Microtherme: Examining Contradictory Concepts of Spatial and Thermal Comfort

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INTRODUCTION

Architecture exists at the confluence of form, material, environment, and structure. While this odd set of bedfellows informs architecture, this overlay produces an experience for the occupant. *Microtherme* is a condensation of thermal and sensorial experiences that produces contradictions of conventional notions of comfort. Sitting adjacent to a burning fire on a cold night is a known comfortable experience, yet it does not fall within the ASHRAE standards of the "Thermal Comfort Zone" (ASHRAE 2016)—a rather narrow definition that assumes continuity over difference. As described by Lisa Heschong, the human body is capable of, if not excited by, thermal extremities (Heschong 1979). For instance, ancient Romans would experience the Roman bath complex by moving from extremity (caldarium) to extremity (frigidarium), managing their own thermal delight. (Yegül 2010) As opposed to a liquid bath, *Microtherme* is a radiant one that co-mingles extremities into singular thermal contradictions. It frames the occupants' experiences—from the act of rolling under a monolithic object to standing up inside the bath, the occupant is confronted with another world inside, thus producing the illusion and thermal experience of wading in a bath of voluptuous concrete. The experience of *Microtherme* is simultaneously a spatial and thermal set of contradictions. While this knowledge and approach is arguably ancient, Kiel Moe argues in his book *Insulating Modernism* that modernism focused on an isolationist theory further ratified by industry standards (Moe 2014). This resulted in a generation of architecture focused on insulation as opposed to thermally active surfaces. With so much attention being paid to the integration of thermally active surfaces in architecture, this paper experiments with a synthetic approach to developing form in resonance with these surfaces to produce a theoretical comfort zone via extreme temperatures.

CONTRADICTIONS

Microtherme is an experiment into comfort. It experiments with this concept by offering and then retracting pre-conceptions. For the purposes of this text, this game of perceptual inversion will be called a "contradiction." *Microtherme* employs contradictions of comfort in two ways—spatial and thermal.

Spatial Contradictions

Microtherme is only seven feet wide, eight feet deep, and eight feet tall. Inside this compact volume, three sequential and distinct spatial conceptions are produced—object, lower, and upper. Upon approach, the visitor is confronted by an objectified hovering wooden mass. A singular and limited port that is large enough to peer inside and fit one arm into the interior to blindly feel inside punctures the mass. This port is located at navel height. When you peek in, it is possible to see glimpses of the lower space, as well as a portion of the upper room, but not enough to understand the entirety of the space. This glimpse is enough to convince someone to investigate further, but not large enough to expose the experience. From the inverse point of view, the port is also at a height where the person inside is not able to know who might be peeking at them. The visitor then rolls under the mass on a bed of carpet to experience a new materialization of a concrete mass rendered supple and elastic. In this lower space, other people occupying the space appear to be draped in a concrete fabric, producing an experience that these living caryatids are structuring and levitating this engulfing mass of concrete. From this vantage, the visitor sees two possible standing locations. Once the visitor stands inside one of these vertical spaces, an opposing perception is rendered. The human form is disembodied, swimming in a bath of concrete.

Figure 1: Exterior view of Microtherme

Similar to Sigfried Giedion's three spatial concepts (Giedion 1971), the visitor transitions from an object to a canopy hypostyle, and finally into a single enclosed space. By transitioning the visitor through these varieties of spatial conceptions, a game of perceptual inversion is played. Upon each transition, the poché of the space allows for misreadings of expectations—from the rigid wooden box to a supple mass of concrete, to the inversion of perception relative to the occupant and the concrete space. At each transition, the visitor experiences a new space entirely, provoking a dynamic relationship between object/space, and occupant. This spatial experience is further compounded with radiant thermal conditions.

Thermal Contradictions

Microtherme is plumbed (see fabrication) as an experiment to test thermal radiant comfort. It is thereby able to alter the surface temperatures between warm and cold. The geometries of the surfaces are created to average and maximize the surface area ratio for these different scenarios, so an occupant is receiving equal parts hot and cold radiant temperatures. Regardless of the configuration, the air temperature is a constant room temperature of 72 degrees Fahrenheit. The hot and cold radiant temperatures span the range of 120 degrees to 48 degrees, producing an average of 72 degrees. While these temperatures are quickly understood through touch, it takes about twenty seconds to receive that feedback with radiant temperature, producing an interesting lag in thermal experience. One scenario that was tested is to have all the upper surfaces cool and the lower surfaces warm. If below the concrete, one gets the experience of sun bathing, as almost all of the radiant surface percentage is warm. It is not until the visitor stands that the cool temperatures are received and the thermal range balanced. This produces a theoretical average of 72 degrees, though the lower body is warm while the upper is cool, like bathing in a warm pool in the winter. Some people are less likely to stand, working under the common assumption that heat rises. The brave few that do are delighted with a thermal surprise. Another configuration heats and cools from left to right instead of top to bottom. If in the small space, the visitor's back will begin to roast while the front will cool. Like being next to a fireplace, the occupant wants to rotate in order to roast another portion of their body—though physically impossible in this space. A negotiation occurs with the other occupant to exchange spaces. This thermal experience ultimately encourages a dynamic relationship between the occupant and the space. As with the Roman bath complex, it requires motion in order to maintain comfort.

GEOMETRY CONSTRAINTS

The dimensions and geometry of *Microtherme* are a negotiation between a variety of considerations—accessibility of the human form, exposure ratio, and structure. In order to negotiate these concerns, the hard constraints are pre-determined and anchored in the system. The irreducible constraints are set as minimums, and a solver relaxation resolves the discrepancies.

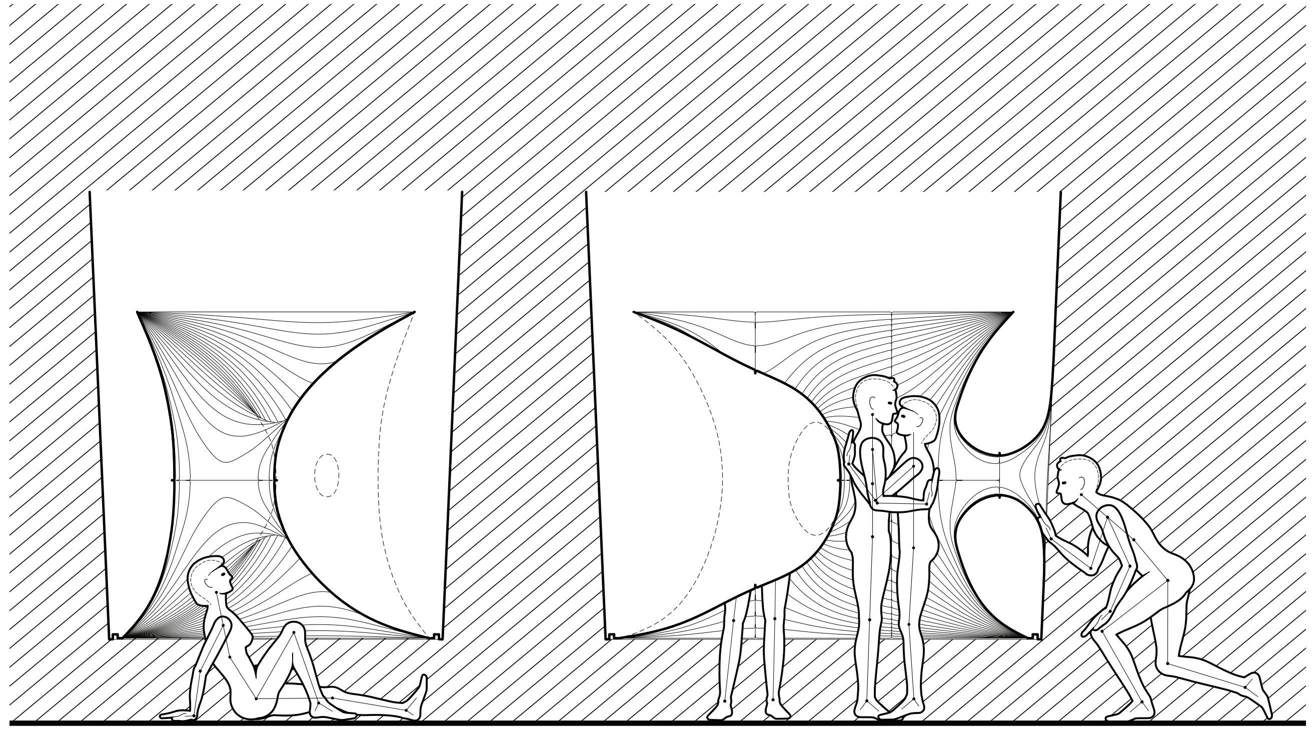


Figure 2: Sections

Geometry Constraints

The constraint dimensions of *Microtherme* are of course informed by the site location, but are largely informed by the smallest possible condensation around the human form. What is the smallest object where these human forms might still interact with enough freedom to dynamically engage the space? When working with radiant thermal surfaces, distance and percentage of exposure are critical; therefore, massive spaces would not be ideal. These spaces need to be large enough to accommodate, while small enough to fit the form like a glove. In order to resolve this conundrum, many of the dimensions are pulled from the work of Niels Diffrient and Alvin Tilley of Henry Dreyfuss Associates, which is commonly used in Architectural Graphic Standards (Ramsey 2000). For instance, the peek port is only five inches wide, the diameter of a hole large enough to get a forearm inside, but not much else. The mass is also hovering 17 inches above the ground, the lowest dimension one can expect a person to roll under. Inside, the two vertical spaces are also determined by human standards. The first is a 21-inch diameter space at the waist, and the second is an ellipse; 21 by 14 inches. The first larger space is large enough for a single person to stand inside, turn around, and share with another person. The second is large enough for a single person to stand within, but not to rotate. Each is relative to different manhole typologies.

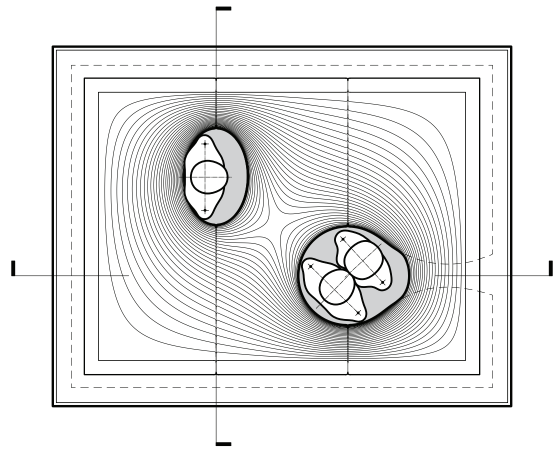
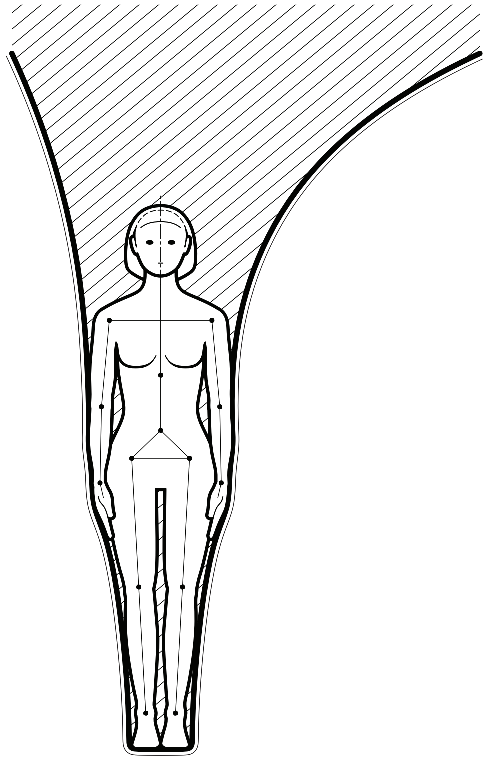


Figure 3: Plan

Form Computation

The relaxation of the surface is produced with a particle-spring solver (Piker 2016) with a series of irreducible constraint surfaces, and bound by dimensions of the human body. This solver then relaxed the surface to ensure that the surface would not encroach on the irreducible limits of the human's accessibility. As it relaxed, a check for percentage exposure was produced to lift or lower the surface during relaxation until a suitable equal

Figure 4: Interior view of the upper space.



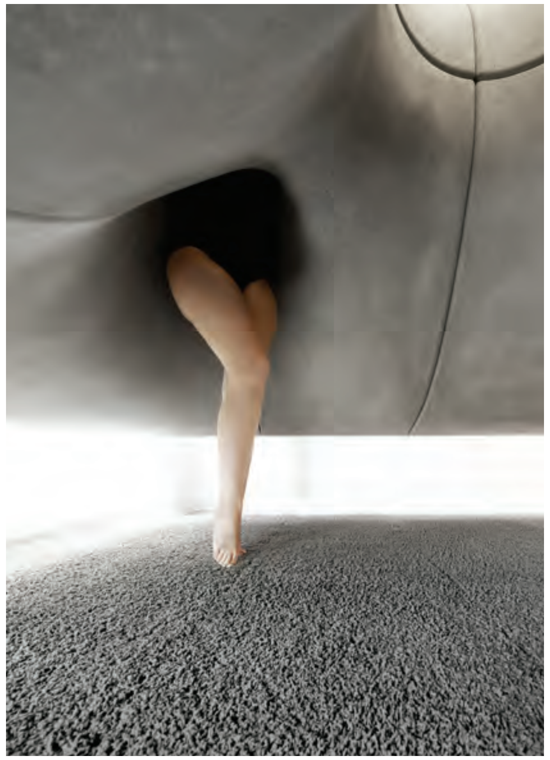


Figure 5: View of the lower space with a living caryatid.

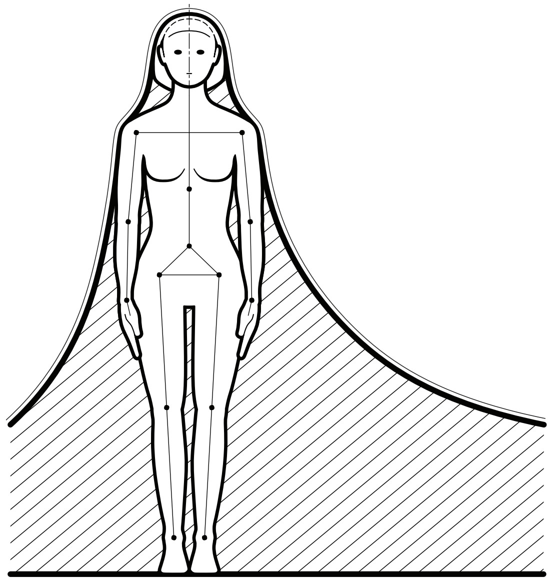


Figure 6: View from the ground looking up into the concrete space.

parts exposure was produced. This resultant surface ensured that curvature continuity would allow the shell structure to distribute its loads, while sufficing the other criteria of accessibility and exposure ratio.

FABRICATION

Microtherme is fabricated from an expanded polystyrene (EPS) foam mold that is coated in water-based surfacing compound. The mold is rough cut from a blank with a custom seven-axis robotic hot-wire, and then finish machined on an five-axis CNC mill. This combination of processes dramatically reduces the time required to cut the molds. The mold is cast by spraying glass fiber reinforced concrete (GFRC) to a thickness of a half-inch. Copper tubing lines the backside of this GFRC shell and is encapsulated in more GFRC to transfer the temperature to the surface as warm and cold water passes through the tubing. The panels are discretized from the larger form, determined by weight, shipping volume, and the reach of the fabrication process. Around the perimeter of each panel, a four-inch flange serves to connect panels to each other. The global structure is hung from the gallery ceiling, with a compression beam above. This beam supports the load down through the wooden enclosure to grab a hold of the GFRC shell from the bottom. The upper perimeter of the geometry is not supported by the structure, but rather serves as a lighting cove for the continuous lighting effect.

Poché, Work-Body, and Anti-Isomorphism

The space between the tension wooden enclosure and the interior concrete shell is invaluable, both for the performance of practicality and perception. This volume is described previously (see Spatial Contradictions) as poché; however, it should be noted that this volume is not a solid mass, only a perceived mass. This vacuum serves a practical purpose of occupying all of the pumps, heaters, tubes, and valves to produce the thermal experience. Wolfgang Meisenheimer describes this space in another way. He calls this space dedicated to the means and methods of making as the "work body" (Meisenheimer 1984). Whether it be for perceptual or practical purposes, a volume of space hidden inside two limit surfaces produces an anti-isomorphic architecture, liberating the exterior to perform its own tasks while the interior can perform its tasks. A similar investigation into anti-isomorphic architecture can be seen in the *Round Room* project (Clifford 2015).

FINDINGS

This research began with a naive understanding of how to balance thermal comfort through radiant surfaces. It promised, in theory, that as long as the range of temperatures is balanced across the percentage of exposure to the body, comfort could be achieved. But, *Microtherme* is decidedly uncomfortable without actively moving through the space. It should be said that it is momentarily comfortable, even relaxing, much like the Roman bath complex.

Figure 7: Interior detail view looking back toward the entry port.

Figure 8: Image of the non-visible side of the GFRC shell. This image exposes the assembly flange and embedded copper tubing.

One of the strange findings is a lag between heat and cool radiant surfaces. While radiant heat is something most people are familiar with, radiant cool is an alien condition. Radiant heat hits the skin and is felt relatively quickly. Radiant cool acts very differently. It seems to penetrate to the bone, taking a bit more time to be recognized by the senses. This lag means that heat is experienced first, and then if one bears through the heat, a cooling effect can be experienced to balance out the extremities. While thermal delight does offer the ability to build comfort through a dynamic transformation of temperature, the standard assumption that temperature can be calculated based on balancing temperature and area ratio might also need to balance temporality. In this experiment, *Microtherme* relies on the occupant to balance their own thermal delight; however, future research might tackle this topic of temporal and rapidly changing radiant temperatures.

In addition, some people found the spaces to be claustrophobic, while others were thrilled by the intimacy of the concrete. It is without a doubt a unique condition to invite someone to experience; however, the dimensions fall inside the standard that one might expect a human to occupy. The difference in these experiences was polarized—that is to say, that people either enjoyed it, or were terrified by it.

Another interesting finding is in the multitude of occupation. Because the space is so occupied by concrete and volume, it is difficult to get a vantage point that allows you to see everything. You either see the lower half, or the upper, but not both. This produces a playful atmosphere in the exhibition space, with multiple people negotiating motion through this compact space. This is amplified by the radiant surfaces, further begging people to continue to move. One example is, if one is standing inside the smaller of spaces, they are able to see if someone is standing in the other vertical space, but they aren't able to see if someone is under them trying to stand up inside their space. This is not possible in the smaller space, but is possible in the larger one. In that larger space, an awkward sequence of positions will result in two people standing inside a single space, though given the intimate nature of these positions, these two are likely to know each other well. What became clear through these interactions is that there is a constant feeling that the visitors are trying to explore, but that they also have the continual feeling of being spied upon.

This paper experiments with a concept of comfort, and undoes preconceptions of both spatial and thermal comfort. It develops a means to compute surface geometries in response to human accessibility and percentage exposure. In doing so, it raises questions about how we approach comfort with respect to geometry and energy.

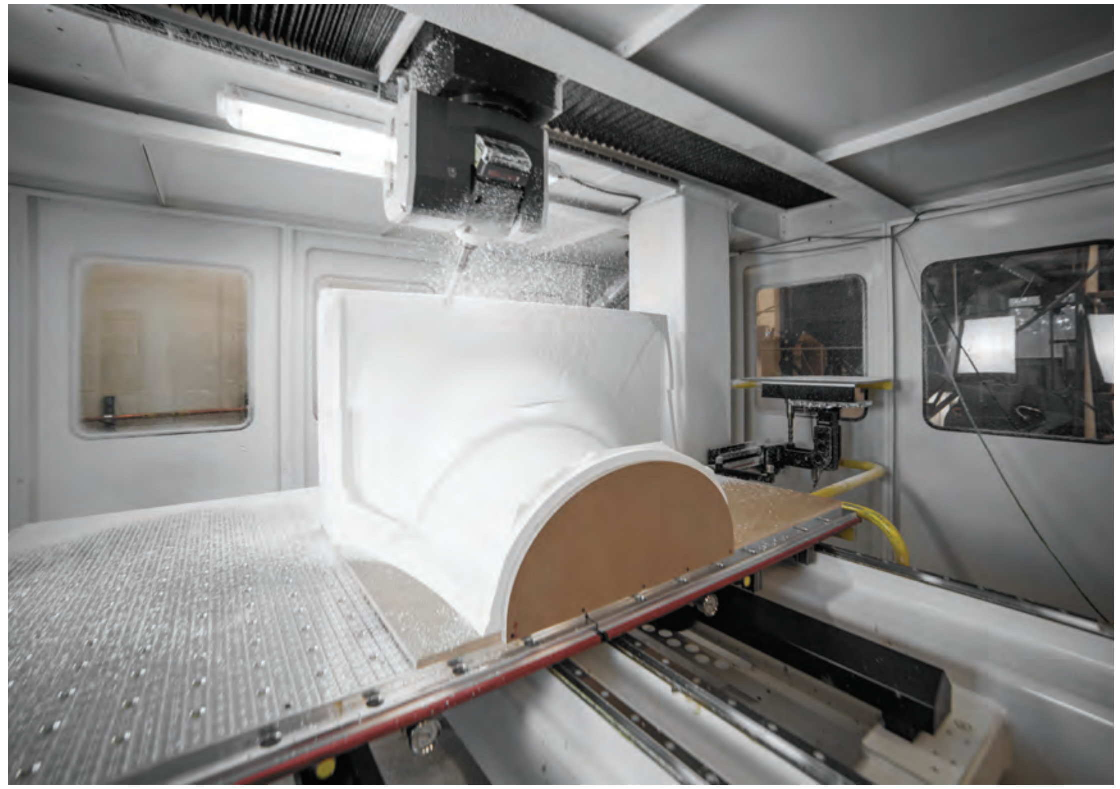


Figure 9: 5-axis milling of the foam molds.

Figure 10: Image of the GFRC shell assembled and awaiting the wooden enclosure that will hang it from the ceiling.

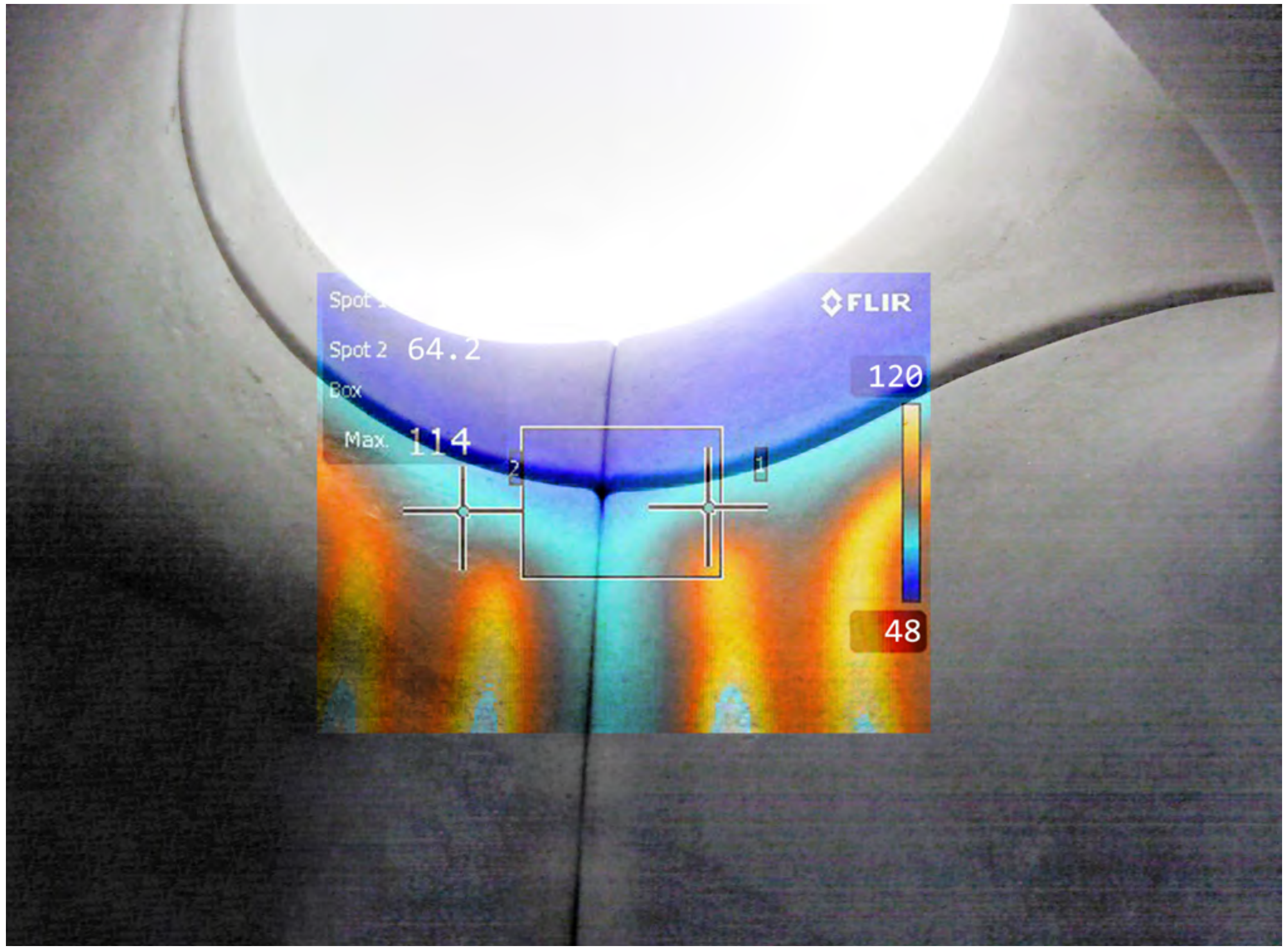


Figure 11: Thermal imaging exposing the temperature.

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The surface relaxation computation employs Kangaroo (www.grasshopper3d.com/group/kangaroo) as the physics engine solver for the particle-spring system developed by Daniel Piker to work inside Grasshopper (www.grasshopper3d.com), a plugin developed by David Rutten for Rhinoceros (www.rhino3d.com), a program developed by Robert McNeel. The surface was generated through T-Splines (www.tsplines.com). The project team includes Myung Duk Chung, Cody Glen, Asa Peller, Maya Shopova, Tyler Swingle, and Luisel Zayas.