research addresses two concerns relevant to carbon reduction. First, coupling the thermodynamic properties of fluid systems and mass, the project addresses the reliance on passive systems over active ones, what Sanford Kwinter identified as a "thermodynamic approach to architecture."[22] Second, the project addresses the realities of energy bound in material production. The resulting prototype interrogates bioclimatic performance through the implementation of thick terra cotta mass enclosures, which have the capacity to perform as passive conditioning systems. The massive, yet porous, envelope, like precedents of thermally active ephemeral architectures, does not sequester but tempers the ambient relation between inside and outside. In addition, this expanded boundary layer of unique material performance offers an alternative means of engaging building systems, since it offers at once structural and environmental solutions.

Producing something akin to a traditional grotto where moisture in the soil's pores provides cooling, the surrounding earth mass maintains a constant interior temperature, the encrusted surfaces create specular light, and the thick porous mass constitutes the conditioning system. The material itself becomes a mediator of a responsive thermodynamics achieved through passive material qualities rather than hidden active systems. This thick earthen mass highlights the tangle between nature, technology, and culture that permeates contemporary design. The gradient of the Terra Cotta Grotto gives power to material and ambient agents like wind, water, and sun along with the human body to create a sensorially rich interior ecology. The grotto does not propose an image but something in keeping with theoretician Bernard Cache's conception of "space that is prior to representation,"[23] a space that needs to be experienced in motion and engagement with the senses rather than the intellect that forms a known, static view of an object.

ENDNOTES

1. For a detailed description of the simulation results and fabrication processes, see: Garófalo, Laura; Guitart, Miguel; Khan, Omar (2020), "Porous Mass: Terra-Cotta Redefined Through Advanced Fabrication," *Technology, Architecture + Design*, 4:2: 232-241, DOI: 10.1080/24751448.2020.1804767
2. See: Riley, Terence, *Light Construction* (New York: Museum of Modern Art, 1995).
3. Ábalos, Iñaki; Sentkiewicz, Renata, "Grotesque-Somatic," *Essays on Thermodynamics and Beauty* (New York: Actar, 2015), 2.
4. Banham presented a parable of a tribe that needed to decide if they should use wood to build a shelter or to build a fire to stay warm. See: Banham, Reyner, "Environmental Management," *The Architecture of the Well-Tempered Environment* (1969) (Chicago: University of Chicago Press, 1984), 18-22.
5. Rykwert, Joseph, "Positive and Arbitrary," *On Adam's House in Paradise: The Idea of the Primitive Hut* (Boston: MIT Press, 1981), 43.
6. The construction types – including mass construction – that lead to the conservative, selective, and regenerative modes of architecture, as well as their pros and cons, are discussed in: Banham, Reyner, Op. Cit., 22-26.
7. A temperate climate example is the Palaeolithic Lascaux Cave in France. Similarly dated sites can be found in other bioclimatic zones such as the Niah Painted Cave Complex, Niah National Park, in tropical Malaysia.
8. That is, from the radiating body into an irradiated body. Note of the authors.
9. Ábalos, Iñaki; Sentkiewicz, Renata, Op. Cit., 2.
10. Poché is a French architectural term that refres to all that is inside the walls between spaces. In the days of predominantly stone masonry buildings, the extraordinary thickness of stone walls allowed for their manipulation as architectural entities.
11. In his text, Iñaki Ábalos explored a suggested shift in the use of passive systems rather than active systems as proposed by Stefan Behlig, of Foster & Partners, along with Arup, one of the most important environmental engineering companies today: "[Behlig] proposes an interesting taxonomy (active systems, passive systems, architectural form), and an inversion of the importance of the intervening elements in favor of their real performance under thermodynamic behavior and some given conditions: that is, giving the primacy back to the architectural form, an idea that becomes interesting for architects – as their role is recognized again – as well as for those who defend typological history as a lesson for bioclimatic adaptation in relation to specific conditions of technical evolution." Ábalos, Iñaki, "La Belleza Termodinámica," ("A Thermodynamic Beauty"), *Circo* 157 (Madrid: Circo, 2008), 2. Translation by the authors.
12. Ábalos, Iñaki; Sentkiewicz, Renata, Op. Cit., 33.
13. "A new thermodynamic materialism brings a fresh vitality in the form of conductive and/or convective channels of thermal gain that are integral to the architectural concept. Thermodynamic materialism redefines not only the very need for matter and our choices of materials and products, but also the way in which we can model interior space, and the instruments and knowledge required to develop a new, synthetic idea of architectural beauty." Ábalos, Iñaki; Sentkiewicz, Renata, Op. Cit., 33.
14. This is particularly evident when Alberti discusses private architecture in "Book Five" of *On the Art of Building* (originally, *De Re Aedificatoria*, 1443-1452). See also: Vitruvius, "On Climate" (Book IV), *The Ten Books on Architecture* (1st C. BC) (New York: Dover Publications Inc., 1960).

15. Donna Haraway coined the term “natureculture” in *The Companion Species Manifesto* (2003) to explain the entanglement of the two conditions, nature and culture. These conditions are based on the distinction of the physical/somatic/material and the intellectual/semiotic/symbolic.
16. This is in reference to conventional construction in the US, and recognizes the effective use of earthen materials in other parts of the world.
17. The energy “cost” of producing clay bricks and tiles is between 2 and 6 GJ/ton, while its closest neighbor cement costs 5 to 8 GJ/ton, and glass jumps to 12-25 GJ/ton, while aluminium ranges from 200 to 250 GJ/ton. The parallel CO2 requirements are .19 Tons of CO2/ton of clay tiles, .22 for cement, and .69 for glass. See: Carthy, William, (Presenter) (August 16, 2019), “Sustainable Terra Cotta,” *Advanced Ceramic Assemblies Workshop*, 2019.
18. Interview of ceramic engineer and John F. McMahon, Professor and Chair of Ceramic Engineering at Alfred University, Dr. William Carty by authors on October 22 of 2019.
19. The writings of Robert Le Ricolais have a particular relevance. See: Le Ricolais, Robert, *Visions and Paradox* (Philadelphia: University of Pennsylvania, 1997).
20. Moe, Kiel, *Thermally Active Surfaces in Architecture* (New York: Princeton Architectural Press, 2010), 35-37.
21. Open microclimates proposed by Toyo Ito, Philip Rahm, Sean Lally, and Diller+Scofidio, potentially inspired by Reyner Banham’s analogy of the shelter and the fire pit as resource models, speak to strategies of dematerialization.
22. Ábalos, Iñaki, “La belleza termodinámica,” *Circo* 157 (Madrid: Circo, 2008), 2. Translation by the authors.
23. Cache, Bernard, *Earth Moves: The Furnishing of Territories* (Cambridge: The MIT Press, 1995).