

Thermal Worlds: Redefining Spatial Thresholds With Temperature in the Geothermal Landscape

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Space is typically demarcated by its physical boundaries. The solidity of wall, ceiling, and floor define architectural interiors. Space in the landscape, though structurally similar, is bounded by larger-scale material conditions, such as tree canopies, horizon, sky, and ground. How can architectural space be defined without architectural materials? As a proposal for the use of temperature as a space-making material for design, this design research project draws from philosophy and phenomenology to understand the body as an instrument for sensory experience. Architectural case studies are used to redefine the notion of physical, visually perceived space and ways intangible experiences are at the forefront of a design. It investigates how the manipulation of geothermal water can unlock the performative, ephemeral, and experiential characteristics of temperature as a material for redefining spatial thresholds within the geothermal landscape of Iceland.

TEMPERATURE AS AN INVISIBLE, PHENOMENOLOGICAL DESIGN MATERIAL DEFINING SPATIAL THRESHOLDS

Temperature is generally invisible to the eye. Our perception of the characteristics that define space and place are largely visual, even though we sensorially inhabit the world through the other four senses of smell, taste, sound, and touch. In his *Introduction to Realistic Philosophy*, John Wild describes how the human body is a device that registers ephemeral and invisible aspects of the environment:

“Sensing is a mode of awareness or cognition. In sensing we assimilate the form without the matter *objectively*, thus becoming aware of something as it is—external to the physical subject of the awareness. But this does not mean, in the case of sensation, that physical influences from the object are not also necessary. For example, the physical warmth of the fire must physically heat my hand if I am to feel its heat... The physical influence received in the skin is not the sensation of heat but the medium by which this is carried to the sense organ under the skin. Moreover as for the actual sensation it is an act of the temperature

sense which is resident in the sense organ, which abstracts the form of heat from the physical changes of the skin medium, and thus makes the heat of the fire noetically present as long as the fire keeps influencing the organ.”¹

The human body is an instrument that measures the physical influences of objects in its environment. It registers invisible qualities such as temperature—its heat or frigidity, moisture or aridity—not only on the skin, but also through smell, sound, and taste. Although these qualities cannot be seen by our eyes, the mind still *sees* and recognizes the presence of temperature, at all times, using the other bodily senses.

According to Wild, there are five factors that structure sensation, and are essential to our sensory awareness: [1] a quality that produces an effect on transmitting medium, [2] the ability of the medium to transmit that effect to a sense organ, [3] the ability of the sense organ to abstract that effect, [4] the abstracted sense, and [5] the material object, made known by the abstracted sense.² Our formulation of this objective information through sensing is divided into three major classes: what we sense *immediately*, what we sense *through some mediation*, or as a result of sensing something else, and what we sense only by accident or association.³ We connect with and build knowledge of the external world through our experiences, collecting information conveyed to us by our senses. Physical objects around us have physical characteristics we immaterially experience and abstract through our senses: seeing forms and colors, smelling scents, feeling heat and moisture. Over time, our sensory experiences build on one another, converting experience into bodily knowledge and awareness. After we burn ourselves for the first time, we become more familiar with sensory cues that prevent such an event from repeating. This gradual understanding accumulates into known instrumental thresholds of our bodies’ limitations. Understanding the physiology of the human body as a sensual instrument for learning and understanding the environment has generally been overlooked by the design disciplines.

All of our senses, operating simultaneously, should be considered as factors for design. The design disciplines have largely focused on the visual as the means to organize, understand, and experience space. Visible, physical objects are privileged as the definers and creators of space. Christian Norburg-Shultz, a well-known philosopher of phenomenology, describes space as “the three-dimensional organization of the elements

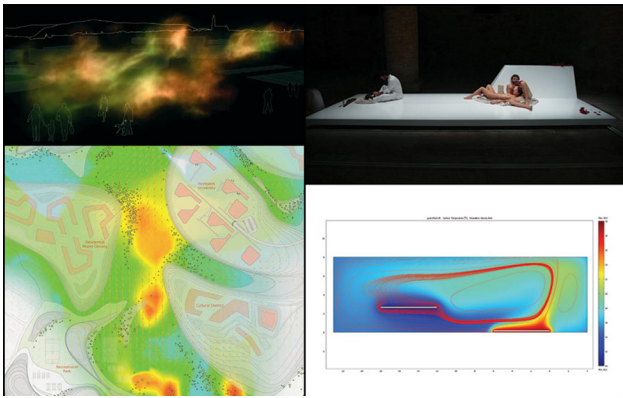
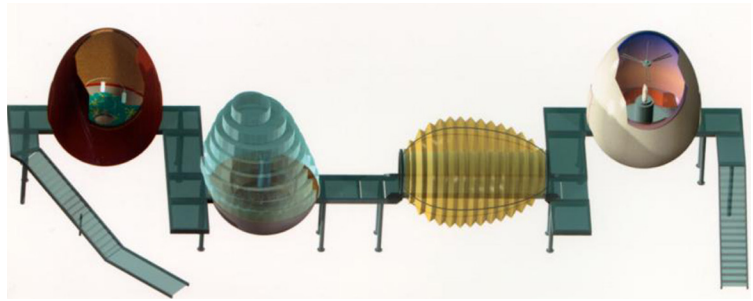


Figure 1: Case Studies in designing with the immaterial material of temperature. Left: Vatnsmyri Urban Planning Competition—Landforms are used to contain pockets of heat, while a colored gradient scale is used to represent the thermal fluxes within the overall proposal. (Drawings by Sean Lally, WEATHERS); Center: Digestible Gulf Stream, Venice Biennale, 2008—Two plates heated at different temperatures create a miniature gulf stream. A color gradient is used to represent the movement of atmospheric temperature within the project. (Photograph and Drawing by Philippe Rahm); Right: Climate Chambers II, 1998 Swedish Pavilion, World Expo in Lisbon—Four egg-shaped chambers connected by a walkway contain exaggerated extremes of climatic conditions one would experience through Sweden’s four seasons. (Drawing by Studio Bigert & Bergström)

which make up a place.”⁴ This emphasis on visible objects neglects the majority of human senses. Instead, drawing from Wild’s description of sensory cognition, can this concrete, visually perceived, three-dimensional spatial boundary be dismantled and converted into a membrane which is invisible to the eye, but cognitively perceived and recognized by the sensing body?

The word *membrane* is used in place of boundary in order to describe an alternate condition. Boundary implies a hard separation between two spaces. Membrane can imply a more layered, transitional condition. Norburg-Schultz explains that the outside-inside relation of concrete spaces implies “a varying degree of extension and enclosure. Whereas landscapes are distinguished by a varied, but basically continuous extension, settlements are enclosed entities. Settlement and landscape therefore have a *figure-ground* relationship.”⁵ By Norburg-Schultz’s description, the figure-ground, outside-inside relationship is purely a visually recognized physical separation. Extension and enclosure are used in visual terms to understand physical space.

Alternatively, if temperature is used as the space-defining element, there is no dichotomy between inside and outside, figure and ground. One would be visually, concurrently inside and outside, simultaneously within the figure and the ground. There would also be a cognitive, thermal separation between the interior-exterior (thermally manipulated spaces) and the exterior-exterior (the landscape and thermal environment as it exists at that moment in time). The thermal membrane is the mediator, a transitional zone between different thermal conditions, allowing the body to cognitively perceive interior comfort within an exterior



environment. Physical elements can be used as operative instruments that manipulate temperature to create interiority within an exterior terrain.

The body’s sensorium, the apparatus of collective perception, can be used more advantageously in design. Landscapes can be designed with spaces that are less visually experienced, and more sensorially immersive with its users, testing an alternative perception of spatial boundaries. In *Thermal Worlds*, thermal thresholds are the immaterial membranes through which spatial differences are experienced and registered by the body and senses. The works of architects such as Philippe Rahm and Sean Lally, and artists such as Bigert & Bergström, all seek to explore and capture the ephemeral, immaterial, and experiential qualities of environments through experimental and built design work.

IMMATERIAL MATERIALS: CASE STUDIES IN DESIGNING WITH TEMPERATURE AND CLIMATE AS SPACE-DEFINING ELEMENTS

The following case studies are examples of how the invisible, ephemeral, ethereal forces and effects of climate and temperature can be used and expressed to create sensorially immersive spaces, environments, or landscapes. They also explore a variety of representational approaches for visually describing the invisible (Figure 1).

Sean Lally’s work explores ways in which thermal resources can affect climate and program. In his Vatnsmyri proposal, the programmatic landforms are linked together with a thermal “wash” that manipulates local climatic conditions, producing artificial microclimates that extend seasonal activities. In contrast, Mats Bigert & Lars Bergström’s “Climate Chambers II” for the Swedish Pavilion at the 1998 World Expo in Lisbon, Portugal, explores the simulation of climatic conditions within discrete spaces.⁶ Four egg-shaped chambers, arranged in seasonal order and connected by a continuous walkway, allow visitors to experience a wide range of extreme weather conditions, simulating what one might encounter through Sweden’s four seasons. One characteristic from each season is emphasized within each space, such as humidity, heat, storms and wind, and freezing conditions. The materials used for these chambers also emphasized the sensory experience that was being activated within the space. Although these two projects and approaches are different, they both explore ways in which climate and temperature affect our sensorial experience and understanding of our environments.

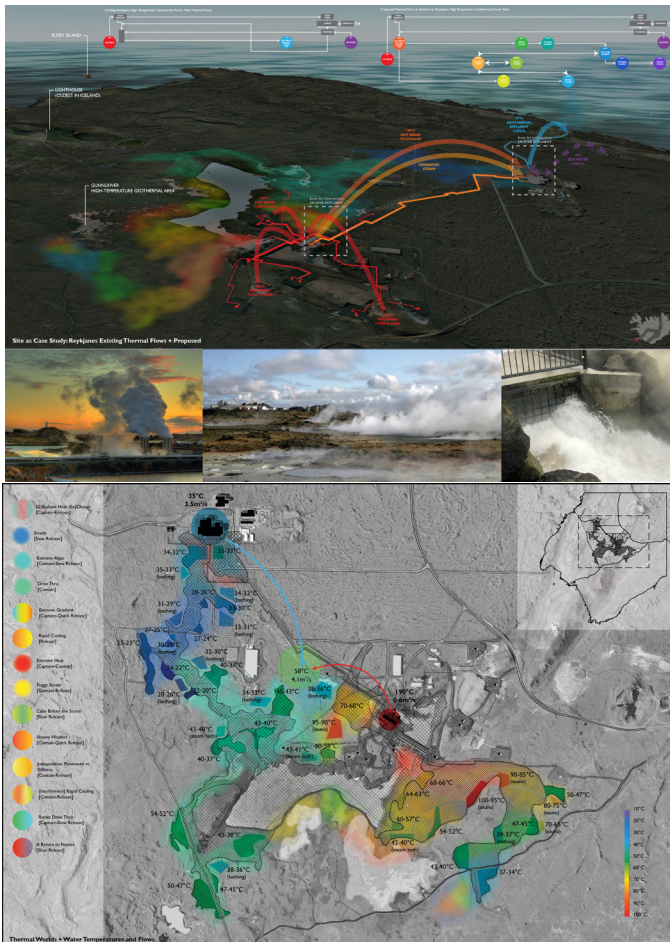


Figure 2: Reykjanes Geothermal Power Plant—Existing Thermal Flows with Overlaid Temperature Gradient Expansion and Framework for Thermal Worlds, with images of the power plant’s surrounding landscape and effluent; Thermal Worlds: Water Temperatures and Heat Transfer Flows—To create a wide-range of micro-environmental interiors—thermal worlds—three programs are overlapped. Each micro-environment is defined by a specific thermal process within the larger design scheme

Philippe Rahm’s architecture is focused around exploring the ethereal forces of light, temperature and heat transfer (radiation, conduction, and convection), and atmosphere (pressure, evaporation, and digestion). In his work, physical constructions perform more as devices for manipulating temperature and atmosphere, while the way these forces behave define human programming based on the body’s threshold for experiencing these forces, creating an invisible landscape around temperature, water, and air. In Philippe Rahm’s recent book *Constructed Atmospheres*, Massimiliano Scuderi’s introduction describes Rahm’s approach to architecture, as “a new discipline that can be defined as meteorological architecture...he engages the possibility of intersecting architecture with ecology, chemistry, and climatic phenomena in order to define a complex spatial infrastructure.”⁷ Meteorological phenomena such as conduction, convection, and radiation, which Rahm uses as materials to define space, “inform the shape of the space, heralding innovative uses and behaviors that induce new modes of living.”⁸ This alternative approach to defining habitable space reflects how sensory cognition can be used more

advantageously in design, and in turn, altering our perception of how space is defined. Rahm’s work enhances and brings to the forefront that our environmental experiences are fostered by constant change.

In his Digestible Gulf Stream project for the Venice Biennale in 2008, two plates heated at different temperatures, one physically suspended with a temperature of 28°C and the other lying on the ground at 12°C, create a miniature gulf stream of temperature movement caused by a convective air current. This creates warmer areas for habitation, and cooler areas around the exterior of this invisible space. A color gradient is used to represent the movement of atmospheric temperature within the project.

GEOTHERMAL WATER AS A THERMAL MATERIAL FOR DESIGN

Geothermal energy takes on a diversity of material transformations in the landscape. Hot water, steam, heated soil, and bubbling mud are only a few examples of its physical, ephemeral, and sensory manifestations. Iceland is an extreme case study for understanding the multi-scalar, life-cycle effects of geothermal water as an active material energy across its landscapes. Geothermal energy and its geographical trace are more evident in this island country than anywhere else in the world. Iceland’s culture, urbanism, architecture, infrastructure, and landscapes are heavily shaped by the heated material, creating a wide range of spatial conditions throughout the country.⁹

Geothermal is intrinsically tied to larger geological and hydrological conditions that form Iceland’s landscape and its ability to produce energy. The country’s existence is a result of these heat-driven processes: from the extraction of geothermal water and steam from energy fields such as Gunnhver and Hellisholt, to power production in Hellisheidi and Krafla, to its distribution for domestic energy use in cities such as Reykjavik and Akureyri, geothermal energy has a lifecycle akin to other materials used to create infrastructures and urban space. The use of geothermal water and steam is prolific across a wide range of different temperature scales for activities as diverse as greenhouse food production, aquaculture, and bathing.

Iceland’s supporting infrastructures and economies, such as food, energy, and tourism, are formed by and reliant upon the material manifestations of geothermal water. It not only shapes the landscape, but also is integral to Icelandic culture, which has harnessed and manipulated its energy for centuries. At the end of every lifecycle stage involving geothermal energy, whether in its extraction, production, or use, there is always a waste material: an output of water at a lower temperature than the input. Every process along its lifecycle uses the heated material at a unique temperature, and discards a slightly cooler ‘waste’ product. These gradients of temperature usefulness sometimes overlap between different processes. Typically, the used, undesired, but still productive waste material is discharged into the landscape or a water body.

RECLAIMING THE INDUSTRIALIZED GEOTHERMAL LANDSCAPE

Geothermal energy extraction yields a consistent byproduct called geothermal effluent: slightly cooled geothermal water which is no longer hot enough to produce power. The Reykjanes Geothermal Power Plant in Southwest Iceland is located approximately one kilometer from the Atlantic Ocean, and operates using 300°C thermal brine drawn from

Heat Transfer Utilization

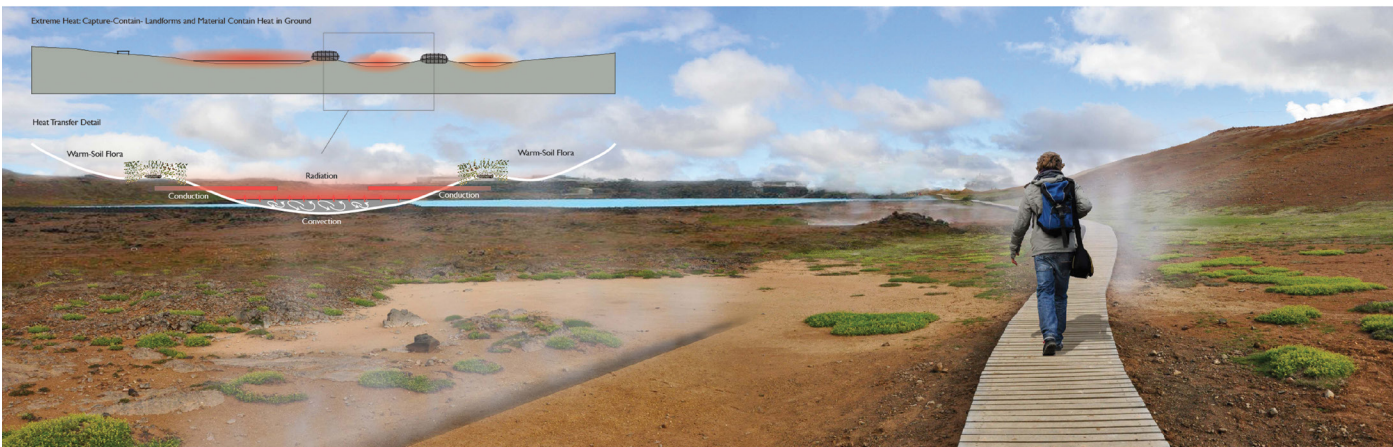
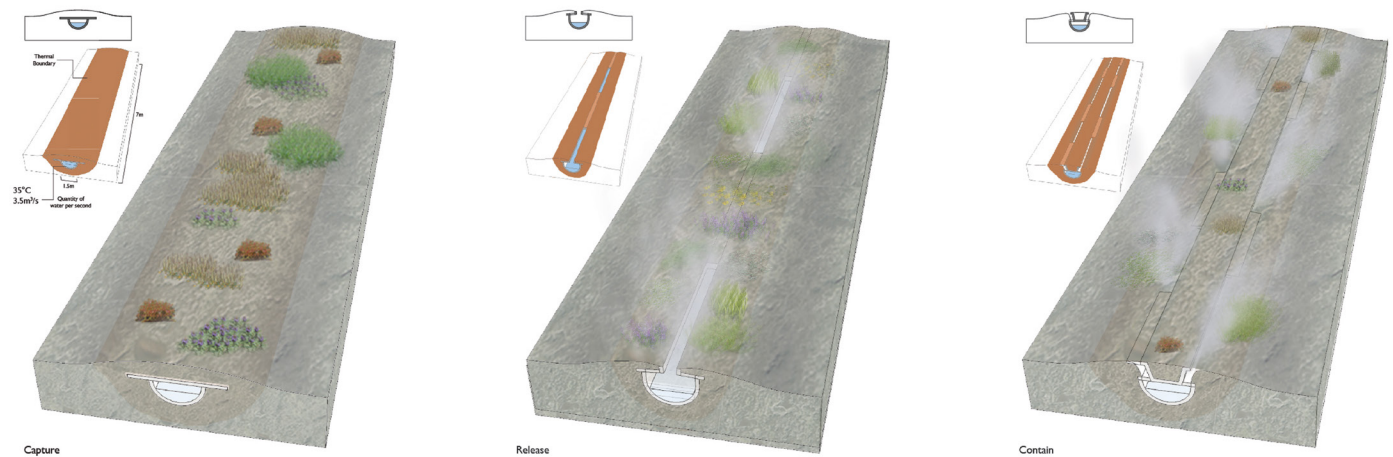


Figure 3: Heat Transfer Utilization: Capture, Contain, Release with Radiation, Conduction, Convection—In order to manipulate the immateriality of temperature, physical material interventions are used to capture, contain, and release heat. Three types of conduit systems establish micro-climates of heated ground, heated air that condenses and produces moist, humid environments, or a hybridized condition of both.

15 boreholes extending 1,600-3,000m below the surface.¹⁰ The thermal brine effluent goes through steam separation, which extracts and purifies the steam from geothermal brine by removing water and minerals. The steam from this heated material powers two 50 MW turbines, supplying energy for a nearby aluminum smelting plant, Norðurál in Hvalfirði. During steam separation, the geothermal effluent cools to 190°C. It is then piped to a cooler, where it is mixed with 8°C sea water, cooled to 57°C, and released through an 800 meter long concrete culvert to the Atlantic Ocean at a rate of 4,000 liters per second¹¹ (Figure 2).

This hot water possesses the potential to yield an alternative outcome. Rather than quickly diverting the water out to sea and away from the extraction and production process, the material and its temperature gradient can be redirected back to its source landscape. *Thermal Worlds* reclaims this active industrial territory as a post-production process, and transforms its landscape into a place of habitation for not only the users who work there, producing and extracting extremely hot water for energy production, but also for visitors, flora, and fauna. It recaptures

and reuses this geothermal effluent as a performative material that enhances the geothermal landscape experience. The heated material's extension across the landscape is choreographed to form thermally-bounded interior spaces within an exterior, whose variability promotes a wide range of micro-habitats, climates, ecologies, and economies.

The project establishes cooperative functions between industry, culture, and ecology by utilizing the geothermal gradient as a transfer of heat energy – they intersect and interact in this reimagined territory. Naturally occurring geothermal environments contain ecotone gradients of algae and vegetation. Their diversity is produced by their small windows of vitality, based on temperature, moisture, acidity, and salinity. Temperature is used as the thread that interweaves algae cultivation and production, revegetation strategies, and temperature's experiential qualities for cultural habitation. In the wide range of thermal environments created by this project, three programs are overlapped to create thermal relationships: algae cultivation for biofuels, nutrition, food, and feed; a botanical garden and research area for geothermal ecology, and a thermal resource park to act as an educational and cultural destination. Thermal worlds are used as a framework across the landscape to mediate between these various programs.

Thermally defined, spatially open interiors restructure this industrialized landscape of geothermal production by diverting its hot effluent back to the landscape from which it is extracted. The reuse of this geothermal

effluent generates a new landscape formed by thermal thresholds created by the compression and extension of its temperature gradient. The thermal gradient is the language of the project and is used as a representational tool for describing the invisible spatial boundaries defined by temperature. Heat is simultaneously performative and experiential, and is exploited as an invisible, phenomenological material through design. Saline pools, steam baths, and saunas are paired with thermally associated communities of algae, flora, and fauna whose transferred heat energy fuels each other, intersecting and interacting in thermal environments. As an interlinked thread that experiences thermal fluxes, the structure of the project is an experiential sequence of shifting temperature gradients that create spatial thresholds within a landscape. Physical boundaries are used to transform the temperature gradient, while thermal boundaries are used to define programs, ecologies, and experiences.

TEMPERATURE AS A SPACE-DEFINING MATERIAL FOR INTERIORITY WITHIN A LANDSCAPE

Thermal Worlds aims to create thermally-bounded interior spaces in the landscape. The project choreographs heat across the site for various levels and forms of habitation. In this case, the spatial boundary is experienced rather than seen. Exterior landscape and interior space are hybridized to create a place in which the definition of either is blurred—the viewer sees across and inhabits a landscape, but their immediate bodily experience is focused within varying thermal envelopes, creating comfortable interior spaces. Temperature, as an invisible, variable material, defines the membrane that surrounds an “interior” space within the landscape. Rather than a visible material tectonic of wall, ground, horizon, or ceiling defining edges of space and programmatic elements, thermal thresholds guide the programmatic development and spatial organization of the site. Temperature is a gradient, ephemeral condition experienced by the body, and is an invisible, phenomenological material, utilized as the medium which dictates programming and defines space. Understanding the full spectrum of the lifecycle of geothermal energy—its production, use, and end-of-life—and its variability in temperature, creates possibilities for how landscape architecture can intervene within this larger system.

Temperature can be captured, contained, and released through mechanisms of heat transfer—conduction, convection, and radiation—using design techniques which incorporate materials and forms that are conducive to the manipulation and transfer of heat (Figure 3). The project manipulates and orchestrates temperature through the design of capture, contain, and release mechanisms constructed with various materials, enclosures, landforms, and plantings that maximize or minimize solar and wind exposure. “Capture” is the method of energy absorption: an input. “Contain” is the trapping and holding of energy. “Release” is a device to rapidly decrease the temperature of the water. The processes of capture and release each contain micro-gradients within their transitions, while moments of contain are more thermally homogeneous. One example of the manifestation of this approach is through the conveyance system of the geothermal water across the site. Material elements manipulate heat to form spaces within each thermal

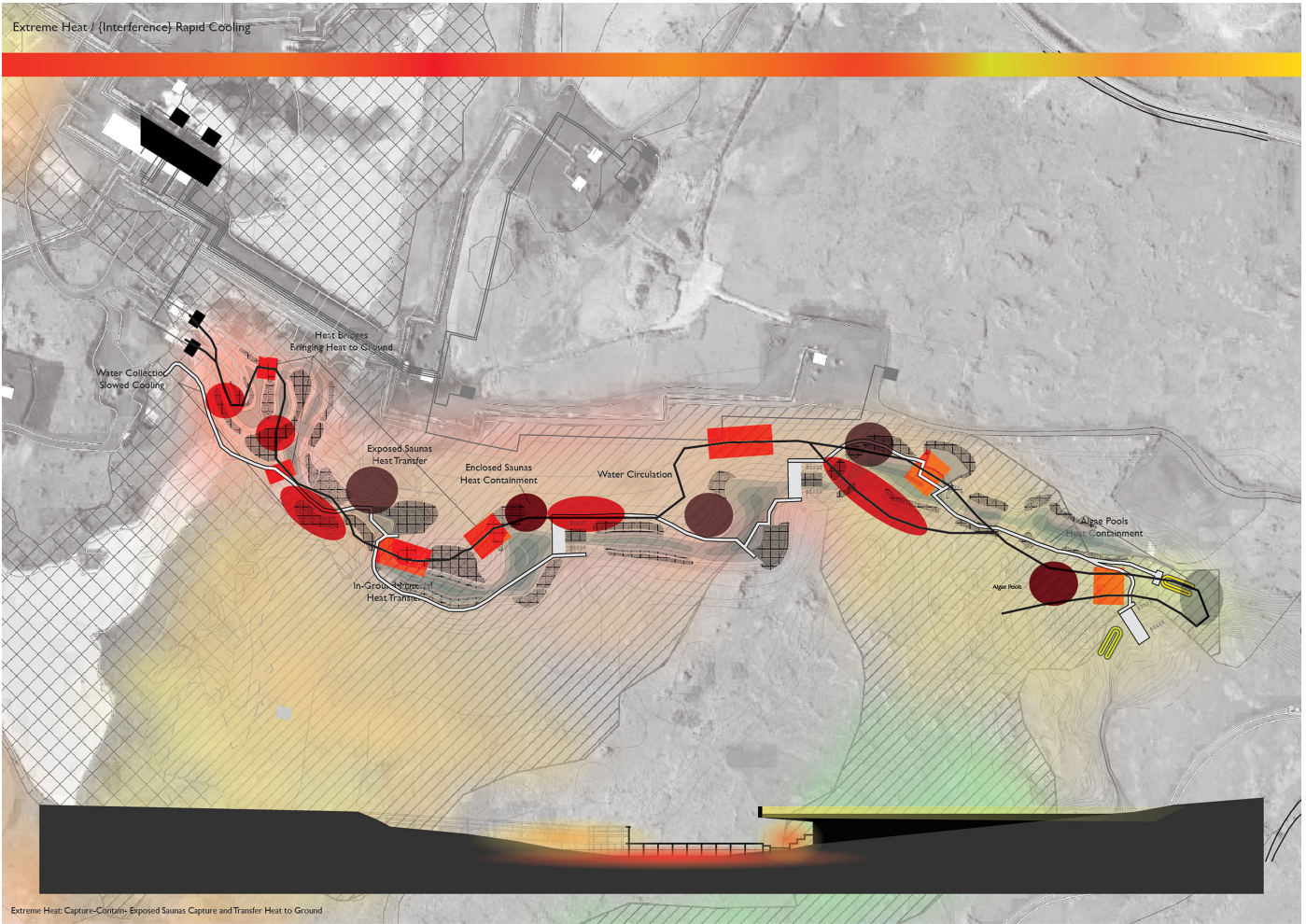
world, and become a means to physically and visibly register these constructed climatic conditions.

The spatial organization of *Thermal Worlds* uses the fluctuation of temperature as a programmatic guide for creating overlaps between various ecologies and industries to allow them to thrive. In order to reuse remnant heat across different temperatures, thermal fluctuations are advantageously populated with a variety of operations and activities. This approach manifests as an exploration of thermally defined spatial thresholds within the landscape, operating at multiple scales by pairing ecologies that thrive within specific temperature ranges with other industries and programs requiring the same thermal range. As these relationships are established, a feedback loop between ecology and industry crystallizes, unlocking new potentials. The establishment of new programmatic relationships coupled by their shared thermal thresholds allows for multiple programs to colonize every gap of temperature as the geothermal water cools.

These *thermal worlds* are micro-environments which heighten or suppress particular aspects of temperature, heat exchange, and thermodynamic laws of achieving thermal equilibrium. The thread of thermal environments linked together as a continuous process that experiences temperature fluctuations creates a sequence and narrative through temperature gradients in relationship to its post-geothermal energy source. The gradient sequence allows for the three programs to form new relationships through heat transfer. *Thermal Worlds* focuses on the ways in which the orchestration of the thermal gradient is manifested as a series of thermally-defined interior spaces, whose concepts are highlighted in two particular thermal worlds, “Extreme Heat” (Figure 4) and “Extreme Algae” (Figure 5).

“Extreme Heat” is an environment where heat is experienced from a distance through radiation and conduction. The topography lends itself to cooling the water by slowing its speed and exposing its surface to the cooling air. Physical interventions transfer the heat into areas for cultural and ecological programming to prosper. Heat is captured and transferred in several ways within this micro-environment. In certain areas, which are protected from wind by the topography, a cantilevered metal plate is suspended above the moving water, absorbing and transferring heat into the ground to create a micro-habitat for a specific type of plant community. In parallel, there are sauna structures that bridge over the moving water, collecting heat in the form of steam from the cooling waters below, while simultaneously functioning as a connection to the other side. Heat from these structures is also transferred to the neighboring ground. Algae cultivation becomes integrated at the cooler end of this thermal world, for that is the highest threshold for algae species to begin to thrive.

“Extreme Algae” takes on an opposite character. Its temperatures are optimal for all programs to occur. As a result, rather than manipulating the geothermal water to cool as rapidly as possible, this thermal world explores how temperature can be stretched in order to retain as much heat as possible across a large swath of land. Topography is used to envelop, contain, and protect the escaping heat from the wind. Algae



Extreme Heat Capture-Contain- Exposed Saunas Capture and Transfer Heat to Ground



Figure 4: Extreme Heat—Extreme Heat is an environment whose heat is experienced from a distance through radiation and conduction. Heat is captured and transferred using several strategies. For example, topography promotes the rapid cooling of the water, by slowing its speed and exposing its surface to the cooling air, while physical interventions transfer the heat into areas for cultural and ecological programming to prosper. The views capture the various conditions and methods for how the cooling effluent creates an interior-exterior environment for industry, ecology, and culture to interact.

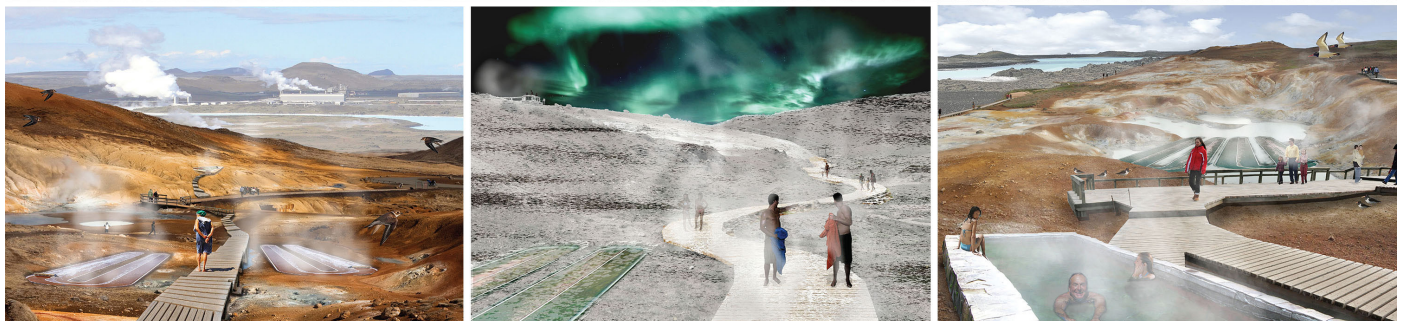
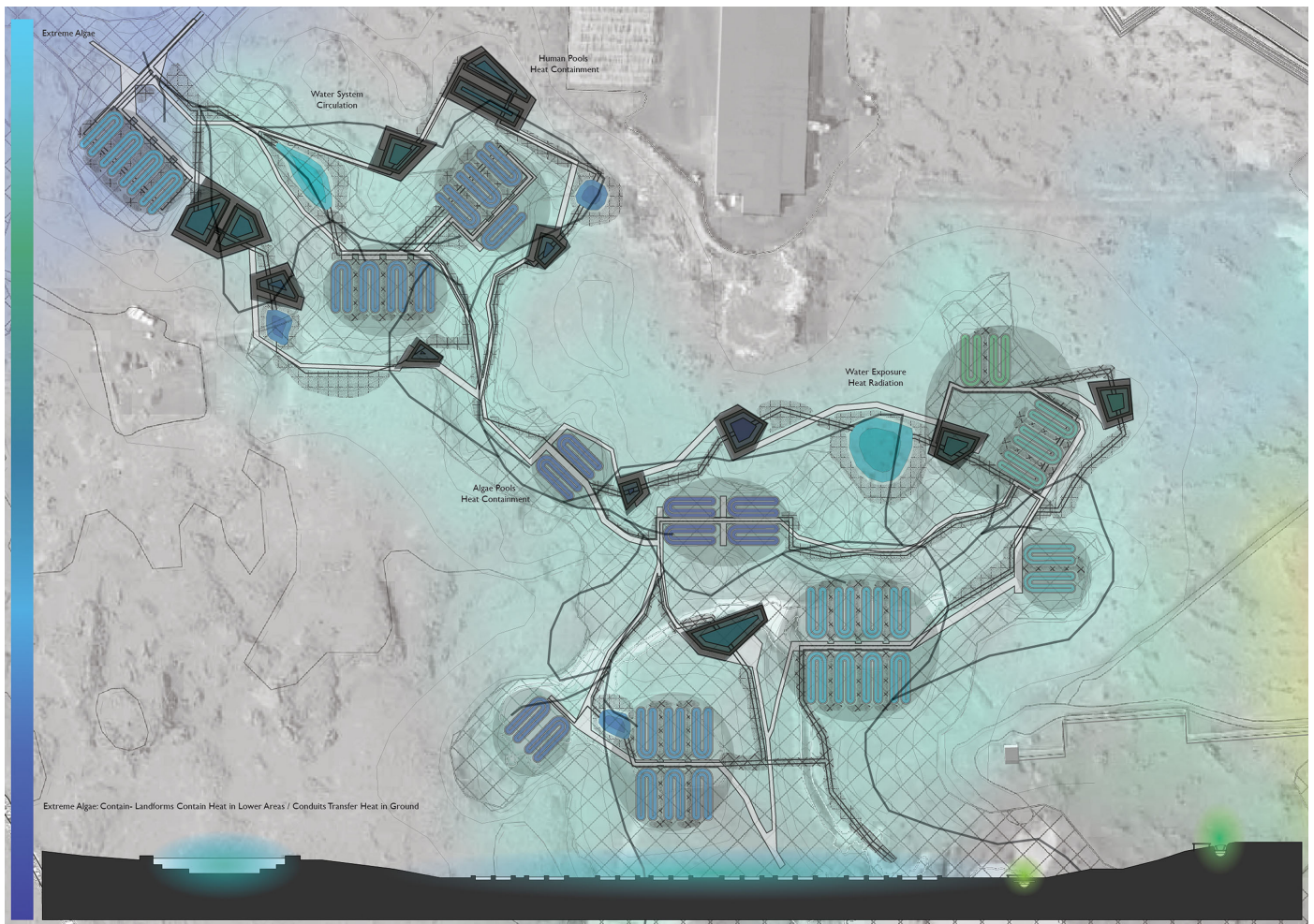


Figure 5: Extreme Algae— This thermal world contains temperatures that are optimal for all programs to occur. To take full advantage of this heated source, the temperature gradient is stretched to retain as much heat as possible across a large swath of land. Algae ponds are sited in low lying areas, using topography to maintain consistent temperatures due to their narrow thermal windows of vitality. As a collective, one is able to see the registration of temperature through the various algal communities present in different cultivated waters. The conduit system is overlapped by human circulation, creating heated paths and microenvironments for humans and ecology. The views capture various conditions and methods for how heat from the effluent is contained, creating environments where industry more closely interacts with ecology and culture. Extreme Algae is a venue for experiencing methods in which heat can be physically contained and more closely experienced..

ponds are sited in low lying areas because they require the most consistent temperatures due to their narrow thermal windows of vitality. Sculpted topography shelters these ponds within a valley. Each algae species also possesses a different tone, from a gradient of greens to blue-greens as well as a few red to purple tones. In this unique case, temperature is visible: the registration of the temperature gradient becomes apparent in the various, multicolored algal communities present in different cultivation waters. Human pools are sited in the higher areas for exposure and views. The conduit system is overlapped by human circulation, creating heated paths and micro-interiors for humans and non-humans.

CONCLUSION

Iceland's culture is bounded by water, resulting from the country's physical, geographical location, and is an essential aspect of cultural identity. In the project *Thermal Worlds*, the physical material of geothermal effluent becomes the medium through which the immateriality of temperature defines spatial interiority within a geothermal landscape. This water, in all of its states and temperatures, becomes cognitively present on the landscape as sensorial registrations in the body and physical manifestations of plant and algal communities. It engages the senses and invites visitors to consider the heated material: its effects, its texture, and the way in which it creates a new perception of space, and a potentially new cultural process of gathering, transporting, and arranging the heated material on a geothermal energy production site. It encourages the visitor to not only see the site, but to experience its multi-layered, multi-scalar, choreographed thermal fluctuations that make it economically and ecologically diverse and productive.

The phenomenological registration of the project is centered on the encounter of this heated material which incorporates all senses as an immersive thermal experience. This is done by encouraging the visitor to be conscious of their body as an instrument to perceive their own temperature thresholds by providing extreme environments as venues for testing individual thermal limits. The project aspires to become a new biological, ecological, and cultural artifact of thermal dwelling for Iceland by utilizing the site's anthropogenic and geological processes to yield a geothermal environment that supports algae production and cultivation, flora and fauna repopulation, and a new cultural destination.

ENDNOTES

1. John Wild, *Introduction to Realistic Philosophy*. (New York: Harper & Row, 1948), p. 413.
2. Wild, "Sensory Cognition", p. 413-4.
3. Wild, "Sensory Cognition", p. 417.
4. Christian Norburg-Schultz, "The Phenomenon of Place," *Architectural Association Quarterly* 8, no. 4 (London: Pergamon Press, 1976): p.4.
5. Norburg-Schultz, "The Phenomenon of Place," p. 5.
6. Joy Monice Malnar and Frank Vodvarka, *Sensory Design*, (Minneapolis: University of Minnesota Press, 2004), p.242.
7. Philippe Rahm, *Constructed Atmospheres: Architecture as Meteorological Design*, (Milan: Postmedia Books, 2014).
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