Mountains and Clouds: Landscape, Meteorology, and Building Form

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MOUNTAINS

Recently, the mountain has taken on a new currency in architecture, appearing in multiple projects as a new architectural "typology."[1] This study is invaluable, but we believe there is a potential to push it further to look at mountains themselves and how they perform in the environment, how they *operate* to respond to and transform environmental conditions, especially climate. Surprisingly, the mountain is not a new topic of interest for architects. For various architects, in the past, the mountain has been both an obsession and a model and as such is revealing of both an attitude to nature and the role of form in nature. Among the seeds of Modernism we can find some interesting—and revealing—obsessions with mountains.

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One architect who had such an obsession was Viollet-le-Duc, whose writings were to have a strong influence on the development of Modernism. Martin Bressani[2] has convincingly demonstrated that Viollet-le-Duc's method of drawing and representing architecture was closely related to his youthful interest in anatomy and anatomical drawing. His thousands of drawings of mountains are symptomatic of this obsession. But rather than picturesque representations of given scenes, Viollet-le-Duc's drawings attempt to reveal the physiognomy of the earth as the outer appearance of a body reveals the musculature and structure below the skin.[3] This way of seeing and representing mountains reflects an eighteenth-century understanding of nature as a species of phenomenon to be revealed through the uncovering of layers. The publication of Lyell's *Principles of Geology* in 1830 had for the first time convincingly revealed the true age of the earth (as opposed to the previously accepted biblical age) and the tectonic movements of the earth's crust along with its molten, restless core. In this case, intense study of the mountain could reveal the forces just below the surface.

As Bressani argues, Viollet-le-Duc applied a similar method to his analysis of historical architecture, understanding both Gothic architecture and mountains as surface revelations of concealed underlying forces—the original positing of the concept of structural expression or "honesty."

On the other hand, for Bruno Taut in *Alpine Architecture* (1919),[4] the crystalline forms of mountains serve as the model for a new glass architecture—a quasi-mystical vision of the darkness of the earth-bound world being transformed into sparkling forms reaching upward. In other words, unlike Viollet-le-Duc's interest in the relation between force and form, alpine architecture is more concerned with the visual effects of the crystalline form of the mountain. Eventually, however, this ecstatic vision of the mountain as a crystalline eruption of form was sidelined by the more "rational," classical, platonic glass forms of international modernism, and the mountain lost favor as a model for architectural form.

In recent years, as mentioned previously, the mountain has reemerged as a model for thinking about architectural form. In Allen and McQuade's book *Landform Building*, there is a distinct focus on the relationship between landforms—of which the mountain is one—and their programmatic potentials. Also described by Inaki Abalos[5] as a hybridization of two typologies, the tower and the park, this analysis focuses on the relation between form and program. On the other hand, another, quite different, interpretation of the mountain is provided by Reiser and Umemoto (RUR) in their book *Atlas of Novel Tectonics*,6 where they mention mountains several times in different contexts—but in all cases to demonstrate the reflection of tectonic forces in only apparently static form, an example of what they call, following Deleuze and Guattari, asignifying signs. This use of the mountain as model reveals a particular understanding of nature. But again, as in the work of Viollet-le-Duc, with an emphasis on the *structural,* the appearance of the mountain is an asignifying sign of those forces that have formed it.

What is omitted in all these conceptualizations are the *external* effects of the mountain—the reciprocal relationship between the mountain's form and the atmosphere around it: an atmosphere that is both forming (through erosion, denudation, etc.) and formed by (through orographic effects) the mountain it traverses. In this view, the mountain is seen as a result of both internal and external forces: internal geological forces that have pushed up sections of the earth's crust and external meteorological forces that have eroded and worn down the mountain but are also adjusted by it. Looking at mountain scenes, we see not just the tectonic forces pushing up but also atmospheric cycles wearing down. What we don't see, but what is equally important, are the effects of the mountain (invisible but nevertheless deeply affecting) that cause clouds to gather, sudden rains to fall, or gentle breezes to blow.

OROGRAPHY

At the global or continental level, the intensive differences in pressure that cause the weather are the result of differential heating of the earth's atmosphere and oceans by the sun, arising from several factors: the earth's tilt, its rotation (causing the Coriolis effect), existing cloud cover, and

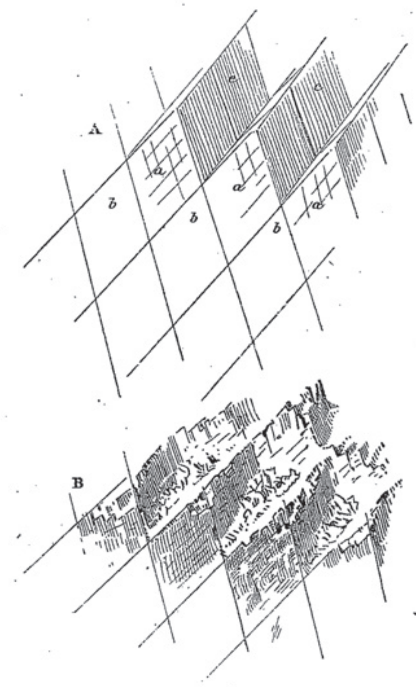

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Figure 1: "Decomposition of the rombohedrals" from *Le Massif du Mont Blanc* by Viollet-le-Duc.

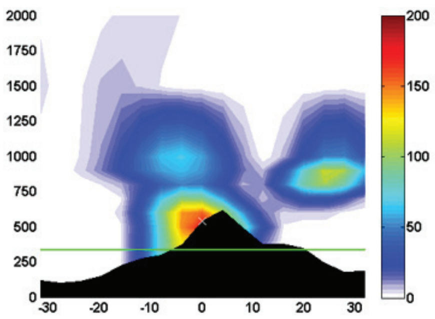

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Figure 2: Cross section through a simulated orographic cloud at Kleiner Feldberg, IMK-AAF, Karlsruhe.[8]

(increasingly) the presence of atmospheric gases. But at the more local level, the level at which we experience the weather, these global effects are tempered by the interaction of moving bodies of air and moisture with the geography of the landscape.[7] Mountains and valleys have a strong influence on the weather and can cause extreme local variations. In meteorology these phenomena are known as *orographic effects*.

Some of these effects are the phenomena of diurnal sea and land breezes (where the difference between air temperatures above sea and land causes wind to blow off the sea in daytime and off the land at night), katabatic wind (a wind that moves down a slope as a result of the cooling of air at higher altitudes), anabatic wind (winds that move or blow upward during the daytime as warm air rises up mountain slopes), orographic lift (where warm, moist air blown in off the sea is pushed up by mountains and cooled, producing rain), rain shadow (the sheltered weather on leeward sides of hills or mountains), etc.

These effects demonstrate how differences in the visible dimensions of the landscape (height, distance, slope, form) can influence the mostly unseen, though equally affecting, performances of the weather. It also demonstrates the interaction of an imminent energy system such as the weather with material actualizations in a specific location. This interaction can be active or reactive—forming the weather or being formed by it (through erosion, denudation, etc.)—but it is in all cases a relationship of *reciprocity*. In addition, it reinforces the perception that objects that we do see in nature are in fact the result of material interactions with forces we cannot see—movements of air and moisture and vice versa.

CLOUDS: AIR AND SPACE

Although architecture has traditionally been a field almost exclusively concerned with the shape and dimension of objects, new developments in sustainability and building performance requirements, etc., mean that architects must work more and more actively with the *unseen energy patterns* of the environment. At the most practical level, many building regulations today dictate the achievement of specific intensive values (temperature, humidity, air pressure) within buildings as much as, if not more than, they dictate extensive values such as dimensions, areas, etc.[9] This suggests a widespread shift, if not entirely from the visible and measurable to the energetic regime of measurement at least to a balanced understanding of both regimes and especially how they interact to influence each other.

What is commonly called "passive design" means using the design of the building, where possible, to adjust temperature, pressure, and/or humidity (intensities[10]) (i.e., relying as little as possible on mechanical or electrical devices to control these intensities). The term "passive design" includes many different architectural strategies, both new and age-old, but what unites all of these strategies is that they all use the form and spatial configuration of a building to minimize its energy usage, using the existing intensities in the external environment to heat or cool an internal space. There are many examples that we will not go into in detail here, but these include stack effect ventilation, sun-spaces, thermal storage walls, underground labyrinths, etc. To take one example, the "stack effect," which is probably the most commonly used passive cooling technique, uses the simple fact that warm air rises to induce movement of air within buildings. In its application, the internal spaces of a building are formed in such a way as to manage and take advantage of this effect. In other words, the stack effect uses the difference between air temperatures in different locations to create an internal "wind" that moves through the building, cooling occupants and extracting warm/stale air.[11]

To date, these kinds of passive design techniques have been used primarily in a technically driven way to reduce energy usage, but the potential is there for them to bring about a fundamentally new way of thinking about architectural space and form that reflects the profound change in attitude to space and the environment that is taking place today.

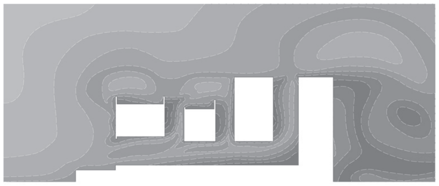
There is, in this case, a very real relationship between air and space. Air is a material that is manipulated by the configuration of its container, taking on the shape of its surroundings. But increasingly, this relationship is also working the other way: the shape of a space is being formed by the requirements of the air within it—not just static requirements at fixed points in space or time but dynamic properties that are changing over time and also driving that change themselves.

Space is not created just for programmatic or purely aesthetic reasons but rather molded by the requirements of the air it holds. Air presses against physical boundaries and inflects their forms. In addition, within itself, its qualities vary from place to place, producing virtual, unseen but sense-able, boundaries within apparently uniform spaces.[12] This can extend beyond temperature and pressure to also include air quality and noise, for instance, as well as more ephemeral qualities such as smell, extending our sensate perception of space beyond the merely optical to include all the senses and their effects. The shape of space begins to affect our experience not just through its visible morphology but also through its atmospheric effects.

INTERNAL WEATHER

To return to the case of the stack effect, internal convection currents cause air to move around the building, creating variable conditions throughout the space— from ideally optimized for human comfort, at points to be occupied, to nonoptimized, at areas that would not normally be occupied. For instance, the top of a stack could be warm (maybe unbearably hot) but would also not, conventionally, be occupied. These unoccupied hot or cold zones are, however, essential in driving the movement of air; in fact, they constitute artificial "desert zones" that, while uncomfortable to us, form an integral part of the internal climate of a building.

These changes can be seen as leading to a form of what we call "internal weather," environmental conditions within buildings that are not climatically fixed but instead vary over time. Instead of the artificiality of William Carrier's so-called man-made weather, we see a truly "human-made weather," a real control of the internal weather conditions of a building using the space and form of the building to manage them.



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METEROLOGICAL SPACE

Thinking in terms of internal weather makes the space of buildings as meteorological as the environment outside but with the difference that, internally, the weather is within the control of the architect. Space generates meteorological effects within a building that adjust levels of comfort but can also potentially go beyond this to create new atmospheric effects. When internal weather becomes part of the design of buildings, space becomes meteorological. It becomes what we call a "meteorological space."

The weather outside alters our moods and impacts our everyday lives, reorganizing social activities and transforming our experience of the world. In meteorological space, difference produces technical performances by managing environmental conditions, but it also produces affective performances. It creates internal performances, both technical and atmospheric, that may also affect us in profound ways. As in the weather outside, differences in intensity produce effects that affect human senses and alter our sensate perception of space and the environment.[13]

From this it can be seen that our use of the internal space of a building is changing, and, as a result, our understanding of what space is and, maybe even more importantly, what it can *do* is changing. If we see the internal environment of a building not as a fixed neutral space but as meteorological, then we need to think about how to manipulate and manage those spatial conditions. In this context the relationship between form and weather conditions in the natural environment, as demonstrated by mountains, is of particular interest.

OROGRAPHIC ARCHITECTURE

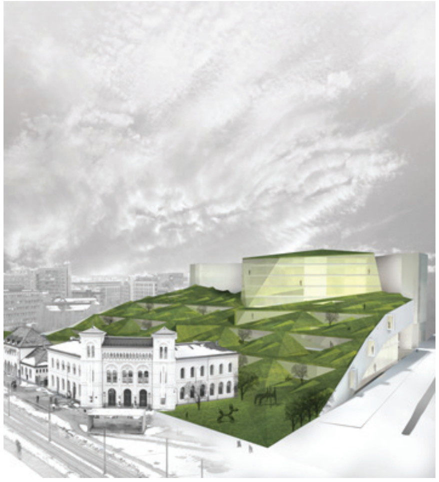
In an open landscape, the orographic form of the hills combines with water bodies and other landscape features to induce local microclimatic performances that are incidental in nature but that may point the way for a more deliberate relation between extensity and intensity[14] in building design.

In a way, mountains, in their impact on the weather, are like a massive geographic architecture: deflecting and diverting the wind, locally intensifying pressures, and causing temperatures to vary and humidity to condense in areas where normally they wouldn't. Today, as cities reach the scale of orographic entities, we are beginning to see the emergence of human-made orographies on the geographic scale. But we are also seeing an activation of the orographic at the scale of individual buildings.

Understanding built matter as a manipulator of "orographic" effects gives us clues how to manipulate form, not as an end in itself or as a symbolic system but as *a means to an end*—the control of internal environmental conditions. The adjustable extensities that are the material of architecture—walls, floors, roofs, openings, etc.—become the means to manipulate the ephemeral but increasingly important intensities of internal environments.

BETWEEN GROUND AND SKY

Given the possibility of an orographic architecture, how can one, as an architect, operate? Unlike geologists, who trace historic movements through excavating strata, architects can shape future performances through the use of the section. The sky is a dynamic, fast-changing fluid system with rapid oscillations between day and night, for instance, while the ground is a more stable, slow-changing mineral system with its own variable conditions such as ground temperature, saturation level, water table, etc. Increasingly, buildings are tapping into these two systems and offsetting the effects of one with the other. While this sometimes takes the form of active devices such as heat pumps, fans, or solar panels, increasingly, passive techniques with spatial implications such as earth sheltering, roof gardens, stack effects, wind- or solar-induced ventilation, thermal labyrinths, heat sinks, etc., are being used to create comfortable spaces between ground and sky using the latent differences of intensities within and between the two realms to affect building conditions. The section becomes the mediator between ground and sky, defining a vertical "boundary layer"[15] of occupiable space between the two—a thin crust of space between the depths of the ground and the airy heights of the sky that we as humans occupy.



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The Modernist "section," a vertical slice of undifferentiated space, is replaced by the heights and elevations of a built "orography," a strategic deployment of material in space to create and control internal weather. This instrumental orography arranges matter in order to guide localized weather conditions. As a result, the section becomes more like a landscape or geography itself, producing local variations in conditions that differentiate a meteorological space. The section is no longer tied to the ground or striated in levels above it but becomes a complex, dynamic orographic instrument.

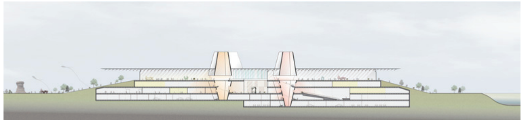
PROJECTS

The paper concludes with two design projects that explore the impact of this way of thinking and working on actual programs and sites.

1. Art Mountain, Oslo, Norway

With a building complex of more than 50,000 m² is it possible to introduce into the city a geographic feature that produces new relations between ground and sky, inside and outside, conditioned and unconditioned spaces. Using an uplifted terrain to rearrange the intensive conditions above- and belowground, the project creates an artificial mountain that operates at multiple scales and across the regimes of microclimate, landscape, program, and city to propose a new orographic typology for the very large urban building. The new mountain creates external and internal microclimatic spaces that are then allied to various fixed and drifting programmatic needs. Externally, the slope of the new rooftop park would interact with the on- and offshore winds of the harbor to increase summer cooling and winter warming. Inflections of the landscape surface—a series of smaller hills and valleys—create more or less sheltered pockets within these general conditions.

Internally, conditions are roughly striated from surface level close to the landscape outside down to deepest, most thermally stable lower levels. Spaces are programmatically divided into highly conditioned, moderately conditioned, and unconditioned. They are then arranged according to the projected temperature gradient across the section of the mountain, with the most conditioned spaces (archives, etc.) deepest within the mountain,



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close to the intensive stability of the earth's strata, and with moderately conditioned spaces (gallery circulation, roof voids, etc.) immediately under the surface of the new landscape. Through this schema, the unheated but self-regulating space of a new urban street cuts diagonally across the site, linking two important areas through the "outdoor interior" of the building.

In the process, Art Mountain, by approaching the phenomenon of the very large building in an urban context from the starting point of geography rather than construction, enters a new spatial dialogue with the existing topography of the city—for instance, the harbor, the headland opposite—and reorients the city by bracketing a new "valley of culture" between this new mountain and the recently completed, equally large opera house on the other side of the city.

2. Taipei Art Plateau

On the east coast of Taiwan, there is a small island known locally as Turtle Island because of its distinctive shape. The island is also distinguished by the typical but pronounced orographic effects of its form and situation. Located on the edge of a warm, humid ocean (the eastern Pacific) close to the Tropic (24.5°N), the island is almost constantly covered by small clouds at the peak of its central mountain. This orographic effect creates a zone of uninterrupted shading in this location, which, as a result, has a unique, intensely localized cooler microclimate that produces local variations in air temperature and dynamics.

This project asks whether we can use this island as the starting point for the building design, not just metaphorically but also operatively in the conditions and effects it produces. Can the extremely specific performance of the island be replicated using less extreme forms, in a less fortuitous location, by using deliberate design (rather than chance) to exaggerate its effects?

The design consists of a new landscape of hills, valleys, and ravines that accommodate the thermally stable and low-lit elements of the program belowground, pushing up to create an artificial plateau on which a series of pavilions, open to the landscape and weather, are located. Above these pavilions an artificial cloud of variable openness creates a drifting shadowscape over the course of a day or year. Together, the artificial earth-sheltered plateau and the light-permeable cloud above create a field of variable and adjustable weather conditions on the exhibition level. A curatorial plan is developed that synchronizes the use of these spaces with the resulting variable climate of the interior.

Further breaking down the division between building and landscape, public and museum, a series of detached pavilions drifts away from the main museum and provides exhibition spaces throughout the surrounding park that can be more or less climatically optimized, more or less open to the public. In this way, rather than laying out a rigidly defined series of rooms through which a predetermined route is to be followed, the project creates a field of weather conditions that vary across a range of climatic optimizations to accommodate different art forms, different atmospheric effects,

ENDNOTES

1. Stan Allen and Marc McQuade, eds., *Landform Building* [Baden: Lars Müller Publishers, 2011]
2. Martin Bressani, "Viollet-le-Duc's Optic" in *Architecture and the Sciences: Exchanging Metaphors*, Antoine Picon and Alessandra Ponte, eds. [New York: Princeton Architectural Press, 2003]
3. Viollet-le-Duc, *Le Massif du Mont Blanc, étude sur sa constitution géodésique et géologique sur ses transformations et sur l'état ancien et moderne de ses glaciers* [Paris: J. Baudry, 1876]
4. Reissued as Bruno Taut, *Alpine Architecture- Eine Utopie A Utopia*, Matthias Schirren, trans. [Munich: Prestel Verlag, 2004]
5. Allen and McQuade, *Landform Building*, p. 3
6. Jesse Reiser and Nanako Umemoto, *Atlas of Tectonic Form* [New York: Princeton Architectural Press, 2006], pp. 117, 121, 164, 224
7. Roger Graham Barry, *Mountain Weather and Climate* [London: Routledge, 1992], p. 67 ff.

and different degrees of relation to the surrounding landscape.

In each of these projects as well as the section, simulation is used as a technique to understand the relationship between form and environmental conditions, allowing us, as architects, for the first time to be able to see the energies and intensities within the environments we are designing and their interaction with the matter that defines them.

METEOROLOGICAL SPACE, OROGRAPHIC FORM

In this paper, we have talked about the attitude to space implied by a meteorological understanding of architecture. This way of thinking could have an impact on both the plan and sectional aspects of architecture, both of which can be reassessed not as the neutral demarcators of homogenous space they were previously conceived to be but as tools to manage and respond to energetic differences. The section becomes an instrument, the primary tool for managing deliberately differentiated conditions. The plan, on the other hand, becomes the tool to apportion such a differentiated space to various zones of use or activity. The plan becomes subject to the intensities the section can create. Working together, plan and section allow an "orographic" management of meteorological effects with buildings, and simulation tools allow us to visualize this more precisely.

The result of working in this way is that section and plan combine to generate an instrument to manage invisible intensities and flows. A reciprocity emerges between visible form and the unseen climatic conditions that impact it and that it actively produces. Along with a technical performance that ameliorates the energetic performance of the building, the affective performance produces new collective and individual experiences of space that resonate with more general reconceptualizations of the relation of energy to matter, human to ecology, artificial to natural, or built space to the weather.

Meteorological space is a space that is no longer conceived as homogenous but rather is pregnant with active differences. Design of space becomes about neither extracting homogeneity from a differentiated environment nor creating symbolic heterogeneity of "meanings" but is instead focused on managing difference and using it to produce change. The concept of a meteorological space can link users back to a milieu that is never in reality homogenous and can create an intimacy with the weather as a concept that restores the connection to a rhythmic, durational space that is not tied to the land or artificially homogenized but is constantly and actively different.

This goes beyond the previous roles of form as symbolic or signifying to become a new concept of performative form or, what we have called here, orographic form. Meteorological space is managed in its effects by an orographic landscape—a formation of building material that is not symbolic of some meaning outside itself but is instead fully performative, producing, managing, and using energy differences within a space in order to make it more habitable but also to create unique temporal atmospheric effects that create potentially new relationships between the users of a building and the changing ecology in which it is immersed. ◆

8. Marco Paukert and Marlon Maranan, "Simulation of orographic clouds" [IMK-AAF Karlsruhe], accessed 11/27/2012

9. For example, in the United Kingdom where U-values, air changes, etc., are tightly regulated but building area and room size are not, especially in the case of housing. See, for example, *Building Regulations for England and Wales, Approved Document: Part L* [London: HM Government, 2010]. Regulations are becoming more and more stringent and detailed in their requirements, a trend that can be seen in most jurisdictions in the developed world.

10. In this paper we use the terms "intensive" and "intensities" as shorthand terms that incorporate temperature, pressure, and humidity. But there is also an important use of the opposition between "intensity" and "extensity." Technically or scientifically, intensities are those values mentioned above that can be measured and vary but *do not* depend on the amount of matter present. In addition, variations in the intensities we are referring to here are not visible except via their secondary effects (e.g., clouds). Extensities, on the other hand, can also be measured, but their values *do* depend on the amount of matter present. They include length, breadth, height, volume, etc. In addition, variations in the extensities we are talking about here—the dimensions and forms of architecture—are visible.

11. There are many books available on this topic today, such as Klaus Daniels, *The Technology of Ecological Building*, Elizabeth Schweiger, trans. [Basel-Boston-Berlin: Birkhäuser Verlag, 1997]; this work gives a good description of how the relationship between temperature difference and pressure works in this technique.

12. Here we see an example of what Deleuze and Guattari call a "rhizomatic" relationship between two separate regimes. The example they provide is that between a wasp and an orchid. Gilles Deleuze and Felix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia,* Brian Massumi, trans. [London: University of Minnesota Press, 1987], p. 11

13. As we know from poetry, fiction, and film, there is a close relation between weather and mood or feelings. When space becomes meteorological, this relation changes from one of poetic evocation to real production.

14. Our understanding of the relation of extensities to intensities is indebted to the theoretical work of Manuel DeLanda. See, for example, Manuel DeLanda, *Intensive Science and Virtual Philosophy* [London: Continuum Books, 2002], but we take a different interpretation to the emergent, where form (extensities) emerges automatically from the action of intensities on matter. We see a much more active role for architects in shaping extensities but with an understanding of their role in manipulating intensities. In fact, this paper is based on the realization that architecture is already dealing with the relation between extensity and intensities (in passive design) but does not necessarily need to emerge from these in some way that is analogous to (or more usually illustrative of) natural systems. However, we do find this a useful terminology not just as a shorthand to refer to a range of environmental values but as a way to understand the relations between visible and invisible, material and performance, topography and microclimate.

15. "Boundary layer" is a term from meteorology that denotes the layer of the earth's atmosphere within 300-1000 m of the ground where turbulent and unpredictable weather conditions are more common than in the (relatively) more stable upper layers of the atmosphere.