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From the Eye to the Skin: Architectural Representation Beyond Vision

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Buildings are assemblies of visible matter that are conceptualized, visualized, and designed through various techniques of architectural representation. Buildings are also assemblies of invisible dynamics that play just as much a role in shaping the physical world as the parts of it that can be seen. These invisible dynamics include environmental phenomena such as conduction, convection, radiation, and evaporation. Through these phenomena, buildings and the materials that make them up, interact with, and become part of, the world around them. These phenomena are primarily sensed though the skin rather than the eyes – through touch rather than vision. There is a critical need to expand the capacities of architectural representation to more effectively deal with how buildings shape, and are shaped by, these invisible dynamics. As well as to deal with how these dynamics are perceived by a building's inhabitants. This essay will discuss invisible dynamics in architectural representation from a historical perspective and then explore how these dynamics can be expanded to more effectively design with invisible aspects of the physical world. The essay will conclude by presenting drawings by the authors that explore how new representational conventions can be developed to visualize and design with invisible dynamics in the physical world.

Introduction

Over the past approximately 500 years, architectural representation has developed as a powerful visual language enabling architects to imagine and describe buildings. The great capacity of architectural representation is its dual role of imagining new worlds, and then describing those worlds. Architects do not typically draw after reality but use drawing to produce new realities. Because they work from the imaginary to the real, the most effective architectural drawings communicate immeasurable and measurable information simultaneously. An architectural drawing communicates qualitative, immeasurable aesthetic information as well as quantitative, measurable information such as length, quantity, orientation, etc. The complex nature of architectural representation is often described with a shorthand, that it is both 'artistic' and 'technical.'

In our era of climate crisis and resource depletion, it is becoming increasingly important for architects to engage invisible environmental phenomena in the design of buildings. For architecture to remain relevant as discipline, it's representational system must evolve beyond an overwhelming bias, inherited from its origins in Gothic and Renaissance building practice, toward conceiving of buildings as static constructions of visible matter perceived through vision. To do this in a way that is

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not merely directed toward solving relatively straightforward problems such as energy efficiency and thermal comfort, but that also seeks to bring cultural value to the built environment, architectural representation needs to bridge between the imaginary and real, between the qualitative and quantitative, and between the 'artistic' and 'technical' when it comes to conceptualizing, visualizing, and designing the invisible dynamics that shape the physical world. The vast majority of drawings that deal with environmental phenomena such as conduction, convection, radiation, and evaporation are reductive diagrams that remain in the technical realm of building science diagrams. For the most part, these diagrams do not adequately acknowledge the radical shift they could initiate from perceiving architecture exclusively through vision, to perceiving architecture through vision and touch simultaneously.

This essay will discuss new strategies for representing invisible building dynamics that are typically represented in an overly technical or reductive manner. It will present drawings by the authors that describe energetic flows across scales from the atmospheric to the molecular, and in so doing will suggest new ways to visualize the invisible dynamics of environmental phenomena. These drawings, which will be discussed at the end of the essay, are the beginning of a larger project to develop a comprehensive visual language accessible to students, educators, and practitioners that can enrich the discipline with a deeper understanding of the environmental phenomena that are typically relegated to building science specialists. Buildings can be designed as participants in, and shapers of, the invisible dynamics that flow through and around them if architects are given the representational systems to effectively conceptualize and visualize these systems.

Literature Review – Energy and Climate in Architectural Representation

There are many examples of drawings and diagrams dealing with relationships between architecture and energy that can serve as examples and guides for the research presented here. These drawings and diagrams are typically made by architects and/or for architects, and they are concerned with bringing conduction, convection, radiation, and evaporation into a visual relationship with built forms. These diagrams are often sections, sometimes plans, and occasionally three-dimensional projections such as axonometric or perspective projections. They are often based on a simplified, or prototypical building in order to illustrate the concept of a relationship between an invisible dynamic and built form, rather than going deeply into the details and specifics of how the invisible dynamic interacts with a particular building. These diagrams use directional lines with arrowheads, often curved or squiggly, sometimes colored, with varying line weights and line types to show how invisible flows of energy and air move around and through a static built form.

This type of drawing combines disparate things: visible matter and invisible matter, static form and dynamic form, regulated architectural projection and unregulated notation. These combinations imply, but do not necessarily acknowledge, that an architectural drawing can inform both visual and tactile perception. The potentials for architectural drawing to more explicitly deal with the visual and tactile simultaneously

will be discussed later in the essay. For now, it is important to note that these drawings seek to describe relationships between architecture and energetic flows. The origin of the relationship between architecture and energetic flows, as we understand it in contemporary architectural discourse, traces back to Vitruvius's story of architecture as it originates from communal gatherings around the thermal comfort of a fire.[1] For Vitruvius, the space of thermal comfort around a fire precedes humans' ability to conceive of arranging matter into built forms that provide shelter. The perception of space as a tactile environment precedes perception of space as a visual environment. The origins of architecture for Vitruvius are energetic.

In this discussion, it is useful to pick up the relationship between architecture and energy in the 1950s and 60s when architects, and the culture at large, became acutely aware of the limited resources available on the planet. Kenneth Boulding's seminal essay "The Economics of the Coming Spaceship Earth," written in 1966, describes a shift in the perception of the earth as an 'illimitable plane' with a frontier beyond human inhabitation, to a 'closed sphere' that became perceptible through air travel[2] and found its ultimate visual manifestation in the 'Blue Marble' photograph taken by the Apollo 17 astronauts in 1972. The 'Blue Marble' was the first photograph taken of the entire earth floating in the black void of space. This photograph made the reality that the earth is a closed system with limited resources immediately understandable. When he wrote the essay nearly 60 years ago, Boulding observed that much of humanity had failed "to come to grips with the ultimate consequences of the transition from the open to the closed earth."[3] One could argue that this is still the case today. As a whole, the cultural, social, and material systems that participate in the conception and construction of the built environment still have not fully internalized this crucial shift – from considering buildings as closed systems within the earth as an open system, to considering buildings as open systems within the earth as a closed system. The representational systems that still dominate discipline and practice, because they deal primarily with visual aspects of the physical world, are inadequate for expressing the implications of this shift. While the realization that the earth has only limited resources did spur development of a wealth of diagrams describing how buildings interact with their environments in the post-war period, this type of representation is still not widely used instrumentally in architectural design. In contemporary architectural representation, drawings and diagrams that incorporate architecture and energy are more likely to be used in analyzing or justifying design decisions, rather than being used at a more fundamental level to inform design decisions.

Some of the most widely disseminated and influential examples of visual representations of invisible dynamics in buildings are found in Victor and Aladar Olgyay's book *Design With Climate,* which was originally published in 1963 (Figure 1). The Olgyays were concerned with how visualizations of invisible environmental dynamics in and around buildings could fundamentally inform design decisions. They developed a step-by-step method of collecting climatic data, incorporating it into

1. Vitruvius, *The Ten Books on Architecture* (Garden City, NY: Dover Publications, 1960), 39.

2. Kenneth E. Boulding, "The Economics of the Coming Spaceship Earth," in *Resources for the Future* (Baltimore, MD: Johns Hopkins University Press), 1.

3. Boulding, 2.

diagrammatic representations, and then using the resulting diagrams to inform architectural design decisions.[4] The Olgyays believed that the way humans conceive and imagine relationships with the environment is central to culture. The visual representations they produced could thus be seen as being conceived in a way to encourage a new modern lifestyle, and new ways of thinking about familiar social patterns[5] based on a deeper understanding of relationships between human bodies, buildings, and the surrounding environment. These relationships, however, were set out by the Olgyays in a way that today must considered reductive. Operating in the spirit of the modern movement in architecture, the Olgyays' method is geared toward creating an unchanging interior climate that provides consistent comfort for an undisturbed male body. The human is seen as a stable, protected figure within a building that acts as a protective envelope, separating the human body from the surrounding environment.[6] Regardless of the season, location, or culture, the interior climate is conceived by the Olgyays as being unchanging and benign.

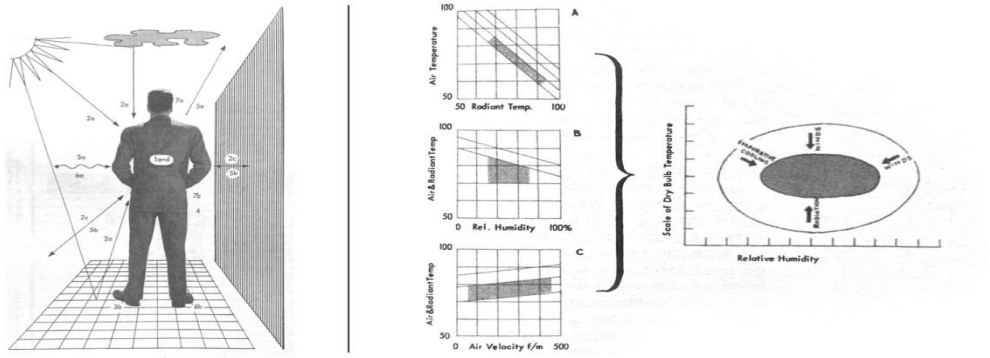

Figure 1. *Heat Exchange between Man and Surroundings (l), Interrelationship between Climate Elements (r)*
Source: Victor Olgyay, Design with Climate: Bioclimatic Approach to Architectural Regionalsim, 16-17.

The Olgyays' diagrams were intended to present an objective reality that would in turn suggest rational design solutions. But any type of representational system, even one that is ostensibly based on rational parsing of data, will convey information and engage audiences differently. As an example, consider Rudolf Geiger's Sankey diagram of radiation from the sun hitting the earth, which has been produced in multiple different variations for different audiences. Geiger's diagram describes percentages of the sun's radiation that penetrate the earth's atmosphere, are reflected back into space, are absorbed by the earth, and are trapped in the atmosphere. Using the convention of Sankey diagrams, percentages of the overall quantity of radiation are shown with the thickness of arrows representing their flows. The diagram was originally presented by Geiger in his book *The Climate Near the Ground*,[7] and then

4. Daniel A. Barber, "The Nature of the Image: Olgyay and Olgyay's Architectural-Climatic Diagrams in the 1950s," in *Public Culture* 29(1): 147.
5. Barber, 133-136.
6. Barber, 149-150.
7. R. Geiger, *The Climate Near the Ground* (Cambridge, MA: Harvard University Press, 1950).

was reproduced line for line by the Olgyays in *Design With Climate* in a context that made it more accessible for architects (Figure 2). It was subsequently reproduced by Russel Ball in *The Passive Solar Energy Book*,[8] and by Greg Arcangeli in *Architectural Science and the Sun*.[9] These subsequent representations reduce the level of detail originally provided by Geiger. Ball's version presents the sun in a whimsical manner suggesting that the diagram is for a popular audience interested in solar design. Arcangeli's version presents radiation flows in a more contemporary abstract manner, presumably to appeal to an audience of contemporary students and practitioners that might find Geiger's graphics outdated and thus assume the information contained in them outdated as well.[10] However, Geiger's diagram could become more useful to architects interested in designing with radiation flows by adding information rather than removing it. Later in the essay, we propose a new version of Geiger's diagram that will do so.

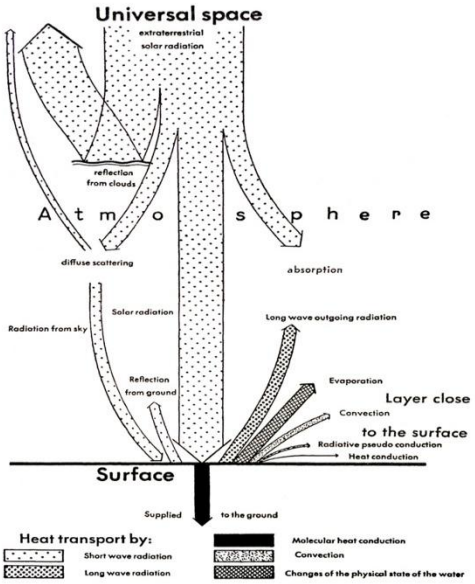

Figure 2. *Sankey Diagram of Radiation Flows toward Earth*
Source: Rudolf Gieger via Victor Olgyay, Design with Climate: Bioclimatic Approach to Architectural Regionalsim, 33.

The Olgyay's approach has many offshoots, some of which are geared more toward building scientists and some that are geared more toward architectural designers. Books such as Baruch Givoni's *Man, Climate and Architecture*[11] reduce the emphasis on graphics as compared to the Olgyays in favor detailed explanations of the physics and mathematics behind environmental phenomena such as

8. E. Mazria, *The Passive Solar Energy Book* (Emmaus, PA: Rodale Press, 1979).

9. M. Fajkus, D. Whitsett, *Architectural Science and the Sun: The Poetics and Pragmatics of Solar Design* (New York, NY: Routledge, 2018).

10. Daniel J. Ryan, "Introduction: redirecting the arrows of climatic design," in *Drawing Climate: Visualizing Invisible Elements of Architecture,* eds. Daniel J. Ryan, Jennifer Ferng, and Erik G. L'Heureux (Basel: Birkhauser Verlag, 2022), 10-13.

11. B. Givoni, *Man, Climate and Architecture* (London: Applied Science Publishers, 1969).

conduction, evaporation, and airflow. With expertise gained from the information presented through tables, graphs, and equations, one could potentially optimize architectural design solutions around environmental phenomena. This way of presenting the functioning of environmental phenomena supports deep comprehension but is inaccessible to architects without specialized knowledge in physics and mathematics. The information Givoni presents through charts and graphs must be interpreted into a visual language before it can be incorporated into architectural representations (Figure 3). And it is only through incorporation into architectural representations that this information can become instrumental in architectural design. Architectural representation is always to some degree mimetic, it has a level of visual similarity with the things it represents. A psychometric chart, a solar graph, or a wind speed graph, on the other hand, is not mimetic. These types of diagrams present information in a different register than architectural representations. A particular point or region in a graph is quantified in relation to other data within the domain of a graph. For this quantitative data, residing in a graph, to interface with the process of designing a building, it has to be applied to a spatial condition. This can be done with a level of expertise in interpreting the data, and an understanding of how the data connects to the space of a theoretical building. However, it is difficult to imagine this type of data as an integrated part of an unfolding design process. Building science data presented in tables and graphs is more effectively used to optimize building forms that have already taken shape.

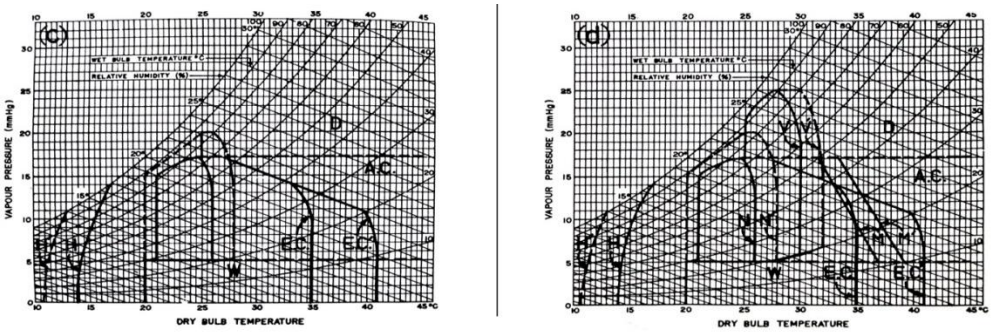

Figure 3. *Building Bioclimatic Charts*
Source: Baruch Givoni, Man, Climate and Architecture, 316.

Books such as *Environmental Control Systems*[12] take a more graphic approach to describing environmental phenomena and their interactions with buildings (Figure 4). A more graphic approach presents relationships between architecture and energy in a manner that is generally accessible to architects and others without specialized knowledge in the building sciences. Moore's diagrams rely heavily on arrows with different graphic styles drawn around plans and sections of simple, conventional buildings that describe flows of air and radiant energy, and how buildings can control these flows.

12. F. Moore, *Environmental Control Systems: heating cooling lighting* (New York, NY: McGraw-Hill, 1993).

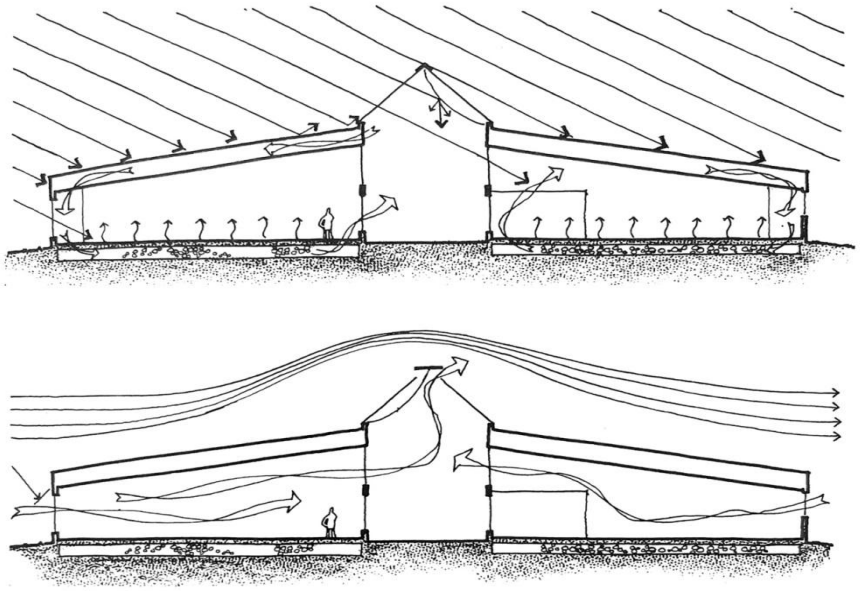

Figure 4. *Passive Solar Heating Section (t), Ventilative Cooling Section (b)*
Source: Fuller Moore, Environmental Control System: heating cooling lighting, 205.

While diagrams such as these do bring invisible environmental dynamics into the realm of graphic representation, we find their shortcoming to be that they remain almost exclusively at the scale of the building. The material principals behind environmental dynamics operate through a wide range of scales, from the micro-scale of the molecular to the macro-scale of the atmospheric, both of which need to be understood, along with a middle scale in which buildings reside, to more fully comprehend the implications of their interactions with built forms. Without a graphic understanding of the fundamentals of how environmental phenomena function at scales outside the visual range, one is left with a similar result to Givoni's building science approach, which is that the building becomes a control system for regulating an environmental phenomenon. The aim of this research is to suggest that architectural representation could evolve in ways that shift environmental dynamics from their secondary status as phenomena that are to be regulated by that which has been designed, the built form, to a primary design consideration. We believe environmental dynamics can have greater impact in shaping built forms and thus the qualitative experience of architecture.

More contemporary examples of representational systems developed to convey a particular aspect of architecture's relationship to its energetic context include *Carbon: A Field Manual for Building Designers*[13] and *Manual of Biogenic House Sections*.[14] While these books deal with a somewhat different relationship between architecture and its environment than that being discussed here, they are useful to consider in terms of how representational systems convey a particular relationship between architecture and its energetic context. *Carbon* uses charts and graphs,

13. M. Kuittinen, A. Organschi, and A. Ruff, *Carbon: A Field Manual for Building Designers* (Hoboken, NJ: John Wiley & Sons, 2022).

14. P. Lewis, M. Tsurumaki, and D. Lewis, *Manual of Biogenic House Sections* (China: ORO Editions, 2022).

which range across large expanses of time and space, to describe relationships between the earth's geology, its forests, and carbon, with the aim of showing where carbon comes from, how anthropogenic processes have moved it from underground into the atmosphere, and how it can be sequestered in forests. These charts and graphs are juxtaposed with drawings of building at different scales showing how carbon can be subsequently sequestered in buildings constructed from trees. *Manual of Biogenic House Sections* takes a similar approach in developing a representational system that explicates relationships between the earth, materials extracted from it, and how these materials are deployed in architectural designs. Readers of the book are able to trace materials from their sources to specific architectural uses in detailed sectional drawings, while also tracking the embodied energy represented by the materials represented in the drawings. Both these books demonstrate how a representational system that expands on conventions already existing in the discipline, can be used to explore and discuss a relationship between architecture and the energy embodied by the materials in its production supply chain. Through a series of visually engaging drawings, these books present a particular way of approaching architecture that is clear and accessible. They both make an argument that if one uses particular materials in particular ways, then the building is successful. The shortcoming of this type of representational system, with respect to the research being presented here, is that the designer is not assumed to engage fundamentally with the invisible dynamics that underlay, and are affected by, the material flows described in the drawings. The implication is that that designer simply needs to understand the larger material and energy context in which they are working in order to produce responsible architecture. While one must acknowledge the critical importance of the message of these books and admire the beautiful and refined systems of architectural representation used within them, they are not suggestive of how architects might engage representation instrumentally in designing environmental phenomena.

The representational approach that perhaps comes closest to treating the invisible dynamics of conduction, convection, radiation, and evaporation as building blocks for architecture, rather than phenomena that need to be mediated, controlled, and/or relegated to the outside of a building or design process, is that of architect Phillippe Rahm. Rahm's work finds philosophical footing in the writing of Bruno Latour who argues against western culture's tendencies to split materiality from design, and humans from their environments,[15] as well as in the writing of Peter Sloterdijk who argues that humans are not observers 'in front' of reality, they are embedded within it. Rahm notes that if we breathe in a toxic substance, the substance becomes part of our bodies, and we are transformed. He describes a plastic bottle not simply as an object we observe in front of us, but as a part of us, as microplastics in our bodies.[16] Rahm effectively throws off much of the modernist baggage that has been carried forward into contemporary architectural representation through the approach of the Olgyays, and other like them, who produce drawings and diagrams that separate the visible forms of architecture from the invisible dynamics that surround it, that treat the

15. Massimiliano Scuderi, "Introduction: Phillipe Rahm and the meteorological architecture," in *Constructed Atmospheres: Architecture as Meteorological Design,* (Las Vegas, NV: Postmedia Books, 2014), 5-6.

16. Scuderi, 69.

visible parts of architecture as the control mechanism for the invisible, and that treat the human body as separate from the buildings that shelter it. What if these prevailing beliefs could be inverted? What sort of representational system would architects need in order to design with the invisible?

The drawings of Rahm's architectural practice documented in *Constructed Atmospheres: Architecture as Meteorological Design*[17] and *Climatic Architecture*[18] begin to suggest how this might be possible. Rahm treats invisible dynamics of the physical world, including conduction, convection, radiation, and evaporation as fundamental building blocks of architecture. As such, two main aspects of Rahm's drawing serve as a jumping off point for the research presented here. First, that the drawing deals with the void framed by architecture as material. Rahm is explicit in describing architecture's reason for being as climatic.[19] At a fundamental level, architecture consists of bubbles of air that have tolerable atmospheric qualities for human habitation. Therefore, the bubbles of air contained in the void must become a part of the architectural drawing. Typical architectural drawings are of course not at all concerned with representing the substance of the voids that are framed by walls, ceilings, and floors, they are simply shown as empty space. Typical energy diagrams, such as those discussed above, deal with the void it terms of how it is controlled and mediated by the visible parts of architecture. Rahm's representational innovation is the introduction of gradient fields that are used to represent different qualities of the void, including temperature, pressure, and humidity. The voids in Rahm's drawings become the habitable spaces where architecture is experienced, rather than the empty space from which one views the architecture. The second aspect of Rahm's drawing that is particularly important to carry forward in this research is the inclusion of the human body as an integrated part of the climatic system. In line with Sloterdijk's mandate to consider the human as 'in' the environment rather than 'in front' of it, Rahm's drawings incorporate the human body as a system that operates within the same invisible dynamics that the building does. Rahm uses the same notational systems to draw the human body as he does to draw architecture, rather than leaving the body as a neutral bystander. This opens the experience of architecture to an array of qualitative sensual experiences that exists beyond vision, in the realm of the tactile.

A Tactile Architecture

The notions that architecture can be experienced by senses other than vision, and that one should be wary of the dominance of vision in the conception and experience of architecture are not new. Juhani Pallasamaa makes this argument in The Eyes of the Skin, where he writes: "The gradually growing hegemony of the eye seems to be parallel with the development of Western ego-consciousness and the gradually increasing separation of the self and the world; vision separates us

17. Phillipe Rahm, *Constructed Atmosphere: Architecture as Meteorological Design.* M Scuderi (ed) (Las Vegas, NV: Postmedia Books, 2014).

18. Phillipe Rahm, *Climatic Architecture* (New York, NY: Actar, 2023).

19. Phillipe Rahm, *Climatic Architecture* (New York, NY: Actar, 2023), 11.

from the world whereas the other senses unite us with it."[20] It is true architecture is increasingly consumed in fragmentary images that distance the viewer from meaningful engagement with the experience of a building as a whole. However, the position taken here is that Pallasamaa's justification for this criticism, and thus the response to it, folds architectural discourse back into its own intellectual arena concerned with hermeneutics, rather than considering development of a tactile architecture as having much broader implications in the search for buildings that produce meaning by becoming more sophisticated in their relations with their inhabitants and environment. Recent developments in neuroscientific research have found that vision does not actually produce the type of separation between self and the world, or between percept and concept, that Pallasamma suggests.[21] There is no visual world 'out there' that we perceive and then intellectualize. The visual world is within the brain, and thus within the body. Vision is just as embodied as the other senses.

So, the skin is not another set of eyes that somehow 'see' through a process of intellectual interpretation, but rather its enveloping surface is another way the body/brain complex interacts with the physical world. It is an entirely different sensory organ from the eyes with a completely different mode of sensing the environment, which is in fact material rather than interpretive. There are many theories describing how architecture produces cultural meaning, all of which necessarily begin with sensory inputs. The philosopher Mark Johnson notes that one does not need to turn architecture into legible 'texts' to create meaning.[22] Meaning is not entirely linguistic; it is not simply an abstract, disembodied concept. For Johnson, it is a much richer, much more embodied experience that "involves the neural simulation of sensory, motor, and affective processes that we associate with the thing or the event that has meaning for us."[23] These are qualitative experiences: "Our world is a realm of immediately felt qualities that have meaning for us even before language."[24]

If qualitative meaning is produced sensorially and immediately, rather than abstractly and intellectually, then architectural representation must begin to deal with the non-visual material realities that play a part in producing this meaning. The skin is always immersed in a bath of air made of a mixture of molecules including of nitrogen, oxygen, water vapor, carbon dioxide moving and vibrating at different rates, and it is always immersed in, and being penetrated by, a flow of energetic waves. The movement and vibration of air molecules, combined with the flow of energetic waves produces a range of different sensations, some of which are pleasurable or comforting, some of which are not. These sensations are a result of the skin interacting in immediate contact with its environment. Our built environments do not need to neutralize or homogenize these sensations because there is design potential in their

20. Juhani Pallasmaa, *Eyes of the Skin: Architecture and the Senses* (Hoboken, NJ: John Wiley & Sons, 2005), 25.

21. Harry Francis Mallgrave, *The Architect's Brain: Neuroscience, Creativity, and Architecture* (West Sussex: Wiley-Blackwell, 2011), 134-139.

22. Mark L. Johnson, "The Embodied Meaning of Architecture," in *Mind in Architecture: Neuroscience, Embodiment, and the Future of Design,* eds. Sarah Robinson and Juhani Pallasmaa (Cambridge, MA: The MIT Press, 2017), 35.

23. Johnson, 38.

24. Johnson, 38.

variations.[25] Might it be possible to develop architectural representations that deal with these tactile sensory experiences in a way that is distinct, but also learns from, the ways representation already works between visual cognition and visible matter? Might it be possible to develop architectural representations that bring the tactile and visual together more effectively?

Representing Invisible Dynamics

One of the keys in bringing the visual and tactile together in architectural drawings, is an ability to represent aspects of the material world that are not perceptible to vision. Visible aspects of the material world are described through mimetic means, which have evolved to represent largely static organizations of objects. To represent invisible aspects of the material world, architectural representation must expand to include the visual language for describing elements that are very large, very small, dynamic, or otherwise visually imperceptible. There are no established representational conventions for these aspects of the material world precisely because they elude visual perception. There are of course many examples of energy drawings in architecture that make use of arrows, gradients, and other notations to describe dynamics that are imperceptible to vision. These, however, are typically done to illustrate settled decisions, rather than to explore the potentials of designing with invisible dynamics. If design drawings need a level of ambiguity,[26] so that they are subject to multiple interpretations, how does one introduce invisible dynamics to architectural representation with the level of ambiguity that allows them to function as design drawings? To explore how this might be possible, it is useful to consider a relatively recent technique of notational diagramming in architecture.

In the late 20th century, perhaps as a response to the computer's ability to flood the discipline with new visual approaches to design, certain architects became interested in thinking about architecture more in terms of 'what it does', rather than 'what it looks like.' To visualize 'doing something,' in relation to different types of invisible, immaterial information such as the performance of events, the relationships between the various parts and users of a building, and the organization of flows of people in and through a building, these architects used notational diagrams. The invisible aspects of architecture they were concerned with were immaterial, as opposed to the invisible aspects of the material world being discussed here. However, the approach to notational diagramming potentially holds a series of insights in terms of representing invisible aspects of the physical world. These notational diagrams were influenced by the philosophers Gilles Deleuze and Félix Guattari's concept of an abstract machine. For Deleuze and Guattari, an abstract machine is a productive tool that contains a structure or code which holds potentials to produce many different outcomes: "We define the abstract machine as the aspect or moment

25. Lisa Heschong, *Thermal Delight in Architecture* (Cambridge, MA: The MIT Press, 1979), 35-6.

26. The neurologist Semir Zeki offers a neuroscientific explanation of how ambiguity works in art by holding multiple equally valid readings or interpretations at the same time. Semir Zeki, "Art and the Brain," in *Daedalus,* 127(2), 87.

at which nothing but functions and matter remain."[27] Functions and matter, in Deleuze and Guattari's terms, deal with aspects of the world that *could* exist but have not yet come into being, they are potentials of the world that have not been actualized. The abstract machine thus produces ambiguity in its reading because it can hold multiple, equally valid, versions of the world.

The architect Stan Allen recognized the potential for a type of architectural drawing, what he defined specifically as a diagram, that is abstract and not mimetic: "Unlike classical theories based on imitation, diagrams do not map or represent already existing objects or systems but anticipate new organizations and specify yet to be realized relationships."[28] Like Deleuze and Guattari, Allen changes the conventional way of thinking about abstraction, rather than considering it to be a simplification of a reality that already exists, an abstraction is a representation that holds the potential to produce multiple realities. The diagram, as an abstract machine, is a productive design instrument. It is "not a thing in itself, but a description of potential relationships among elements; not only as an abstract model of the way things behave in the world, but a map of possible worlds."[29] As they are not mimetic, they are not scaled-down pictures of buildings, the graphic information in diagrams is notational. Similar to music or dance notations, architectural notations can describe a performance, an event, movements, and relationships between parts. Allen writes, "notation…directs attention toward all of the intangible properties of the real that cannot be set down in graphic form. Many aspects of the experience of architecture can never be predicted or simulated by representational drawing."[30]

Although they preceded Allen's writing, one of the clearest examples of notational diagrams that direct "attention toward all of the intangible properties of the real," and function as a "map of possible worlds" are architect Bernard Tschumi's theoretical architectural drawings, The Manhattan Transcripts. These drawings are a visual manifestation of Tschumi's assertion "that there is no space without event, no architecture without program…Our work argues that architecture–its social relevance and formal invention–cannot be disassociated from the events that 'happen' in it."[31] The Manhattan Transcript drawings generally follow a tripartite scheme where one frame is a photograph of an event involving a human body or bodies, a second frame is a diagram of movement vectors and nodes transposing the movement in the photograph into a notational diagram, and a third frame develops a spatial or architectural consequence derived from the other two, which is a distorted or transformed version of a recognizable architectural composition. Tschumi uses notational diagrams as a way of capturing aspects of architecture that are immaterial and invisible yet have enormous consequence on the experience of space as he explores potentials for architectural design. Tschumi's diagrams are productively ambiguous in that they point to multiple, equally valid, outcomes. To put it in Deleuze and Guattari's philosophical terms, Tschumi's diagrams are abstract machines that are functional

27. Gilles Deleuze and Felix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia* Transl. Brian Massumi (Minneapolis, MN: University of Minnesota Press, 1987), 141.

28. Stan Allen, "Diagrams Matter," in *Any: Architecture New York,* No. 23, 16.

29. Allen, 16.

30. Stan Allen, *Practice: architecture, technique and representation* (New York, NY: Routledge, 2000) 32.

31. Bernard Tschumi, *Architecture and Disjunction* (Cambridge, MA: the MIT Press, 1998) 139.

rather than formal, they serve as a type of code for generating spatial potentials.

While Allen and Tschumi write and draw about immaterial aspects of architecture such as event, movement, and relationships between parts, we propose that notational diagrams based on Deleuze and Guattari's concept of the abstract machine might be used in a similar manner to inform other non-mimetic aspects of architectural representation, the invisible dynamics of the material world. Following Tschumi we argue that architecture–its social relevance and formal invention–cannot be disassociated from the invisible dynamics, including conduction, radiation, convection, and evaporation that happen in it. In a similar manner, we propose to investigate modes of architectural representation that allow these invisible dynamics to become an integral part of generating spatial potentials.

Architectural Representation for Invisible Dynamics of the Material World

The drawings being developed in this research will eventually be organized into five chapters. The first four chapters will cover principles of the four invisible dynamics that impact the experience of buildings: 1) conduction 2) radiation 3) convection 4) condensation/evaporation. Each chapter will be a visual explanation of one of these four phenomena. Visual explanations will be geared toward an audience of architectural students and practitioners without a deep knowledge of building science fundamentals. In addition to offering a visual explanation of each phenomenon, these chapters will develop a notational language that is capable of visually communicating design potentials and outcomes afforded by conduction, radiation, convection, and condensation/evaporation. The fifth chapter will be a series of case studies of buildings from different eras, which explore relationships between architecture and energy, and demonstrate how the building science fundamentals and visual language developed in the first four chapters can be used to represent buildings in terms of invisible dynamics. The goal is to evolve a representational language for architects that gives them the ability to design spaces around invisible dynamics of the material world, as much as they use representation to design the visual aspects of buildings. Three selected drawings will be discussed here to demonstrate how the research is moving toward this goal. The first drawing focuses on radiation as it pertains to atmospheric transparency (Figures 5-7), the second drawing focuses on condensation as it pertains to water collecting on a cold surface, (Figures 8-9), and the third drawing is a case study of conduction in a yakhchāl, a historical Persian building type for producing and storing ice (Figure 10).

The atmospheric transparency drawing describes interaction between electromagnetic radiation and the earth's atmosphere. This is a version of a drawing that, as noted previously, has been done several times in different ways to convey certain relationships between architecture and energy.[32] This drawing explains how the earth's atmosphere creates an environment suitable for life by filtering and capturing specific wavelengths of the electromagnetic spectrum. Our version of this drawing

32. See Daniel J. Ryan, "Introduction: redirecting the arrows of climatic design," in *Drawing Climate: Visualizing Invisible Elements of Architecture,* for a synopsis on how different version of this drawing bias different outlooks on the relation between architecture, energy, and the environment.

differs from previous versions primarily in that it represents radiation at the molecular scale in relation to the atmospheric scale. The left side of the drawing shows electromagnetic radiation at the atmospheric scale, indicated by vertical pink lines, coming toward the earth from the sun and from deep space (Figure 6). The drawing shows that the shortest wavelength, highest energy radiation is blocked by the earth's atmosphere, while longer wavelength, lower energy radiation is allowed through. Lower energy radiation filtering through the atmosphere warms the earth's surface. This range of electromagnetic radiation is called visible light, because our eyes have evolved to detect it. At roughly the midpoint of the drawing, electromagnetic radiation switches from shorter waves received by the earth to longer waves emitted by the earth. Some radiation emitted by the earth escapes into space, and some is trapped in the atmosphere, causing additional warming of the earth's surface.[33]

While these properties of the earth's atmosphere are relatively well known and described by previous versions of this drawing, what is less well known is how electromagnetic radiation and the molecules that make up the atmosphere interact to either absorb radiation or allow it to pass through (Figure 7). The atmosphere is made up of a series of layers with different molecular compositions at different elevations. In the stratosphere, 40-50km above the earth's surface, oxygen and nitrogen molecules absorb short wavelength ultraviolet radiation and transfer energy to heat immediately. As these molecules absorb radiation, their electrons move to higher energy levels. Kinetic energy increases, leading to increased collisions between molecules and thus increased heating. Nitrogen tends to absorb higher energy UV radiation, while oxygen absorbs a larger spectrum of wavelengths that are mainly lower energy UV. At lower a lower elevation in the ozone layer and troposphere, outgoing, long wavelength infrared radiation is absorbed by carbon dioxide, methane, and water molecules in a dipole moment. In a dipole moment, charges of the molecule are asymmetrical, which causes motion that interacts with electromagnetic radiation at a specific wavelength. These molecules do not directly transfer radiation to heat. Instead, CO_2 and H_2O molecules act as conduits to transfer energy from radiation to other molecules like nitrogen and oxygen.[34]

In these detail drawings at the molecular scale, air is not invisible, it is physical matter creating environmental effects outside the range of visual perception. These drawings bring the principles of how the atmosphere interacts with electromagnetic radiation to create a habitable environment at the earth's surface into a graphic language that is accessible to visual thinkers. They introduce notational techniques for visualizing air as a heterogeneous physical material with specific properties in which buildings, bodies, and everything else on the surface of the earth, are immersed in and interact with. We propose that architectural representation must begin to incorporate air as a substance that interacts with buildings and their

33. This is of course known as the greenhouse effect. As human activity adds more heat trapping gasses such as carbon dioxide and methane to the atmosphere, warming of the earth's atmosphere is increasing.

34. Refer to the following sources for information on the interaction between electromagnetic radiation and the molecular makeup of the earth's atmosphere: S. Pal Arya, Introduction to Micrometeorology, Academic Press, 2001, San Deigo, 28-44. https://scied.ucar.edu/learning-zone/how-climate-works/car bon-dioxide-absorbs-and-re-emits-infrared-radiation and https://www.ncbi.nlm.nih.gov/books/NBK304366/#:~:text=The%20wavelength%20of%20UV%20radiation,(100%E2%80%93280%20nm).

inhabitants, rather than treated as neutral void. Air has dynamic physical properties that are intimately tied to the qualitative performance of buildings, as well qualitative aspects of the environments in and around them.

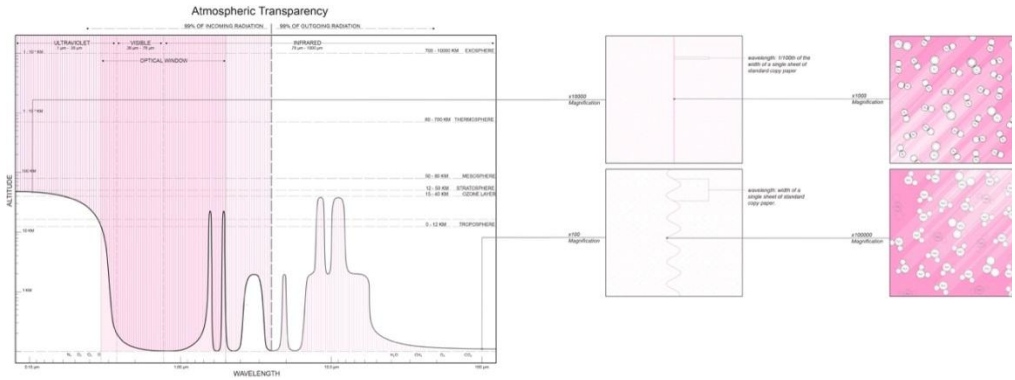

Figure 5. *Atmospheric Transparency – Wavelength Graph with Associated Wavelength Scale and Molecular Scale Detail Call Outs*
Source: The authors.

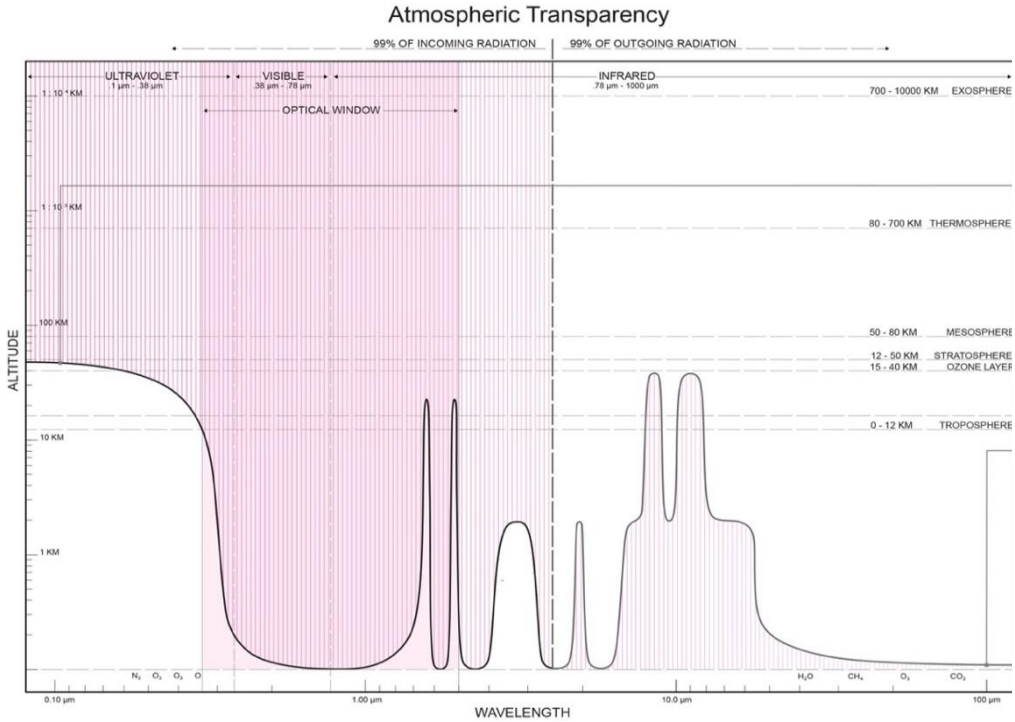

Figure 6. *Atmospheric Transparency – Wavelength Graph*
Source: The authors.

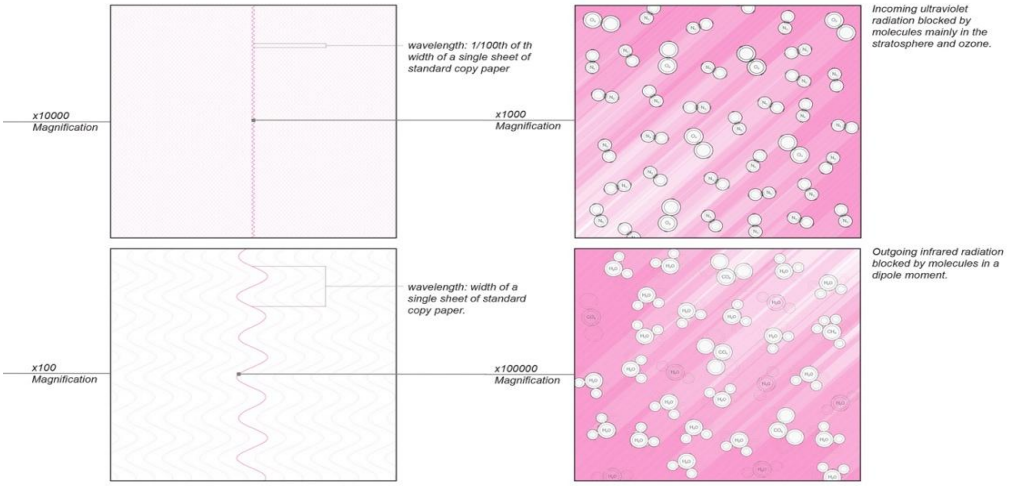

Figure 7. *Atmospheric Transparency – Wavelength Scale and Molecular Scale Detail Call Outs*
Source: The authors.

The condensation drawing (Figure 8) also visualizes air, and the water vapor it contains, at the molecular scale in order to explain an invisible dynamic in the physical world, in this case the phenomenon of water collecting on cold surfaces. The cold body at the center of the drawing, shown in blue, causes the temperature of the air around it to cool in relation to the warmer surrounding environment. This creates a temperature gradient, which is shown in the drawing shifting from pink (warmer) to blue (cooler). At warmer temperatures, air molecules, including nitrogen, oxygen, argon, and other trace gasses, vibrate with greater energy. The space of vibration is represented in the drawing by a greater number of lines surrounding each molecule, showing that a molecule occupies more space. As the cold body causes temperature to decrease nearer to it, air molecules vibrate with less intensity and move closer together. As a result, water molecules suspended within the air molecules also vibrate with less intensity and move closer together. When a certain threshold distance is crossed very close to the cold body, the water molecules slow down to a point where they become close enough together to change phase and form liquid water on the surface of the cold body (Figure 9).

The phenomenon of water condensing on a cold body in a warm environment is intuitively well-known because of experiences such as water collecting on the outside of a cold glass of ice water. What is not as well known by architects are the molecular properties of air and water vapor that cause condensation to happen. Like radiation interacting with the earth's atmosphere, condensation operates at a very small scale outside the range of visual perception. The aim of these drawings is to present a visual demonstration of invisible phenomena that effect the design of buildings. With a more complete understanding of the physics of condensation, architects might design exterior building envelopes that more effectively prevent water vapor from accumulating where it is undesirable, but more interestingly, they might find ways of intentionally introducing condensation to buildings as a design element that increases the tactile pleasure of architecture.

Figure 8. *Condensation around a Cold Body*
Source: The authors.

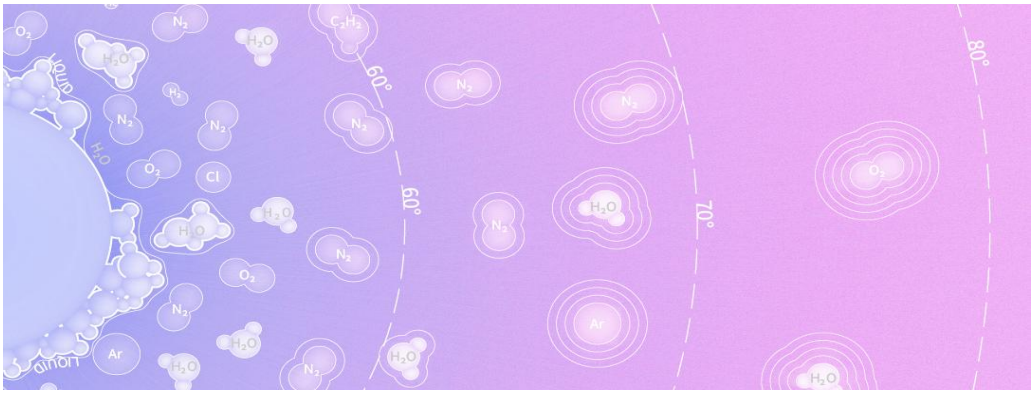

Figure 9. *Condensation around a Cold Body – Detail*
Source: The authors.

Drawing Methodology

The third drawing presented here moves from the general conditions seen in the first two, to interactions between invisible phenomena and architecture, in this case the interaction between conduction and a yakhchāl. The methodology used here is intended to be a step toward integrating tactile qualities of architecture into conventional representational systems that deal with buildings as exclusively visual constructs. The yakhchāl building type was chosen for this exercise because it is an example of a building form that is derived much more from how it interacts with the four invisible dynamics, than from notions of visual composition. These structures have been dated to as far back as 400 BCE. They were constructed in arid regions of present-day Iran from stone and earthen bricks sealed and reinforced with a water-resistant mortar made

of clay, lime, volcanic dust, sand and sometimes animal hair, egg whites, dates, or straw. The structures and the ice they contained were insulated with wood and thatch. A yakhchāl consists of three main components, a below-grade room with a tall conical roof for ice storage, a large, shallow pool of water for ice production, and a shade wall to protect the pool from solar radiation. A yakhchāl is often connected to an aqueduct system that feeds water directly into the ice production pool.

A yakhchāl interacts with all four invisible dynamics discussed here to produce and store ice year-round in a climate where the temperature is often and hot, and only rarely drops below freezing. In this case study, the aim is to draw the building as an organization of invisible dynamics rather than visible form. Presently, the building is described in terms of conduction. It is sectioned, exploded, and shown at a range of scales to show how the conductive properties of the building create temperature gradients that allow ice to be produced and stored. All components of the building are drawn with color gradients and isothermal lines showing how temperature gradients are distributed across all parts of the building. As this drawing, and other case study drawings like it, are developed further, information describing the other three invisible dynamics will be layered into it, creating a comprehensive picture of the building's performance as an ice-production machine. We believe this drawing methodology can then be used to augment conventional architectural representational systems to design contemporary buildings that more effectively deal with invisible dynamics to become not only more energy efficient, but also to become tactilely more pleasurable for their occupants.

Figure 10. *Yakhchāl of Kashmar Showing Icehouse and Shade Wall*
Source: Wikimedia Commons.
https://commons.wikimedia.org/wiki/File:Yakhch%C4%81l_of_Kashmar2021-04-05_17.jpg

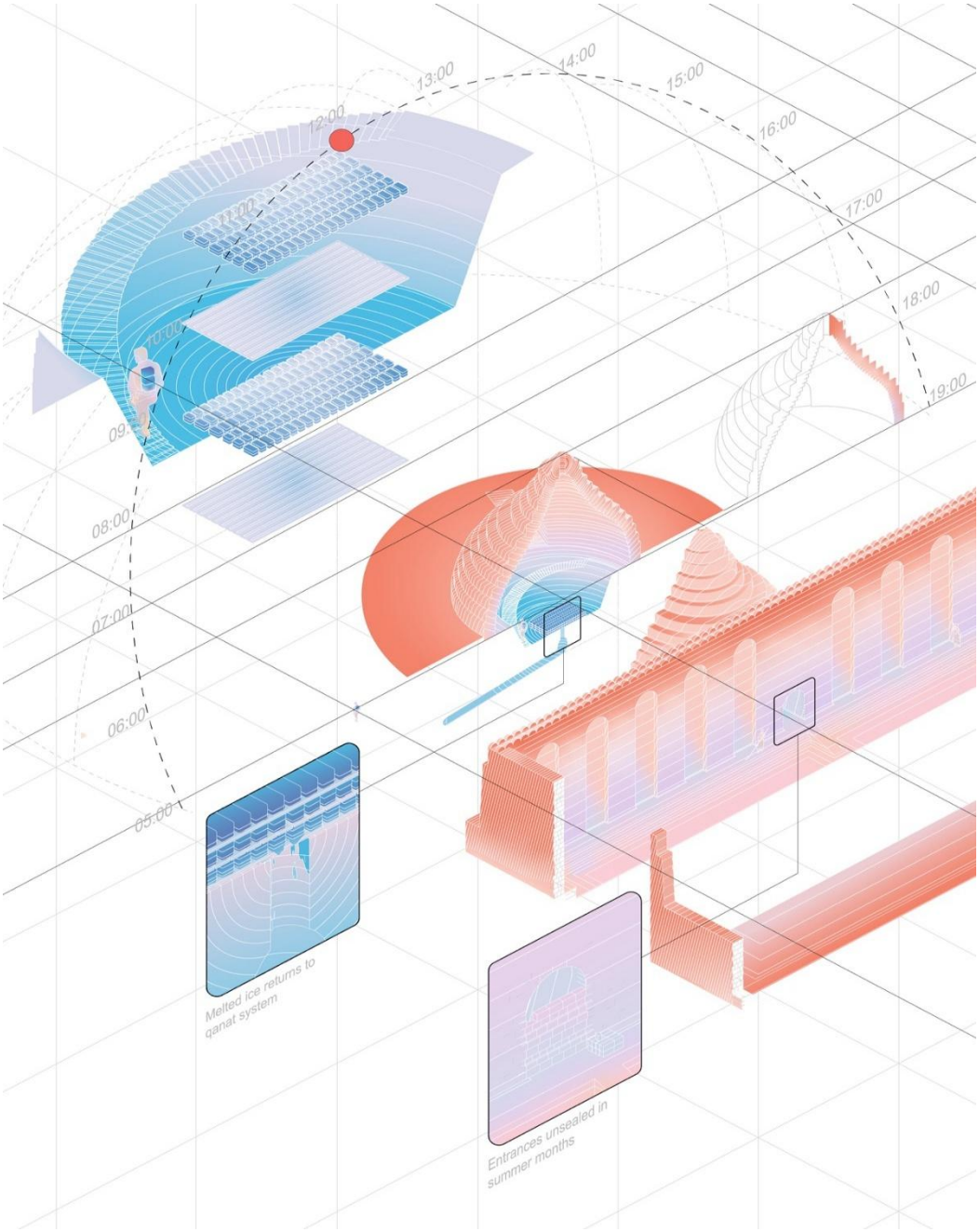

Figure 11. *Yakhchāl Case Study – Conduction*
Source: The authors.

Conclusion

There is a prevailing belief that architecture, and thus architectural representation, resides in a nebulous realm between artistic and technical thinking. There is a romanticism tied to the profession and practitioner in an imagined ability to alchemically combine aspects of artistic and technical practice into a coherent work that both solves a defined problem, and at the same time produces cultural meaning. This imagined mysteriousness is reinforced in a multitude of culturally constructed dichotomies that include the sciences and humanities, machines and organisms, mechanical and thermodynamic systems, the body and the intellect, problem-based reasoning and visual aesthetics, percept and concept, and vision and touch. Architectural representation is a powerful visual language precisely because, in the best cases, it is synthetic rather than dialectic. The best architectural drawings deal with the measurable, quantitative parts of the world, and the immeasurable, qualitative parts of the world by synthesizing them rather than separating them.

Architectural representation in contemporary discipline and practice is a visual medium that deals primarily with the visible world. The proposal at the heart of this research is that it could evolve and be augmented to deal with invisible dynamics in the physical world with a level of sophistication similar to that with which it deals with visible aspects of the physical world. That is to say architectural representation could evolve to deal with measurable, quantitative parts of the invisible world, as well as immeasurable, qualitative parts of the invisible world by synthesizing them rather than separating them. This involves developing representational techniques that are able to describe tactile environments. Tactile environments are by definition invisible. They are not sensed through the eyes, but through the skin. Tactile environments are not static, they are dynamic: molecules move and vibrate, energy flows. Tactile environments operate at very small and very large scales, from the molecular to the atmospheric.

Humans shape the world in relation to our senses. Architectural representation currently deals primarily with shaping the world in relation to vision, sensory inputs received by the eyes. It deals with how visible matter is organized into stable, visible structures. Our proposition is that the world could be shaped more in relation to touch, sensory inputs received by the skin. It is not necessary to conceptualize or interpret tactile aspects of architecture because they are of the material world. They simply happen to be invisible and are thus more challenging to bring into the domain of architectural representation than visual aspects of the world. The aim of the drawings presented here, and the larger body of research this essay initiates, is intended to give architects deeper knowledge of the invisible dynamics – conduction, convection, radiation, and condensation/evaporation – that fundamentally structure the physical world around us, and then suggest a series of representational techniques that can aid in designing the built environment in more effective dialogue with these invisible dynamics.

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