

# **Energy and Matter:**

The design of a nature centre, tunnel, and neutrino observatory

by

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## **Author's Declaration**

I hereby declare that I am the sole author of this thesis.  
This is a true copy of the thesis, including any required  
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## Abstract

Neutrino physics proposes radical new conceptions of matter. Contemplating the extraordinary and mysterious nature of neutrinos in architectural terms, *Energy and Matter* considers the ideas and implications of this exciting field in three inter-linked design proposals—a nature centre, access tunnel, and neutrino observatory—that connect multiple disciplines in the natural sciences, engineering, and architectural theory. Located in the mountains above Modane, France, the nature centre is conceived as the outward expression of the neutrino observatory that is buried deep within the western Alps. Working from a position that acknowledges the significance of technical concerns, this thesis proposes an architecture that readily engages with technology, construction, and building systems, as well as the specialized instruments used to detect neutrinos, while exploring and evoking the equivalence and fluidity of energy and matter, form and forces. This hybrid approach expands the narrow functionalism that characterizes the design of modern observatories, and reasserts architecture's role in the design of buildings for science, allowing these enormous collective projects to communicate their cultural significance as manifestations of our current understanding of the universe.



## Acknowledgements

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Thank you to the scientific organizations who furthered my research by making publicly available so many valuable proposals for built and future neutrino observatories at real sites around the world.

This thesis would not have been possible without the unwavering and true companionship of Deborah Wang, my better half.



## **Dedication**

To Deborah.



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## Introduction

*“In just a few seconds, the Sun has emitted more neutrinos than there are grains of sand in the deserts and beaches of the world, greater even than the number of atoms in all the humans that have ever lived. They are harmless: life has evolved within this storm of neutrinos.”<sup>1</sup>*

*Energy and Matter* contemplates the extraordinary and mysterious nature of neutrinos in architectural terms. The ideas and implications of radical new conceptions of matter proposed by neutrino physics are considered in three inter-linked design proposals that connect multiple disciplines in the natural sciences, engineering and architectural theory. The designs of a nature centre, access tunnel, and neutrino observatory explore the equivalence and fluidity of energy and matter, form and forces. Working from a position that acknowledges the significance of technical concerns, this thesis proposes an architecture that readily engages with technology, construction and building systems, as well as the specialized instruments used to detect neutrinos. This approach is balanced with an equally deep attention to the expressive potential of architectural form. This hybrid strategy reasserts architecture’s role in the design of buildings for science, allowing these enormous collective projects to communicate their cultural significance as manifestations of our understanding of the universe.

Neutrinos open up a field of vision beyond light, beyond electromagnetism, a way to see through the blinding surface of the sun. Although invisible, they may also offer a way to see beyond the edge of the visible universe; that is, beyond the edge of historic time. They may begin to answer some of most fundamental questions about the development of the universe.<sup>2</sup> They are also profoundly puzzling, unlike any other matter we know. As the three types of neutrinos move through space, they oscillate between types, their mass, energy, and identity changing fluidly.

The study of neutrinos is immensely challenging. As their name suggests, neutrinos are tiny neutral particles,<sup>3</sup> which have no electric charge,

1 Frank Close, *Neutrino* (Oxford: Oxford University Press, 2010), 1-2.

2 Neutrinos may play a role in understanding matter-antimatter asymmetry. Ibid, 16.

3 Wolfgang Pauli posited a hypothetical neutral particle called the ‘neutron’ as a solution to the problem of radioactive beta decay in 1930. Enrico Fermi developed the idea further, renaming the particle to ‘neutrino’ to avoid confusion with the more massive neutrons that form atomic nuclei.

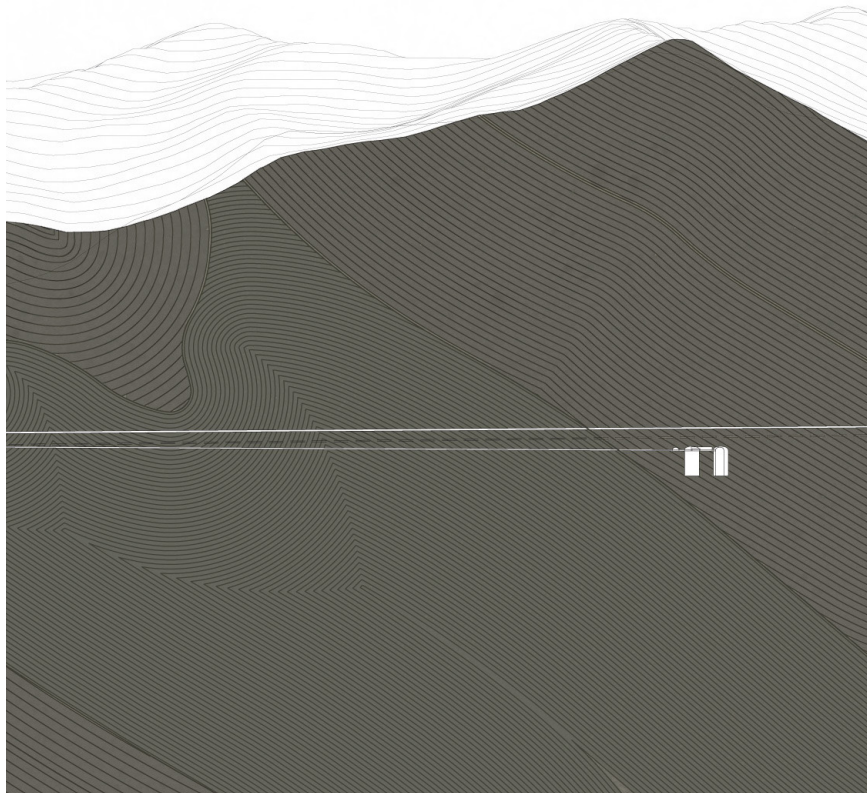


Figure 0.1:  
The neutrino detector caverns are buried in the heart of the Alps, under nearly two kilometers of rock. (Detail of drawing 1.1)



Figure 0.2:  
Canada Post issued stamps commemorating the Canada France Observatory on Mauna Kea, Hawaii and the Dominion Observatory in British Columbia. Only the telescope domes are shown. The observatory has come to mean the instrument.

and almost no mass. “Under typical conditions, a neutrino is 100 billion billion times less likely than light to interact with matter and a neutrino will pass straight through our planet Earth as effortlessly as the breeze through an open window.”<sup>4</sup> Extreme conditions are needed to observe these ghostly particles. Neutrino laboratories are located deep underground, in active and abandoned mines, at the bottom of oceans, even burrowed into the Antarctic ice cap (fig 0.1).<sup>5</sup> These remote locations provide shielding that filters out other energetic particles so that only neutrinos can reach large sensitive detectors.<sup>6</sup>

The remoteness, scale, and particular demands of neutrino laboratories set them apart from other science buildings. These same qualities link them typologically with astronomical observatories. In addition to their common physical and formal characteristics, many neutrino detectors are effectively telescopes that look out at the sun, stars, and galaxies,<sup>7</sup> extending the range of astronomical observation. By looking at neutrino laboratories, and particularly neutrino observatories, in the context and history of astronomical observatories, we can understand the development of the conditions that influence their design.

Within the framework of observatory history, a number of trends become clear. We can see the gradual separation of public and instrument spaces, shifts in the role of the observer, and the transitions of observatories from culturally significant works of architecture to technically driven instrument enclosures.<sup>8</sup> Early observatories communicated their importance and cultural significance architecturally, expressing the idea of an ordered and harmonious cosmos in their built form, and by situating the astronomer within an architectural microcosm. As observatories and instruments evolved, so did the conceptual approach to their design. The astronomer, now thought of as

4 “HALO Explained,” *Helium and Lead Observatory*, accessed December 3, 2013, <http://www.snolab.ca/halo/HALOexplained.html>.

5 An experiment in the Homestake Gold Mine, led by Ray Davis, Jr. discovered the first solar neutrinos. The Sudbury Neutrino Observatory (SNOLAB), and the Kamioka Observatory are both located in active mines. The ANTARES neutrino telescope is located 2.5km under water in one of the deepest parts of the Mediterranean Sea. The sensors that make up IceCube are cored 1.5km into the Antarctic polar ice cap.

6 Given the unlikelihood of neutrino interactions, very large detectors are needed. Massive quantities of target material simply increase the chance of spotting the signal of a neutrino collision.

7 Neutrino detectors can have different experimental purposes, and in some cases multiple uses. They can be used to study neutrinos produced in the sun, in the collapse of super-novae, and even from the radioactive core of the earth. In addition to its role as a massive neutrino telescope, the KamiokaNDE and its successor Super-KamiokaNDE were also used to study neutrino oscillation using beams of high-energy neutrinos.

8 The evolution of observatory design is discussed in detail in part one.



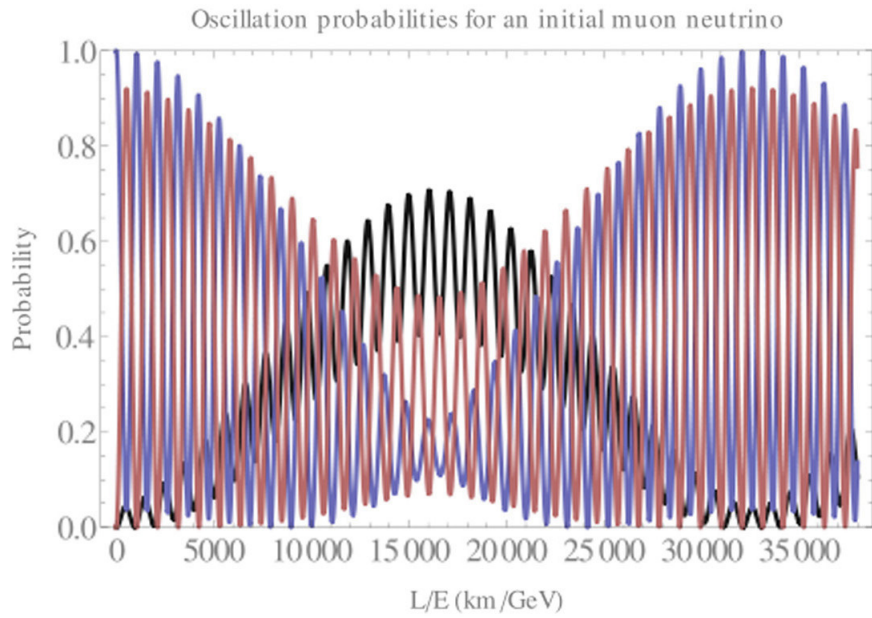


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A graph showing the long range oscillation probability of muon neutrinos. The waveform colours represent the neutrino types: blue represents muon neutrinos, the red tau neutrinos, and black electron neutrinos.

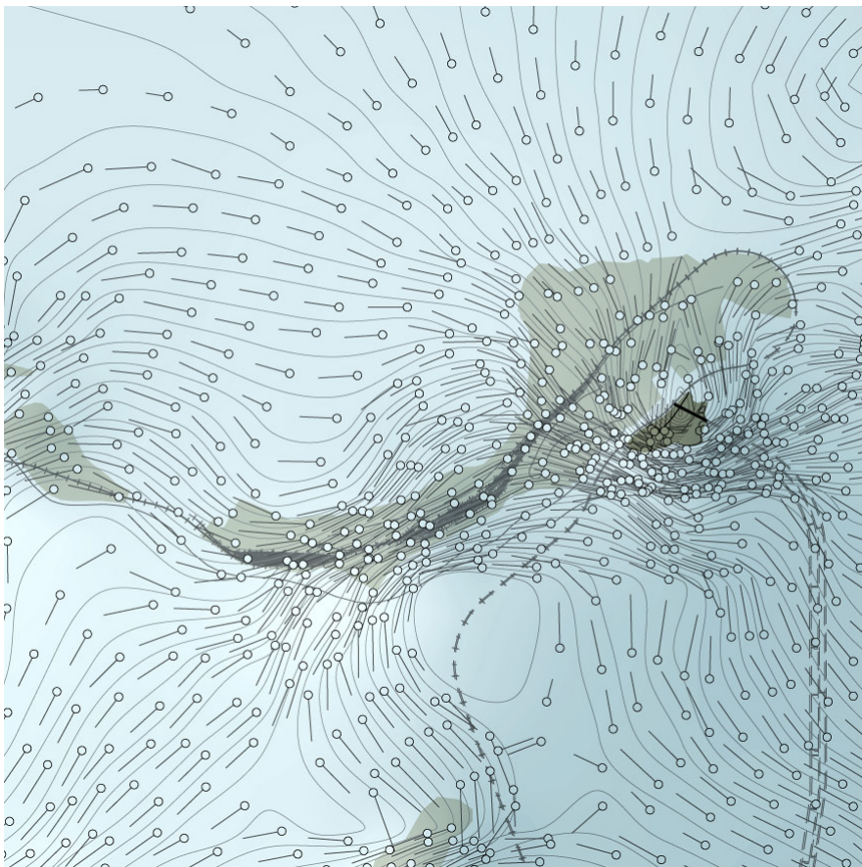


Figure 0.4: The transfer of thermal energy from the heart of the mountain to its surface generates air currents that interact with natural weather patterns resulting in eddies and pressure systems. (Detail of drawing 0.6)

a distanced objective observer, occupies instrument spaces that are dominated entirely by technical and utilitarian concerns. The public programme,<sup>9</sup> now physically separated from instrument spaces, plays a much reduced role or has disappeared entirely. Indeed, the commonly held understanding of a modern observatory represents only the instrument programme (fig. 0.2). Despite the great collective effort to build and maintain contemporary observatories, and the profound discoveries made at them, what results are buildings whose architecture is reduced to its “productivity and use value,”<sup>10</sup> driven by a narrow interpretation of functionalism that denies them the opportunity to express their cultural and architectural significance.

This thesis argues for the renewed importance of architecture in observatory design, and asks what that architecture could be. The question of how to design a neutrino observatory, is a specific example of a much larger question. Architect and critic Detlef Mertins frames this broader question well, asking how cultural production should respond to the conditions of modernity and modernization<sup>11</sup> – to what is distinct about a specific time, and to transformations in material culture and technology.<sup>12</sup> This approach implies that neutrino physics, and the understanding of the universe it confers, must inform the conception of this architecture. Likewise, it contends that technology (and its development) must play a significant role. But what does neutrino physics suggest about geometry and built form? How can architecture engage with construction technology, and the specific technology of neutrino detection, in a meaningful way that enables these buildings to fulfill their cultural role?

The particular form of a neutrino is an effect of interaction of energy, a product of interference patterns between the quantum fields. Unlike most other subatomic particles, the quantum fields of all three neutrino types interact with each other, creating a phenomena called neutrino oscillation whereby neutrinos fluidly change mass, energy, and even type (fig 0.3). Architect and theorist Luis Fernández-Galliano describes a similar dynamic relationship of energy and matter in architecture. He asserts that form and

9 I use the term public space to refer to all non-instrument spaces. Therefore, I include administrative and support spaces like offices, libraries, and workshops as well as public space.

10 George Baird, *The Space of Appearance* (Cambridge, MA: MIT Press, 1995), 133.

11 Detlef Mertins, *Modernity Unbound: Other Histories of Architectural Modernity* (London: Architectural Association, 2011), 9.

12 Ibid, 5. Mertins draws on literary critic Marshall Berman’s definitions of modernity, modernization, and modernism.

energy are intrinsically linked: “Matter needs energy to maintain its form, and form can be thought of a wealth of stored energy.”<sup>13</sup> His ideas connect an understanding of energy in architecture to the processes of building construction, and to the energy flows needed to maintain built form. The phenomena of neutrino oscillation also implies a consideration of mutual influence and interaction between buildings, and between buildings and their surrounding environment. Architecture should be understood through its relationship to, and impact on, forces present in its physical, cultural ecological environment (fig. 0.4). These forces and energy pathways play important roles in the design of this thesis, and allows the technology of neutrino detection and building systems to be readily engaged. Likewise, by extending the linkage of energy and matter between buildings and environments, this thesis conceives of the observatory buildings in a thermodynamic relationship.

The movement of a neutrino can be thought of as both a pure unaffected vector and as a dynamic vibration. The neutrino quantum field, the medium through which countless overlapping wave patterns interfere, can be imagined as a heterogeneous, differentiated, and grainy field. This concurrent and plural geometry offers an alternative to the static Cartesian grid. Instead it supports a combination of linearity, dynamic mutation, and disturbance. These geometries are deployed on multiple scales, and their expression in the architectural form, structural systems, and material patterning of this project is discussed in more detail in the following essays.

The fluidity of energy and matter, and the heterogeneity of form and geometry that characterize neutrinos and their behavior, project a view of reality that is indeterminate and dissolved. The fundamental difficulty in accessing the pervasive neutrino matrix adds to this. Architect and theorist Ignasi de Solà-Morales argues that it is “through the aesthetic that we realize the model of our richest, most vivid, most ‘authentic’ experiences in relation to a reality whose outlines are vague and blurred.”<sup>14</sup> In his essay, *Weak Architecture*, de Solà-Morales responds to both to the crisis of the modern project and the heterogeneous contemporary condition. In extending his ideas to the experience of modern science and neutrino physics, we can allow aesthetic experience to “exercise its seductive influence, its power to unveil,

13 Luis Fernández-Galliano, *Fire and Memory: On Architecture and Energy* (Cambridge, MA: The MIT Press, 2000), 63.

14 Ignasi de Solà-Morales, *Differences: Topographies of Contemporary Architecture*, edited by Sara Whiting, translated by Graham Thompson (Cambridge, MA: MIT Press, 1997), 60.



its capacity to imply rather than constitute the intense apprehension of reality.”<sup>15</sup> It is through architectural experience that we can convey the energy, fluidity, and plurality, as well as the uneasy intangible character of neutrinos. Architecture operates as the outward expression of the ideas being explored within, communicating a new understanding of the universe through its form, atmosphere, and relationships.

The abovementioned themes and ideas are explored through three interconnected projects sited in the Alps, on the border between France and Italy: 1) a nature centre, 2) a tunnel, and 3) a neutrino observatory.

Part one considers the project within the history of astronomical and neutrino observatories. The essay traces the separation of experimental, administrative, and public observatory spaces in both physical and architectural terms. The nature centre is positioned as a development and response to these precedents. The design proposes a radically expanded instrumentality that reacts to multiple conditions – functional, cultural, technical, and thermal – and that considers the relationship of energy and matter. The conception of the nature centre and observatory are directly linked. The nature centre is shaped by the situation, character, and construction process of the observatory, and is its outward face. Operating as a thermodynamic system, the nature centre both harnesses and dissipates the geothermal heat built up in the observatory, providing cooling for the underground lab space using its evaporative skin. The relationship is entirely symbiotic – each building is sustained by the energy that flows through it, embodying Fernández-Galliano’s assertion that “architecture can be understood as a material organization that regulates and brings order to energy flows; and simultaneously and inseparably, as an energetic organization that stabilizes and maintains material form.”<sup>16</sup> The enormous mound of spoil created during the excavation of the observatory is the foundation of the nature centre. Cables and struts, distributed in the loose rock, support the cantilevered building as it explodes out over the valley below. This hovering structural response to the buried observatory complex, can also be understood to evoke the vast amount of energy embodied in the spoil mound (fig.0.5).<sup>17</sup>

Part two develops the design of the tunnel that links the nature centre to the observatory. The tunnel is the umbilical cord of the observatory,

15 Ibid., 61.

16 Fernández-Galliano, 5.

17 Fernández-Galliano, 63.

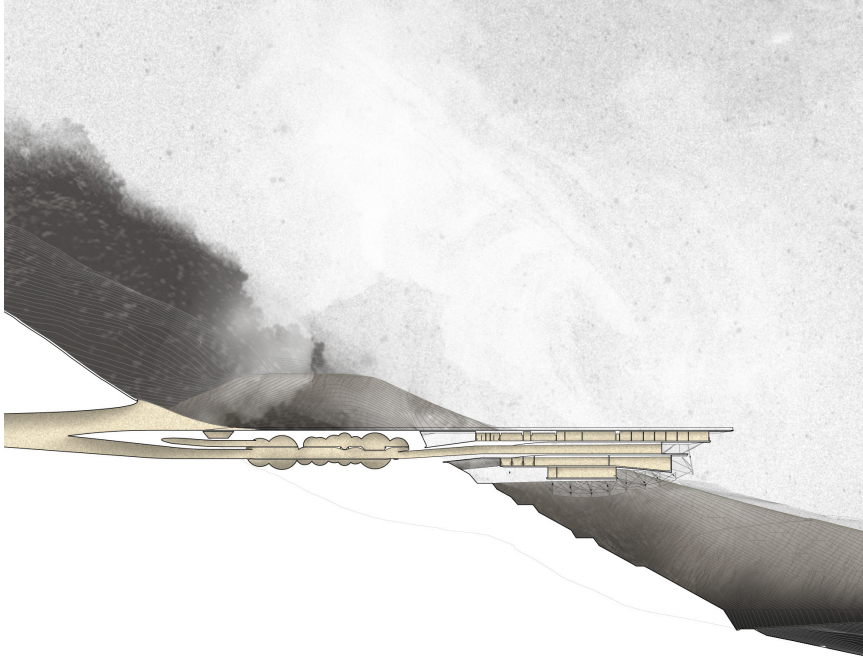


Figure 0.5: The nature centre acts as a geothermal energy dissipator, cooling the neutrino detectors deep within the mountain. It also makes manifest the vast amount of embodied construction energy stored in the mound of excavation spoil. (Detail of drawing 2.1 Site Section)



Figure 0.6: Light, colour and material operate in combination, dissolving distinctions between matter and light, giving light substance - a perceptible fog - that evokes the pervasive neutrino matrix. (Detail of drawing 18.3 View looking up from the base of the detector)

providing access to it, and supplying it with air, water, power, and cooling. In the tunnel, energy flows and material form are one and the same. All of the distinct systems are collected in the mouth of the tunnel, becoming totally embedded in the two basic elements that make up the tunnel: the lining and platform. The design focuses on the particular form of these elements and their connections, and the transition between complete integration and dissolution of the systems.

Part three proposes the design of a large underground neutrino observatory. The observatory is comprised of an entrance hall, support spaces, experiment halls, and three enormous neutrino detectors. The design proposal focuses on the entrance hall – the narthex – and the large neutrino detectors. Both spaces develop in relation to thermodynamic processes that effect their form and configuration, as well as their public and technical programme. The neutrino detectors fuse form, experiment operation, and heat dissipation currents with the movement of visitors around the detector. As visitors circle spiral down the detector, the magnitude of the detector and the physical expression of the pressures acting on it, as well as the palpable flow of energy, stimulate analogies and approximations of the invisible field of mutable neutrinos all around us. The particular design and detailing of the narthex and detector spaces push the exploration of matter and energy further, by creating an environment that blurs the perception of light, form, and scale (fig 0.6). By expressing the fundamental forms and systems with radical precision, the observatory spaces reveal subtle phenomena that imply the qualities of the neutrino matrix.



## Fréjus Nature Centre

Bounded by the main railway connecting Turin and Grenoble, and the motorway leading to the Fréjus Road Tunnel, the Fréjus Nature Centre perches on the slopes of the Cottian Alps above Modane, France. This nature centre exists within a number of frameworks, each with their own cultural references and building typologies. The project refers to the heritage of mountain lodges and refuge stations that grew out of enlightenment alpinism, the hot springs and thermal baths that dot the Alps, the design of long-span bridges, as well as the visitor interpretation centres found in national parks and conservation areas. In addition to its connection to these more conventional models, the nature centre forms the entrance to a large underground neutrino observatory. The relationship of the nature centre to the observatory plays a decisive role the design of the centre, influencing its location, form, and design approach. A survey of the history of observatory design illustrates a number of important underlying conditions of this project, and sets it in a specific light. This nature centre is, on one hand, an example of the support building typology that separated from observing spaces during the evolution of observatories. On the other hand, it is a projection and synthesis of the divergent design tendencies reflected in historical approaches to instrument and support buildings.

The history of astronomical observatories reaches back to the Neolithic Era, and includes proto-observatories like Stonehenge and the Mayan temple El Caracol; naked eye observatories such as Uraniborg, Stjerneborg (fig. 1.1), and Jantar Mantar (fig. 1.2 & 1.3); and a series of telescope-based observatories beginning in the 17th century and continuing up to the present day. Over the past century, the range of observational astronomy has expanded beyond visible light to include a wide spectrum of electromagnetic phenomena from infrared to microwave. More recently, the discovery of neutrinos has provided an entirely new and expanded field of astronomical observation.

In proto-observatories and naked eye observatories, architectural space is directly used to perform the observation of the cosmos. In many ways the buildings are the instruments.<sup>1</sup> These observatories generally situate

1 Maharaja Jai Singh II's Jantar Mantar observatories in Jaipur and Delhi, India are series of buildings that act as instruments for measuring the sun and stars.





Figure 1.1:  
 Tycho Brahe's 16th century  
 naked-eye observatory  
 Uraniborg



Figure 1.2:  
 Maharaja Jai Singh II's 18th  
 century Jantar Mantar, Jaipur,  
 India



Figure 1.3:  
 Maharaja Jai Singh II's 18th  
 century Jantar Mantar, Jaipur,  
 India

the observer within a model of the cosmos, both literally and metaphorically. This spatial relationship illustrates a world view, and approach to observation. At Uraniborg and Stjerneborg, Brahe's observatories are clearly conceived as idealized micro-cosmos<sup>2</sup>, illustrating underlying ideas of heavenly geometry and connection between the macrocosm and microcosm. Similarly, the room or building sized instruments at Uraniborg (fig. 1.4) or Jantar Mantar firmly place the observer within the cosmos, and subject to its forces, emphasizing the scale of man in relation to the much larger universe.

The advent of telescopes marked a shift in the design of observatories, and the beginning of a trajectory from the early observatory as a complete work of architecture, to the eventual physical, conceptual, and aesthetic separation of instrument and ancillary spaces. With the introduction of specialized technical instruments to aid observation, the stars could be studied from within the generic architectural space of the laboratory. Perhaps more significantly, the astronomer no longer occupied the cosmos (or micro-cosmos), but was outside, observing from a distance. With the need for greater precision, instruments grew in size, influencing the orientation, structure and spatial qualities of specialized buildings that house observing, studying, and living spaces. These trends can be readily seen in parallel with the development of astronomy and telescope technology, but also perhaps as a response to larger cultural changes, such as the specialization and segregation of scientific disciplines, and their overall separation from public life.

Early observatories counted among the significant buildings of their time, owing to the cultural, military, and mercantile importance of astronomy in the late renaissance and baroque. As such, observatory buildings were designed to communicate their value physically and aesthetically, and were designed by notable architects, and included the same formal, stylistic, and ornamental qualities as other noteworthy buildings of their time. Early observatories were conceived as a single coherent work of architecture. While they contained purpose-built spaces for astronomical instruments, they also contained libraries, kitchens, offices, laboratories, and lodging for astronomers, students, and visiting scholars,<sup>3</sup> accommodating all aspects of the astronomer's life and work. From this status as coherent

2 The plans of Uraniborg and Stjerneborg build on fourfold geometry, recalling cardinal directions, the classical elements, or possibly a derivative of a quincunx (as in the Westminster Abbey Cosmati Pavement).

3 "Uraniborg - Observatory, Laboratory and Castle," TychoBrahe.com, A Universal Website, accessed July 15, 2014, <http://www.tychobrahe.com/UK/uraniborg.html>.



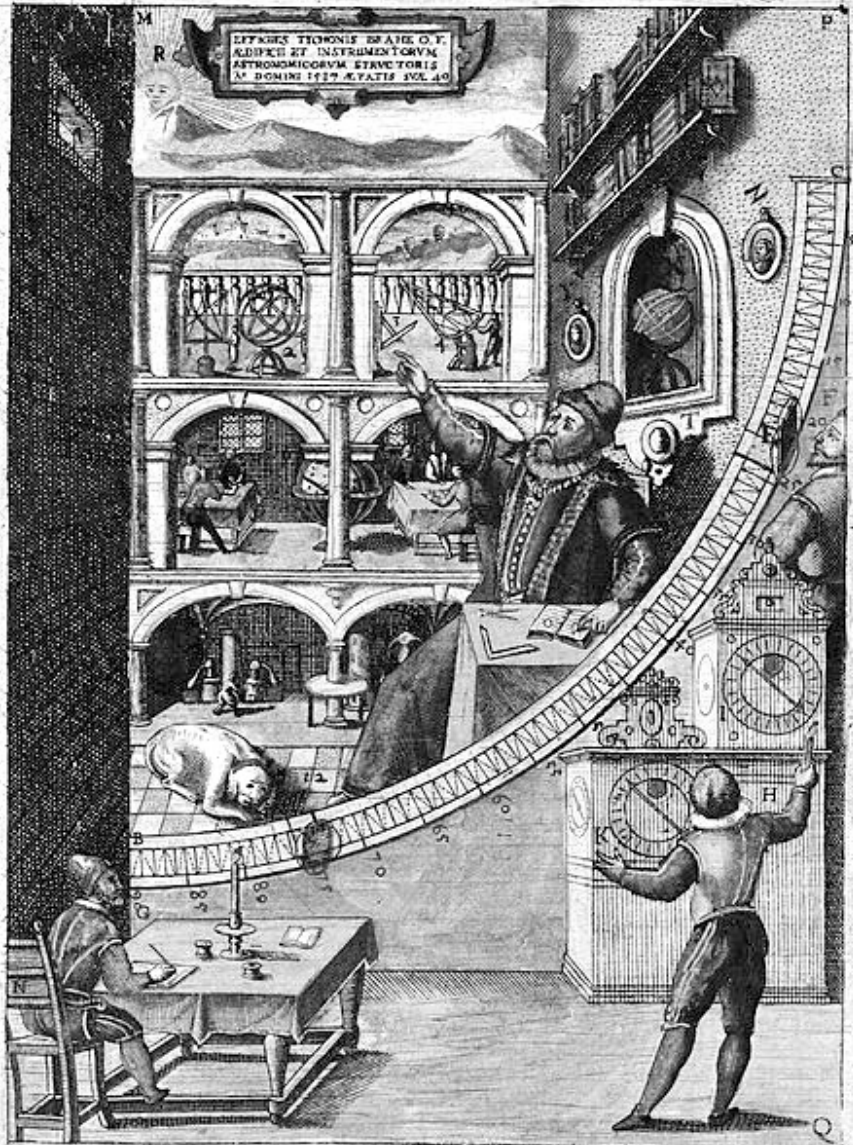


Figure 1.4:  
The large mural quadrant and  
small wall slit used to record  
star positions at Uraniborg

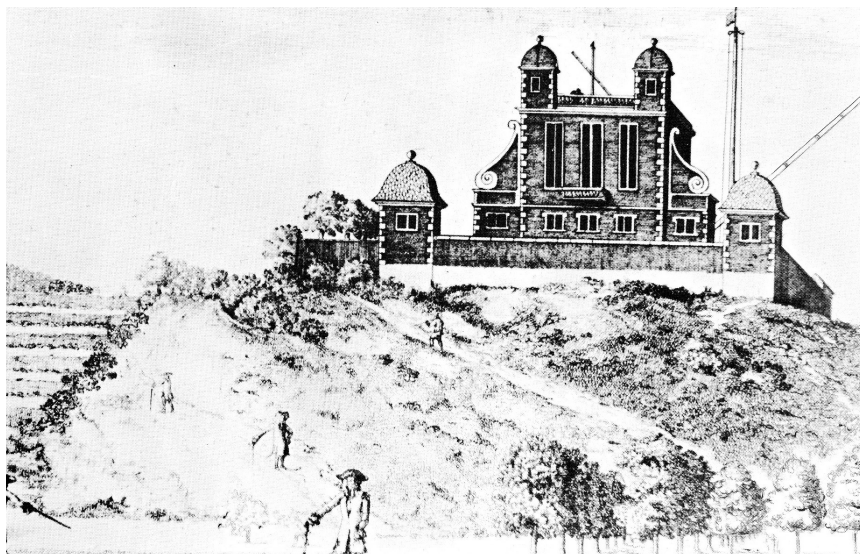


Figure 1.5:  
North elevation of the Royal  
Greenwich Observatory



and comprehensive multi-use buildings, splits emerged whereby instruments were removed into separated individual buildings. At first, these specialized buildings were located on a campus in close proximity to the other observatory building. Later, the instrument buildings were located remotely. At the same time, the instrument buildings became increasingly specialized, responding to the technical requirements of the telescopes they housed, in many cases becoming dominated by utilitarian concerns and reduced to basic engineered sheds. Case studies of the Royal Greenwich Observatory, Pulkovo, Strassborg and Nice Observatories, Lick Observatory, David Dunlap Observatory, and the Sudbury Neutrino Observatory explore this typological and architectural transition in greater detail, while Erich Mendelsohn's Einstein Tower offers a counterpoint.

Architect and mathematician Christopher Wren was commissioned to design the Royal Greenwich Observatory at the request of King Charles II. Wren responded with a scheme for a modest, yet well-proportioned brick building that presides over the river Thames from on top of Greenwich hill. The symmetrical central volume is abutted with two short stair towers and large scroll buttresses, and set along a wall flanked by two small summer houses. "The north façade thus presented to the riverfront a rich and ordered composition, enlivened by the varying position of the telescopes when set up for use"<sup>4</sup> (fig. 1.5). Indeed, Wren included dummy windows to maintain the harmony and order of the north façade, and indeed of the whole composition. Wren conceived of the observatory with the observer at its centre, placed in the middle of a great octagonal room, around which the architecture expanded in a rhythm of symmetrical layers. The observatory's basement contained a kitchen, unheated parlour, and store rooms.<sup>5</sup> On the ground floor there are four rooms that contained a bedroom and study for the first Astronomer Royal, John Flamsteed, and rooms for his assistant (fig. 1.6). On the second storey, there is one large octagonal room that housed instruments including a large mural arc sextant, quadrants, and small telescopes. Two tall pendulum clocks are built into the walls. The observatory was expanded incrementally to the south with small and large additions for both instruments and living

4 Marian Card Donnelly, *A Short History of Observatories* (Eugene, Oregon: University of Oregon Books, 1973), 21-22.

5 Graham Dolan, "Flamsteed House and the Early Observatory," *The Royal Observatory Greenwich*, accessed July 1, 2014, <http://www.royalobservatorygreenwich.org/articles.php?article=916>.

*The* ROYAL OBSERVATORY, GREENWICH.

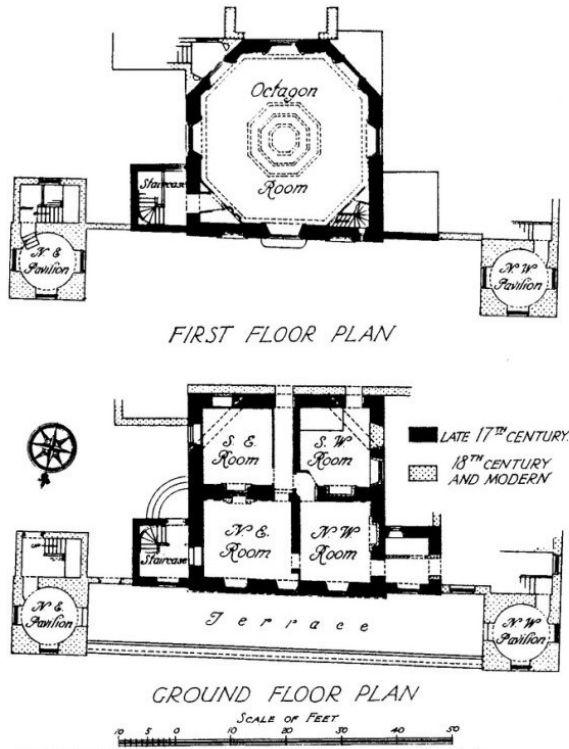
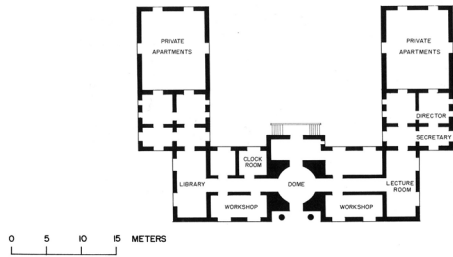
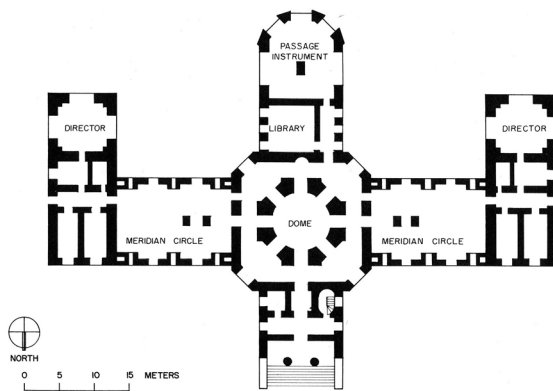


Figure 1.6:  
Floor plans of the Royal  
Greenwich Observatory



*Göttingen, University Observatory, plan.*



*Pulkowa, Central Observatory, plan.*

Figure 1.7:  
Comparison of the floor plans  
of the Göttingen (above) and  
Pulkovo (below) observatories.

accommodations, all without ever challenging the architectural prominence of the north façade.

Built between 1835 and 1839, the Pulkovo<sup>6</sup> observatory was the first large institutional observatory,<sup>7</sup> and like the University Observatory at Göttingen before it consists of U-shaped plan with a central observatory block topped by a large central dome, with two side domes located at the junction of the two wings. However at Pulkovo, architect Alexander Brüllof designed a much larger central block, while the wings remained roughly the same size and still contained offices and living quarters (fig. 1.7). The building is entered through a temple-like portico, possibly inspired by the pantheon,<sup>8</sup> but was otherwise relatively spare. The large central block was fully occupied by observing rooms, signifying a shift in the proportional allocation of space towards larger instrument spaces.

The Strasbourg Observatory marks the beginning of the trend to physically separate instrument and habitable spaces. Here, the great dome and its large refraction telescope, a second observation space with two small domes and a meridian room, and the living quarters were separated into three distinct buildings. Built between 1875 and 1880, the buildings were arranged on the university campus and connected by covered walkways to protect scholars and astronomers from bad weather (fig. 1.8).<sup>9</sup> The architect Hermann Eggert designed the three buildings individually (fig. 1.9), rather than as a complete whole,<sup>10</sup> focusing the attention and architectural expression on the great dome, and giving it a temple-like appearance.

This approach to design and construct separate buildings for observing instruments and support spaces was extended with the Bischoffsheim Observatory at Nice, France. Built between 1881 and 1887, it was the first European observatory built at altitude, and the buildings were located to suit the topography of Mont Gros (fig. 1.10).<sup>11</sup> Architect Charles Garnier (already famous for the Opéra de Paris) designed a number of individual buildings containing both instruments, public and support program including a

6 Donnelly spells this Pulkowa, however I have opted to follow the transliteration favoured by the Russian Academy of Science: Pulkovo.

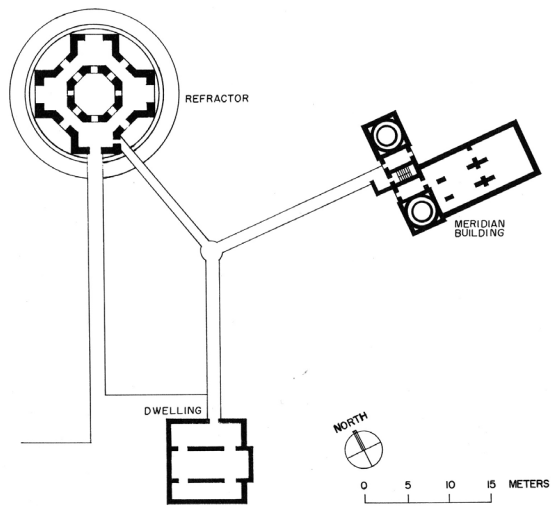
7 Ibid, 72.

8 Ibid. Donnelly notes that Brüllof had recently returned from Rome.

9 André Heck, *A Multinational History of the Strasbourg Observatory* (Dordrecht: Springer, 2005).

10 Donnelly, 111.

11 Françoise Le Guet Tully, "La Patrimoine de l'OCA: Disposition des bâtiments sur le site," *Observatoire de la Côte d'Azur*, accessed June 17, 2014, <http://patrimoine.oca.eu/spip.php?article50>. The observatory was built at 375m above sea level



52. Strasburg, University Observatory, 1877, plan.

Figure 1.8:  
The floor plan of the  
Strasbourg observatory.

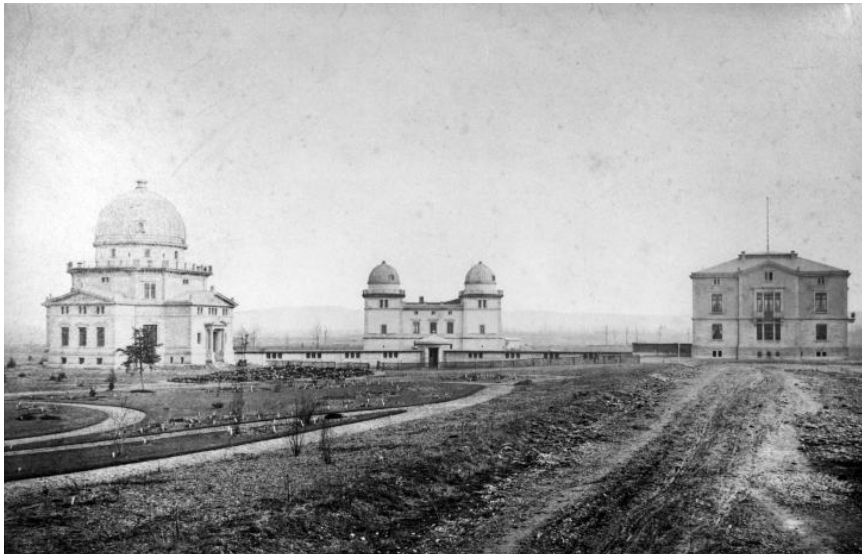


Figure 1.9:  
Photo of the Strasbourg  
Observatory. The great dome  
is on the left, and the residence  
is on the right.



Figure 1.10:  
The Nice Observatory  
distributed on the slopes of  
Mont Gros.

laboratory, residence, library, and large telescope. Garnier's building for the large refraction telescope was a fairly elaborate Egyptian-inspired neo-classical design, which was topped with a large unornamented ribbed metal dome that he designed in collaboration with Gustave Eiffel (fig. 1.11).<sup>12</sup> Following the construction of the Nice Observatory, the desire to move observatories to higher altitudes would become prevalent, as would the tendency to have separate buildings for instruments and support program.

The Lick Observatory on Mount Hamilton, built 1885-1888 at an altitude of 1283m, and the Mount Wilson Observatory, built 1904-1908 at an altitude of 1738m, are both important examples of this trend of separation. At Mount Wilson, the separation between buildings, specifically between the instrument buildings and the support buildings was stretched much further – the offices were located over 40km away in Pasadena, California.<sup>13</sup> Furthermore, these observatories mark a significant change in the architect's role from planner to advisor,<sup>14</sup> where engineering concerns outweighed architectural design, and the expressed desire of the observatory director was that “the first object should be to prepare everything with reference to its use, and then to give the building such an architectural effect as seems best without interfering with its utility.”<sup>15</sup>

The David Dunlap Observatory in Richmond Hill, in addition to illustrating the inclination to physically separate instrument and support spaces, also clearly shows the different aesthetic approaches that came to characterize the design of the two types of space. The Toronto firm of Mathers and Haldenby was hired in 1932 to design the administration building, producing a beaux arts classical limestone building complete with stone quoins, bas relief panels and detailing (fig. 1.12).<sup>16</sup> Though such a grand and embellished building was understood by the architects and client to befit an observatory administration building, the great telescope dome was in stark contrast. It was an unornamented construction of steel

12 Ibid.

13 “The Carnegie Observatories: History” Accessed July 18, 2014. <http://obs.carnegiescience.edu/about/history>. The Mount Wilson Observatory was funded by the Carnegie Institution. In 1969m, the Carnegie Observatories went on to establish the Las Campanas Observatory in La Serena, Chile, more than 8300 km from the main offices, library, archives and machine shops in California.

14 Donnelly, 119.

15 Edward S. Holden, “Notes on the Early History of Lick Observatory,” *Publications of the Astronomical Society of the Pacific* 4, no. 24 (June 11, 1982): 139, quoted in Donnelly, 117.

16 “David Dunlap Observatory and Park,” Heritage Canada the National Trust, accessed July 16, 2014, <http://www.heritagecanada.org/en/issues-campaigns/top-ten-endangered/explore-past-listings/ontario/david-dunlap-observatory-and-park>





Figure 1.11:  
Photo of the telescope  
building at the Nice  
Observatory showing Garnier  
and Eiffel's floating dome  
under construction. Also note  
the winged Egyptian god  
above the entrance.

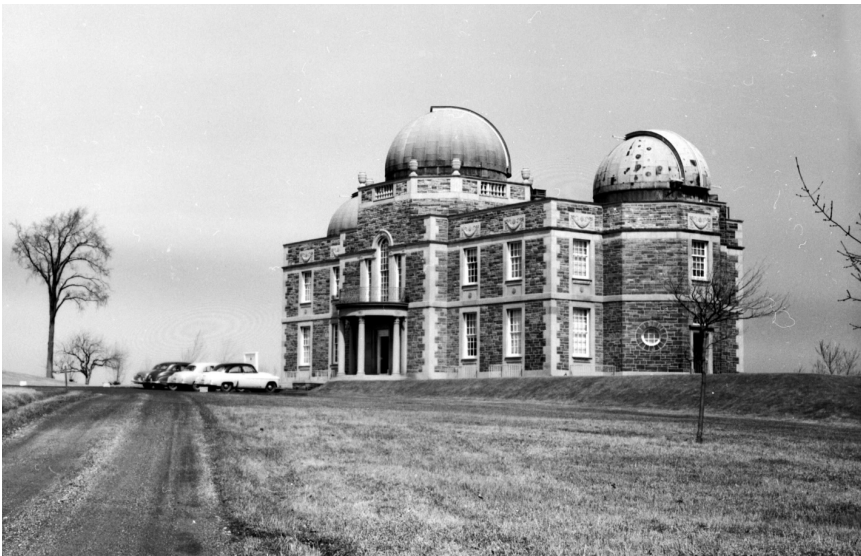


Figure 1.12:  
Mathers and Haldenby's  
administration building at the  
David Dunlap Observatory



Figure 1.13:  
The telescope dome at the  
David Dunlap Observatory

ribs and sheet metal that “gave the building a somewhat mechanistic appearance.”<sup>17</sup> Utility and economy determined its design, and likely sharing the sentiment of the director of the Mount Wilson Observatory, the telescope dome needed only to contain the telescope and cover it with a moveable dome of the required span (fig. 1.13). In fact, the dome’s designer is not even mentioned. A contemporaneous account of the building project by the Dunlap Observatory’s director describes the dome and administration building in detail, noting Mathers and Haldenby’s involvement only in the latter.<sup>18</sup> Though the dome at the David Dunlap Observatory was the focus and *raison d’être* of the observatory, and indeed at many observatories after it, it was fully removed from the realm of architecture, willfully ‘un-designed’, and conceived as an independent utilitarian enclosure.

As observatories grew to incorporate larger telescopes, and were built at higher altitudes, the separation of the instrument spaces from other spaces, and general attitudes about their design, became entrenched. The telescope domes became the visible focus and singular identity of the observatories, while the support buildings disappeared entirely or played a much reduced role. Already removed from the realm of architecture, the design of the telescope buildings continued to be dominated by utilitarian ideas and aesthetic. Architect and critic George Baird, in broader terms, describes this concept of pure instrumentality. Baird, referring to Hannah Arendt, describes instrumentality as a condition “where the ends not only justify the means ... but produce and organise them,”<sup>19</sup> where architecture is characterized above all by its productivity and use value. Indeed, a narrow interpretation of rigorous functionalism and economy were, and still are, primary concerns in observatory design, and with time began to dictate the form and design of the buildings. The Kitt Peak National Observatory, California (1962); Mauna Kea Observatory, Hawaii (1967); MMT Observatory, Mount Hopkins Arizona (1987); and Paranal Observatory, Chile (1998) (figs. 1.14-1.17), clearly illustrate this functionalist and instrumental approach.

In the midst of this general movement from the early observatory as a monumental and complete work of architecture, to the contemporary

17 Donnelly, 137.

18 Clarence A. Chant, “The David Dunlap Observatory,” *Journal of the Royal Astronomical Society of Canada* 26 (1932): 289. Chant describes both buildings in great detail, but only attributes the administration building to Mathers and Haldenby, omitting any design attribution for the dome.

19 George Baird, *The Space of Appearance* (Cambridge, MA: MIT Press, 1995), 133.





Figure 1.14:  
Kitt Peak Observatory,  
California.



Figure 1.15:  
Mauna Kea Observatory,  
Hawaii.



Figure 1.16:  
The MMT (multi mirror  
telescope) at Mt Hopkins  
Observatory, Arizona.



Figure 1.17:  
Paranal Observatory, Chile.



Figure 1.18:  
The McMath-Pierce solar telescope at Kitt Peak,  
designed by Skidmore Owings  
& Merrill.





Figure 1.19:  
Erich Mendelsohn's Einstein  
Tower, Potsdam, Germany.



Figure 1.20:  
Detail of the Einstein Tower's  
window openings and scupper.

observatory as a fragmented and instrumentalized cluster of telescope sheds, there are some notable exceptions. Indeed even within the examples I have listed so far there are outliers. For instance, the McMath-Pierce solar telescope at the Kitt Peak Observatory, designed by Skidmore Owings & Merrill (fig. 1.18), gracefully incorporates functional requirements, challenging mechanics and cooling into an elegant and monumental form that evokes two balancing obelisks or gnomons.

Erich Mendelsohn's Einstein Tower is another poignant exception. Designed between 1917 and 1920, and built between 1920 and 1922, the tower (fig. 1.19) is described by architectural historian Kathleen James as "a pivotal point between the prewar fascination many German architects had with monumental architecture and the postwar *neue Sachlichkeit*."<sup>20</sup> Designed to house instruments to test Einstein's theory of relativity by observing the sun's light spectra, the "Tower provides the first example of what became Mendelsohn's characteristic manipulation of dynamic form within functional bounds, as he attempted both to represent and serve Einstein's controversial new scientific theory."<sup>21</sup> Working closely with his friend, and client for the tower, astrophysicist Erwin Finlay Freundlich, Mendelsohn responded carefully to the technical requirements of the solar telescope and other programme spaces. At the same time, Mendelsohn was also profoundly influenced by Einstein's theory of relativity, and the equivalence of matter and energy dictated by the theory shaped his idea of the relationship between mass, motion, and light. He conceived of matter as fluid and animate, and of the tower as an organism – a hybrid form of technology and a living body.<sup>22</sup> The sculpted curves of the overall massing, window openings, and even roof scuppers, evoke the dynamism of a body moving through space (fig. 1.20), and articulate an understanding of the technology and character of its materials – the steel skeleton supporting a plastic reinforced concrete flesh.<sup>23</sup> At the same time, the Einstein Tower captures the cultural spirit of its time, evoking the movement of Kandinsky's expressionist painting, the fluidity of Art Nouveau, and dynamism of Boccioni's sculpture.<sup>24</sup> The Einstein Tower is

20 Kathleen James, "Expressionism, Relativity, and the Einstein Tower." *Journal of the Society of Architectural Historians* 23, no. 4 (Dec. 1994): 405.

21 Ibid, 392.

22 Ibid, 407.

23 James, 405. James notes that Mendelsohn's vision of plastic sculptural reinforced concrete may well have been naïve, and owing partly to the challenge of forming the curves, and to cost saving the tower is mostly constructed of brick and plaster stucco.

24 Ibid, 394-407.





Figure 1.21:  
A typical drift in the  
Creighton mine on the way to  
SNOLAB

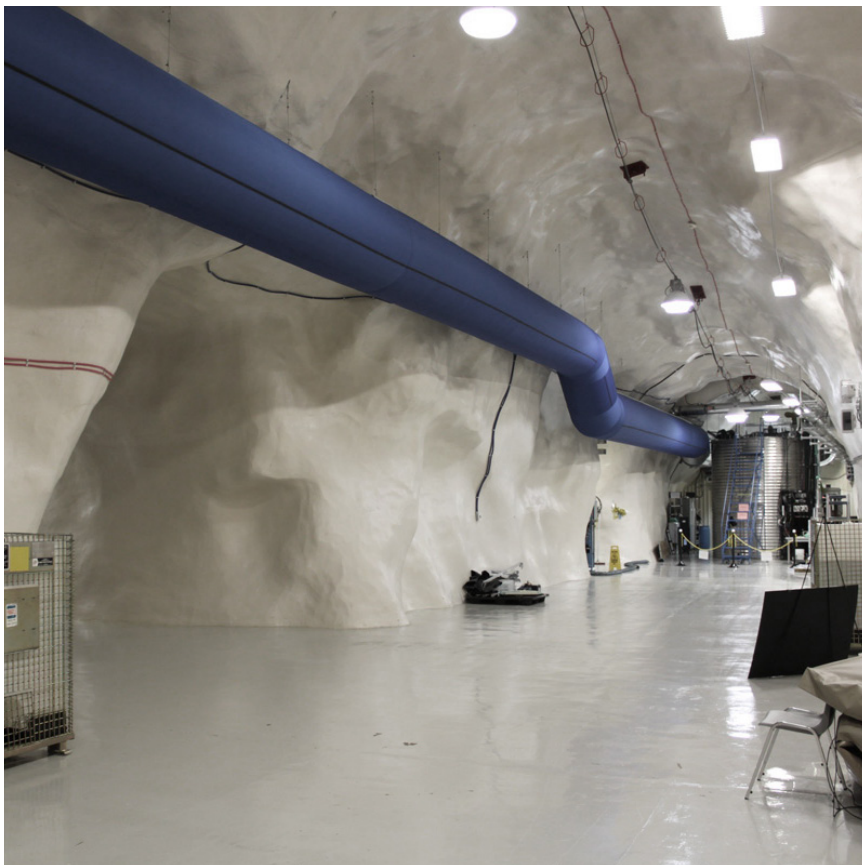


Figure 1.22  
A experiment hall in the  
SNOLAB ladder labs. The  
smooth painted walls and floor  
are indicative of the strenuous  
requirements of maintaining a  
class 2000 clean room facility  
deep inside an active mine.

often cited as an example of expressionist architecture, but as James suggests, a more nuanced understanding places the tower in between monumental and instrumental categories. Mendelsohn's Einstein Tower is best understood as a hybrid of evocative form and rational engagement in science and building technology in an attempt to genuinely express the theory of relativity in built form.

The Sudbury Neutrino Observatory (SNOLAB) (1990-99) was conceived within the instrumentalist conceptual paradigm, but augments this approach with a hybrid of rigorous utilitarian functionalism and parasitic opportunism. SNOLAB is grafted onto to the subterranean edge of an active nickel mine that operates on the rim of the Sudbury basin. Everything about its design and operation is contingent on its physical separation and location more than two kilometres underground. Each person and piece of equipment in the lab must first make the journey down the mine cage, then horizontally through 2km of rough mine drifts before arriving at the lab entrance. SNOLAB's presence in an active mine necessitates defensive protocols to deal with the background radiation present in mine dust and surrounding native ore. Multi-stage cleaning of incoming equipment, and the thorough showering and complete re-clothing of all incoming staff and visitors is needed to establish a class 2000 clean room facility in the midst of a hostile environment.

Power, water, air, and cooling are grafted onto existing mine infrastructure. Cooling is the most significant of these systems, pulling heat out of the laboratory spaces all day, every day of the year. The air handlers and chillers mechanically extend the thermal capacity of the fresh air provided by the mine air supply which the mine first pulls through the spoil dump in order to temper it. The lab spaces are packed with air handlers, equipment, piping and wires, connecting the various spaces and experiments and ultimately feeding back to the lab entrance. The conditioned finished space of the lab – its bright, cool, clean and large caverns – exists in stark contrast to the raw mine drifts just outside its door (figs. 1.21 & 1.22).

The observers – neutrino physicists – exist in multiple and varying relationships to the observatory spaces and instruments. The conceptual distancing implicit in objective observational modern science is underscored by the separation of the instruments from occupied space. The super-sensitive light receptors that track the presence, direction, and energy of neutrino

interactions are enclosed in a sealed light-proof cavern, and surrounded by a bath of shielding water. Once constructed, scientists and visitors can only walk above the SNO detector on an opaque deck, imaging the vast volume below. This distance allows the observers to work within the underground laboratory environment, remotely at the administration building within the mine complex of surface buildings, and also to participate on the distant campuses of the university research consortium members.

In contrast to the remoteness and distance of observation at SNOLAB, the experience getting to the lab is intense and present. Descending in the rattling mine cage, you can feel the increasing atmospheric pressure, your ears popping. The 25-30% surplus of atmospheric pressure brings with it a feeling of fatigue. The rock, held back with bolts and sheets of metal mesh radiates heat. The dim lights and rush of mine air blowing past call attention to the dependence on these systems for survival and the distance from the surface. This raw sensation balances the intangibility of neutrino observation, and recalibrates our relationship with both the earth and cosmos, situating us within the thickness of the earth in order to look out at the cosmos.

This proposal for the Fréjus Nature Centre is a nuanced response to the legacy of observatory design, and extension of the parasitic condition of SNOLAB. Rather than rejecting the narrowly functional and instrumental condition of observatory design, I propose an expanded approach to instrumentality, drawing in multiple and layered considerations of building technology, thermal movement and mechanical systems, structural forces, programme and function, vernacular building, construction processes, and environmental stewardship, into the design process. The nature centre explores the limits of this multifold instrumentality, and embodies them in a finely-tuned and integrated architecture.

In its relationship to the neutrino observatory, the nature centre and neutrino detector caverns are also analogous to the physically separated elements of an astronomical observatory. Where the neutrino observatory is a collection of spaces that house detectors and experiments, the nature centre contains a wide range of ancillary and supplementary programme that relates to its role as a support building, and its alpine context. However, my design for the nature centre rejects the aesthetic dichotomy between science spaces and public or support spaces, between instrumental and monumental architecture, and instead pursues a hybrid approach that, through multiplied

interwoven instrumentality, expresses its cultural significance in the close attention paid to its physical, cultural, and environmental context.

Conceived as the outward expression of the underground observatory buried deep beneath the France-Italy border, the nature centre sits at the mouth of the observatory access tunnel and cantilevers over the excavation spoil heap, looking over the city below. The nature centre acts as a beacon and entrance point for the hidden observatory, pointing to its presence and indicating the scale of the hollow underground spaces by the enormous quantity of stock-piled excavation spoil (fig 1.23). The excavation process, and the synthetic landscape that results, are central to the form and focus of the nature centre, which examines strategies for the ecological regeneration of the spoil heap. The form and structural system of the nature centre directly engage the spoil mound as an anchor and counterweight for the cable stays that support the cantilevered building. The nature centre is coupled thermodynamically to the observatory, and forms a part of a thermal loop. It removes the geothermal heat that accumulates within the mountain, using it to generate electricity and warm thermal baths that are buried within the spoil mound.

Reaching out in order to look back on the spoil, the nature centre manifests a speed and trajectory that suggest an energetic source deep within the rock. Like the Main Ring Lake at Fermilab outside of Batavia, Illinois, the form of the nature centre and the spoil mound itself trace, and refer to, subterranean space. However, unlike the Main Ring Lake, the references here are not direct transpositions of form, but isometric and scalar translations<sup>25</sup> that reveal only partial information. The spoil mound volume indicates the aggregated scale of the underground caverns that make up the neutrino observatory, but gives no indication of their configuration. But even with this intuitive and physical reference to the magnitude of hollow underground space, precise estimation is challenged, since the only the surface dimensions are knowable and the depth of the spoil mound is unclear. One is left with a tangible feeling of something that one cannot objectively know.

The excavation of the observatory chambers and access tunnel causes a radical re-organization of the geological strata, disrupting the churned forms of metamorphic rock, and replacing it with a new indistinct fluidity.

25 The dimensions of the spoil mound and the underground hollow volumes are isometric in the mathematical sense. The sets of dimensions are linked and have undergone transformations in terms of geometry and physical form.

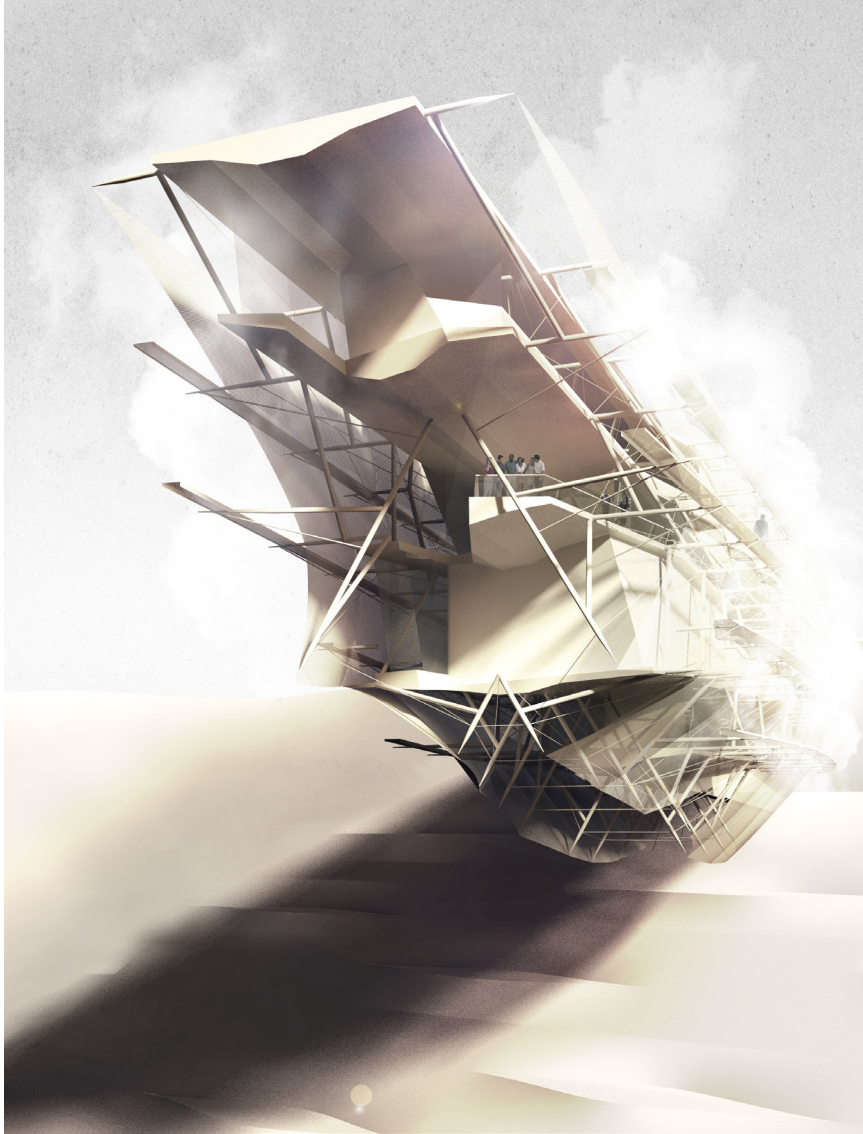


Figure 1.23  
Rendering of the Fréjus Nature  
Centre projecting out over the  
spoil mound.



The sedimentary precursors of the calcareous schist that make up the Col du Fréjus were laid down layer by layer in horizontal strata at the bottom of an ancient ocean. Under immense pressure and temperature, these sediment were gradually transformed into foliated schists, which were again deformed as the tectonic plates collided in slow-motion, crumpling, twisting, and folding the layered rock. The resulting rock mass is at once ordered and convoluted, seemingly static in a human frame of reference, but behaving like a viscous fluid at the scale of geological time. The order and placement of the various rock types, veins of mineral inclusions, and rock strata are broken by the boring machine in the excavation process, and are transplanted from the centre of the mountain to its surface and deposited in a near homogenous arrangement. As the tunnel boring machine inches through the rock, each successive layer of the vertical rock face it encounters is pulverized and transported to surface where it is dumped down the face of the growing spoil mound. Since the excavation and disposal process is incremental, what was once finely layered solid becomes a dispersed rock 'foam' that is deposited in diagonal layers that homogenize and blur all detail, maintaining only macroscopic differences. The process of removal transfers the borders between geologically distinct nappes to the spoil heap, retaining basic information about broad changes in rock type, but muddling the boundary between them, and allowing the distinct types to overlap and bleed into each other.

The nature centre focuses on this synthetic landscape of excavation spoil, using it to examine the regeneration of sensitive ecosystems after the devastation of rockslides, the dispersal of mine tailings, or other scarred landscapes. From its extended position, the nature centre offers an opportunity to observe the process of unassisted re-naturalization, and monitor active strategies for regeneration including re-forestation, directed plantings, and low-intensity agriculture (fig. 1.24). These diverse strategies for regrowth can be seen by visitors and nature centre staff from the long observation deck promontory on top of the nature centre building, and can also be explored along walking trails that connect a number of large and small terraced areas and lookouts. This focus on the establishment of plant and animal life of the spoil mound anticipates a range of naturally occurring and manmade conditions, including the frequent rockslides that occur throughout the Alps, the corresponding need to stabilize loose material, the construction of the Lyon-Turin base tunnel and the resulting massive volume of spoil it will

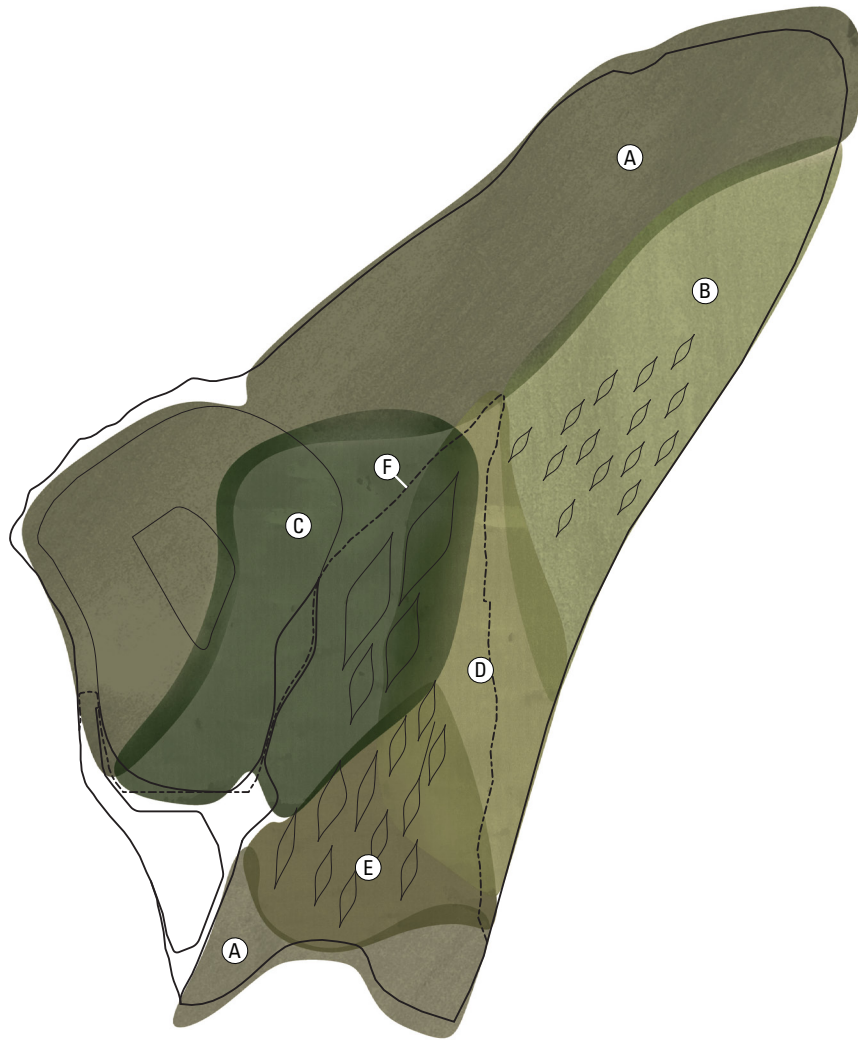


Figure 1.24:  
 Plan diagram showing  
 placement of re-growth  
 strategies.  
 Legend:  
 a. Buffer - unassisted  
 renaturalization  
 b. low intensity farming -  
 vineyards and orchards  
 c. forest  
 d. meadow - native grassland  
 e. grazing - sheep and goats  
 f. walking trail

create,<sup>26</sup> and the more general questions of mending the scarred landscapes of ore tailings, open pit mines, and the residues of tar sands extraction.

In addition to being the nature centre's focus of study, the spoil mound is also its physical foundation, providing the weight necessary to enable the nature centre's reaching lightness. Beginning deep within the ground, a three dimensional network of low-strength friction anchors bind the cables into the loose spoil, distributing the forces over a diffuse area, activating the aggregated weight and internal friction of a sizable portion of the spoil to found the cantilevered building. As the cables extend out from multitude of anchors, they are aggregated into larger and larger bundles, finally concentrating into two thick bundles at the moment they puncture through the surface of the spoil mound and run over saddles that sit atop two concrete pylons. From this moment of concentration, the cables then splay out to support the cantilevered nature centre, connecting to nodes on the centre's exoskeletal structural matrix. The regular array of cable stays, when overlaid with the floor plates causes the distribution of the nodes in such a way as to create an evolving irregular three dimensional truss (figs. 1.25 & 1.26), the form of which evokes the sense of movement captured in the photographs of Étienne-Jules Marey (fig. 1.27), and recalls Hans Grubenmann's remarkable layered alpine wood bridges (fig. 1.28).<sup>27</sup> The structural matrix acts as an expanded intermediary layer, a zone of interference,<sup>28</sup> where the tensile force of the cables stays is resolved into the compressive floor diaphragms. From thickened edges at the matrix interface, the floor slabs open to form a thinned hollow tubular structures that gather and balance the transferred forces of the cables. These hollow middle sections are subdivided with thin baffles to form cellular structure, reducing weight while stiffening the slab. The voids function as air plenums and conduits for building services. The slab profiles, based on the concrete box girders that are widely used in bridge construction, can be produced in precast concrete segments that are linked together using embedded cables to allow for unsupported cantilevered construction. It is on

26 A new railway tunnel is currently being constructed to link Lyon and Turin more directly. One of the four construction access points and future escape tunnels is very near Modane. At 57km, the construction will generate an enormous quantity of excavation spoil.

27 Angelo Maggi, Nicola Navone, eds., *John Soane and the Wooden Bridges of Switzerland: Architecture and the Culture of Technology from Palladio to the Grubenmanns* (London: Sir John Soane's Museum; Mendrisio, Switz.: Archivio del Moderno, Accademia di architettura, Università della Svizzera Italiana: 2003).

28 Interference as understood in physics as the interaction of systems of waves. The structural forces embedded in the cable and floor systems intermix and reinforce each other as they overlap within the matrix truss work.

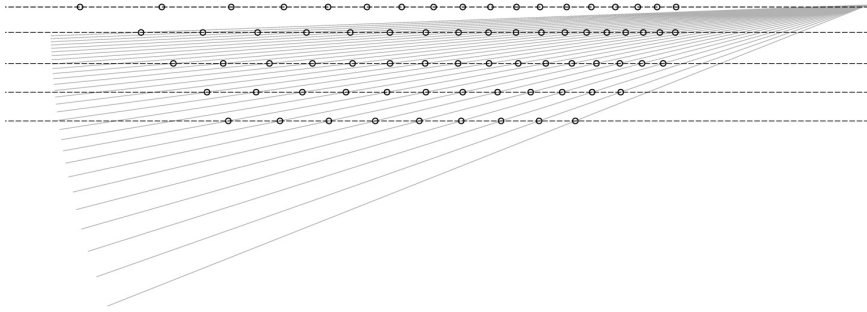


Figure 1.25:  
Diagram of superimposed  
structural systems and the  
resulting nodes at points of  
interference

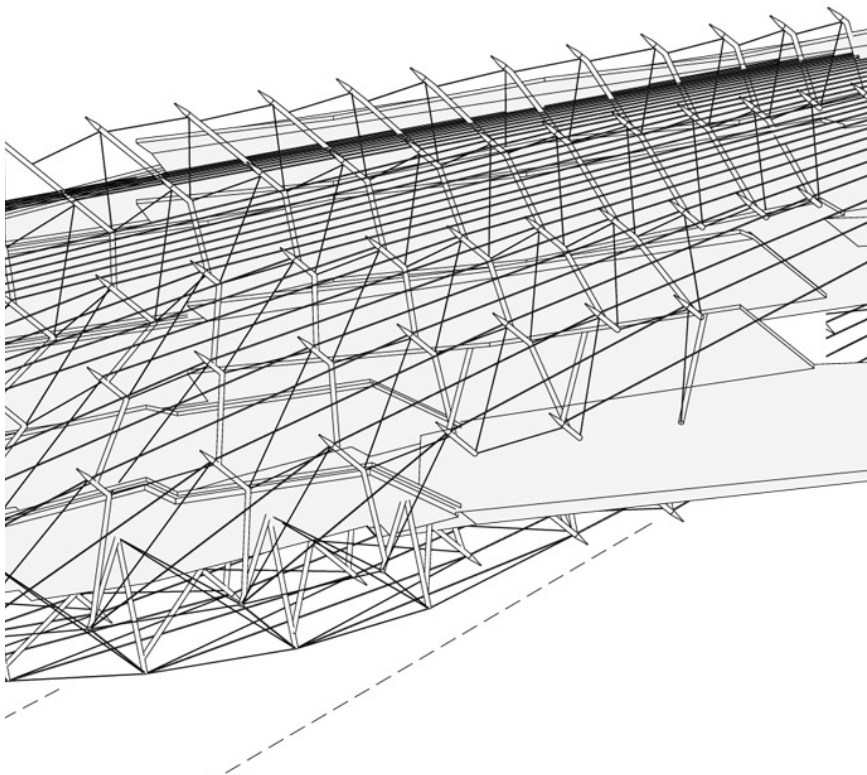


Figure 1.26:  
The three dimensional truss  
elements of the structural  
matrix

Figure 1.27:  
Étienne-Jules Marey, Walking  
Man, chronophotography,  
1884.

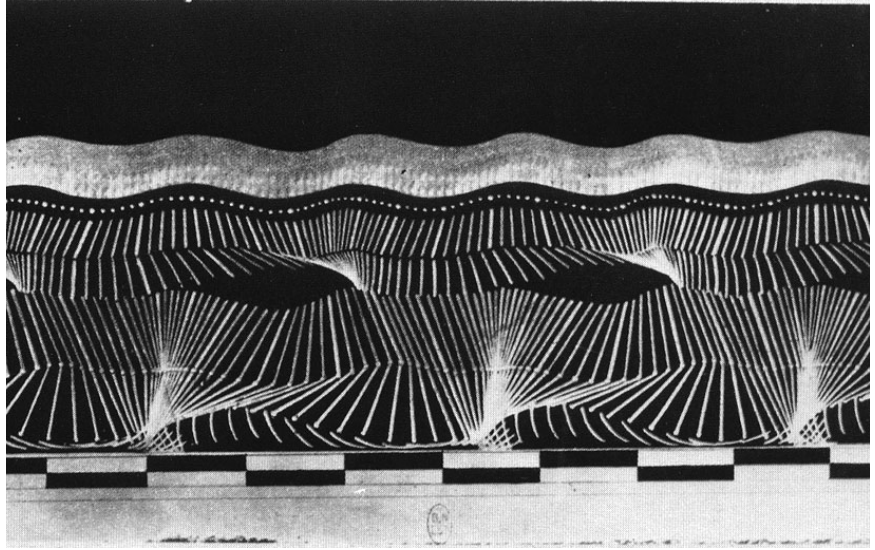
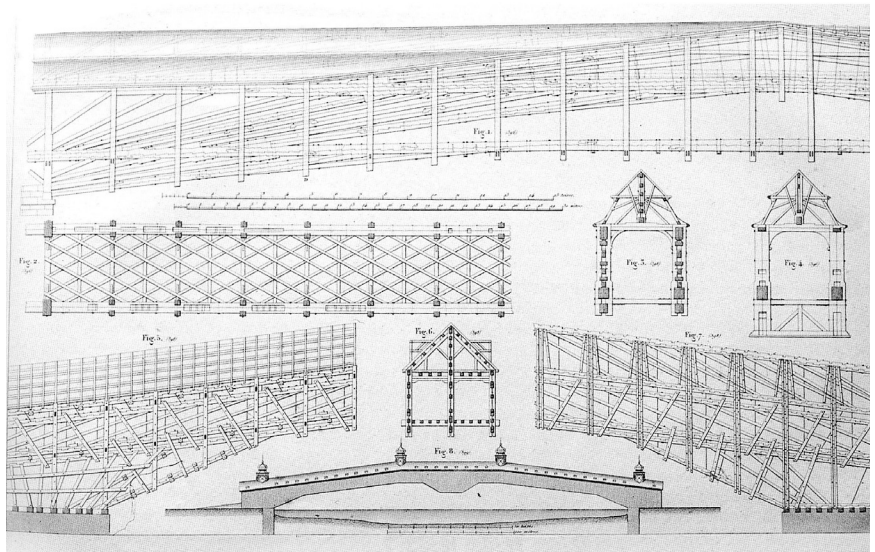


Figure 1.28:  
Grubenmann's design for the  
Schaffhausen Bridge.





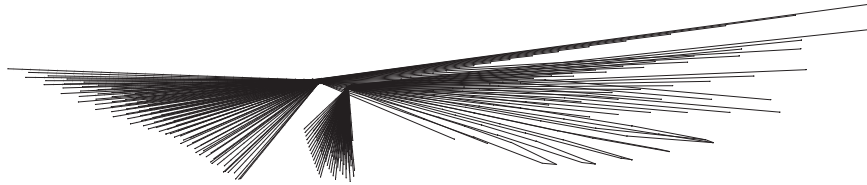


Figure 1.29:  
Dispersion and multiplication  
on each side of the spoil  
surface. Perspective drawing  
of the cable stays and spoil  
anchors.

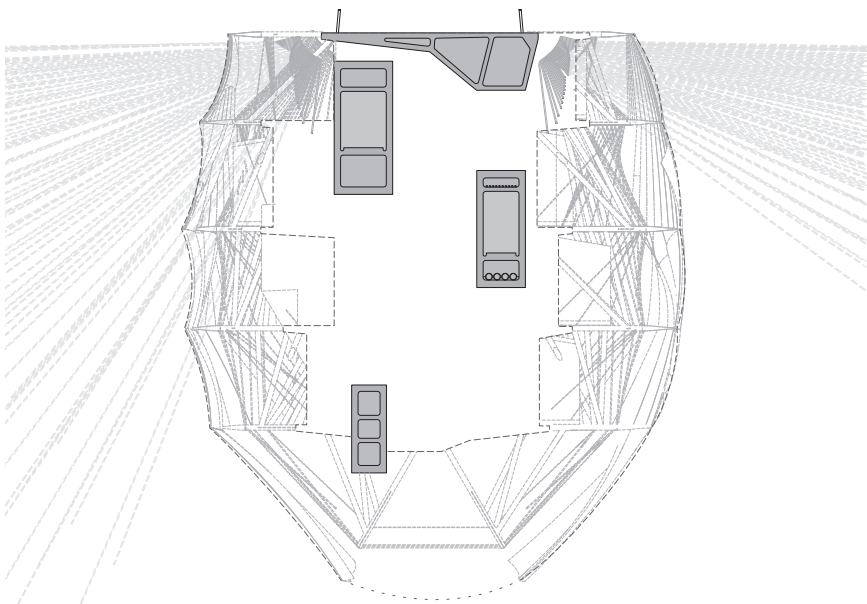


Figure 1.30:  
The moment of coherence.  
Cross section of struts and  
cable bundles at the spoil  
surface. (Detail of drawing 5.1  
Fréjus Nature Centre Cross  
Sections)

these concrete platforms that the interior and exterior programme spaces are arranged, allowing for the flexible positioning of programme volumes and shaping of public and circulation space.

The profiles of the box girder decks evolve over the length of the nature centre, tapering near the tip, and gradually deepening, narrowing, and merging as they focus the forces into four discrete tubular struts. These four struts, besides carrying structural loads, also serve as the connecting walkways and carriers of building services from the underground entrance caverns and thermal baths, to the above ground nature centre spaces. Together with the two cable bundles, the four tubular struts densely concentrate forces, movement and energy of the building and are the only points where the nature centre intersects with the surface of the spoil mound. In this way, the spoil surface forms the conceptual mirror plane of the nature centre, and echoes physics of neutrino oscillation and quantum field theory, whereby on either side of its visible surface, the defined form each discrete element explodes apart, intermingling, and diffusing into turbulence or complexity. (figs. 1.29 & 1.30)

The nature centre is coupled thermodynamically with the neutrino observatory, acting both as a radiator and absorber of the geothermal energy accumulated in the observatory. The ambient rock temperature in the heart of the Col du Fréjus is nearly 38°C. This unremitting heat surrounds the observatory spaces, necessitating constant cooling of the labs. The neutrino detectors themselves operate optimally at 12°C, setting up an even steeper temperature gradient. As heat is being constantly pulled out of the observatory environment, it is transferred to a water loop that runs to the nature centre where the geothermal 'waste' heat is used for heat and power (fig. 1.31). A thermal transfer station within the nature centre concentrates the heat and transfers the energy into multiple sub-loops that operate within the nature centre itself. These hot water sub-loops are used to generate electricity using a micro-turbine, heat the pools in the thermal bath, and fuel the building's radiant heating system. Finally, the nature centre's metal mesh skin cools the water as it percolates over its surface. Evaporation draws heat out the cooling water before it is collected for return to the observatory, leaving the nature centre wrapped in a veil of water vapour and steam (fig. 1.32). The mesh surface is embedded within the thickness of the structural matrix, and through variations in the pattern of its openings, it shades the building's



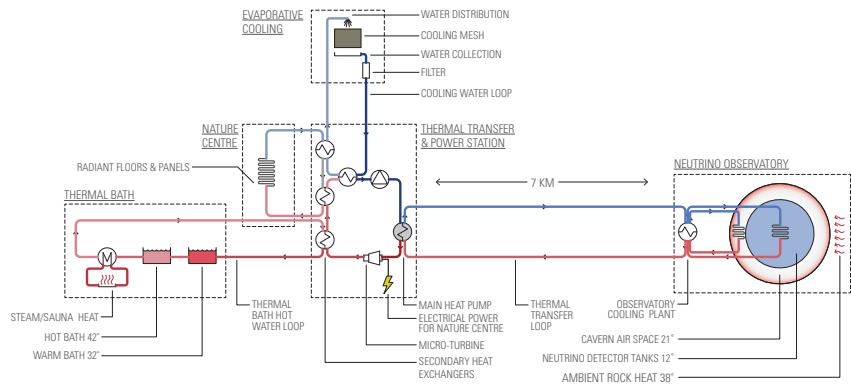


Figure 1.31: Diagram of thermodynamic exchange between the nature centre and observatory. A series of intersecting energy loops distribute and dissipate geothermal heat.

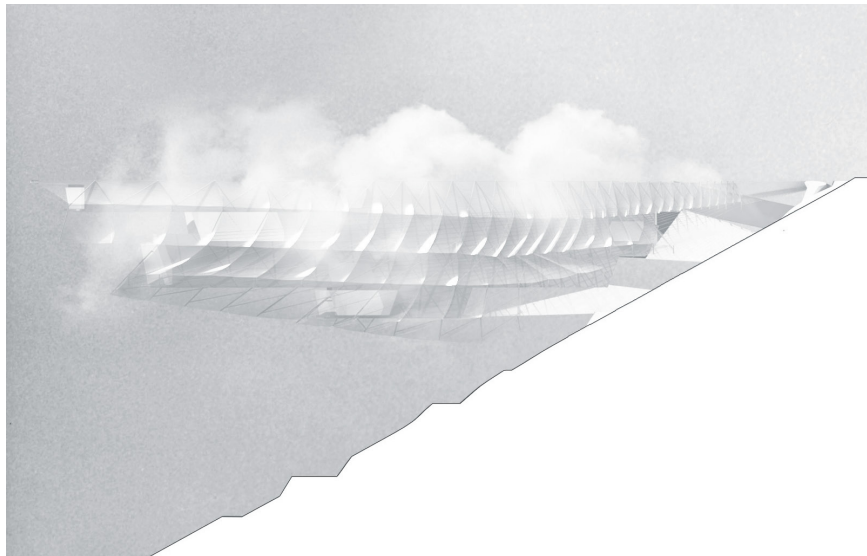


Figure 1.32: Steam evaporating from the cooling skin of the nature centre's south face.

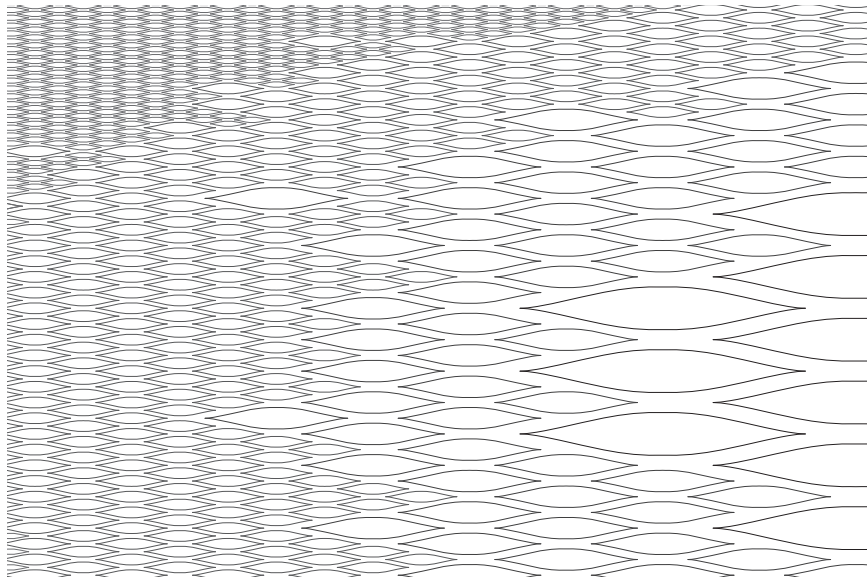


Figure 1.33: Detail of the openings in the mesh skin.

glazing and opens up to allow views of the surrounding landscape. The pattern of openings is also developed to precisely control air flows through the mesh, promoting evaporation with greater density, and air movement and views with larger openings in the expanded stainless steel mesh (fig. 1.33). The relationship of air movement and evaporation regions structures the gaseous medium, forming what chemist Ilya Prigogine terms dissipative structures,<sup>29</sup> the emergent macro-scale patterns that form in far-from-equilibrium states. Regions of dense, moist air mix with fast-moving dry air, interacting to create vortices, convection cells, and turbulence patterns around and above the building.

Upon arrival to the nature centre, visitor pass through a series of large caverns buried in the spoil mass, walking beneath the thermal transfer station and thermal baths. Climbing a gentle staircase within one of the hollow structural struts, visitors pass through surface of the spoil, and arrive at an open reception area and information desk. Looking ahead, a long corridor extends out, lining the surface of the building, and capturing the vector energy of the building launching out of the spoil mound. The interior side of the corridor is shaped by through the gentle inflection and arrangement programme spaces to allow for varying densities of occupation, moments of pause, gathering, and views of landscape. The subtle movement creates a dynamic equilibrium through which the intense linearity of the corridor is dissolved into a rhythm of informal spaces. In addition to the main public circulation, a systems private and service corridors operate in parallel, providing back of house access to the thermal bath spaces, and controlled access to administration and scientific research areas. Across from the reception area is a large exhibition space that houses permanent displays, accommodates visiting exhibitions, and can serve as a large multi-purpose space for special events and conferences. A small restaurant is located at the tip of the nature centre, which has views out over the spoil mound, the alpine valley, and city below. One the level below, there is a large lecture theatre that can be subdivided into two medium-sized tiered multimedia classrooms for workshops and seminars related to the nature centre's or observatory's activities. In addition to these extroverted uses, nature centre building also includes a small hotel and thermal bath. Tourists and visiting scholars are

29 Ilya Prigogine, *Time, Structure and Fluctuations*, (Nobel Lecture, Université Libre de Bruxelles, Brussels, Belgium and the University of Texas at Austin, Austin, Texas, USA, December 8, 1977)

accommodated in seven rooms that look out to the surrounding landscape. A series of pools are buried within the spoil mass, reinterpreting the heritage of colonizing natural hot springs, and creating an abstracted equivalent that is displaced from its geothermal source in the heart of the Alps, and transposed from a usual home on a mountain side to voids within the newly foamed rock.

In a broader sense, the nature centre's program compliments that of the neutrino observatory, operating at physical and timescales between the extremes explored in neutrino physics. Where the neutrino detectors study phenomena at incredibly small sub-atomic scales, and explore their relationship to incredibly large scale questions,<sup>30</sup> the nature centre operates in the intervening scales, centering on the scale of a human and extending down to the realm of plant biology and up to the scale of geology. By focusing on the particular and subtle characteristics of the many disciplines, systems, energy flows, and technology that overlap in the nature centre, an expansive and multi-layered instrumental design approach emerges. This manifold instrumentality offers an alternative to the narrow functionalism and segregation that has generally come to pervade the design of spaces for science. By engaging in a detailed way with multiple frames of reference, the result is an evocative and highly specific architecture.

30 Neutrinos range in size from approximately  $1 \times 10^{-26}$  m to  $1 \times 10^{-26}$  m. Neutrinos may provide a way of understanding the matter and anti-matter asymmetry that was produced during the formation of elementary particles during the processes of baryogenesis and leptogenesis that occurred in the early stages of the universe in the big bang. Neutrinos may also offer a means to see beyond the cosmic microwave background radiation that defines the edge of the observable universe.

## Tunnel

The tunnel serves as the umbilical cord for the underground observatory. It facilitates the construction of the observatory and sustains its operation. The tunnel delivers fresh air and returns exhaust air, it supplies power and water, and it plays a critical role in cooling the observatory. In addition, the tunnel is the principal access to an observatory that is buried inside of the mountains, 7km from the surface. From their distinct sources within the nature centre complex and spoil mound, the tunnel traces the routes of these pathways and systems, fusing them together and integrating them into the basic tectonic elements that form the tunnel: its walls and floor.

Schematic proposals by the research and construction consortium<sup>1</sup> of the neutrino observatory make a clear case for the construction of a dedicated access tunnel for a future underground neutrino observatory,<sup>2</sup> and identify a number of possible routes. These proposals also suggest tunnel boring machine (TBM) as a viable excavation strategy. TBM excavation employs a circular cutting head to burrow through the rock. Behind the cutting head are a series of back-up systems including conveyor belts to remove the muck or spoil, and mechanical arms to install sections of precast concrete lining on the tunnel walls. Within the circular cross section of the tunnel, a platform is suspended to support a roadway and electric railway, and to divide the tunnel space in two.

The precast concrete lining, in its most basic configuration, is the skin and skeleton of the tunnel. The lining elements form a solid ring that resist rock pressure and cave-ins, and by way of a drainage layer on its outer surface, it protects the tunnel's interior space from water ingress. The lining is enhanced through the addition of hollow ribs on its inner surface that augment its structural stiffness and its skin-like character by cooling the tunnel walls. Air is drawn through the hollow ribs and into the exhaust air plenum below, absorbing heat along the way (see fig 2.1). This air-cooled skin mediates heat gain from the surrounding rock, helping to control the

1 The project is called LAGUNA-LBNO, an acronym derived from Large Apparatus studying Grand Unification, Neutrino Astrophysics and Long Baseline Neutrino Oscillations.

2 Access for construction equipment, spoil removal, and the need to maintain the full and safe operation of the Fréjus Road Tunnel and Safety Tunnels are identified and the determining factors. Riccardo Stucchi and Davide Vietti, "LAGUNA-LBNO at Fréjus," (presented at the general meeting, Hamburg, 25-27 February 2013), accessed July, 3, 2013, <http://laguna.ethz.ch/indico/getFile.py/access?contribId=67&sessionId=6&resId=0&materialId=slides&confId=8>

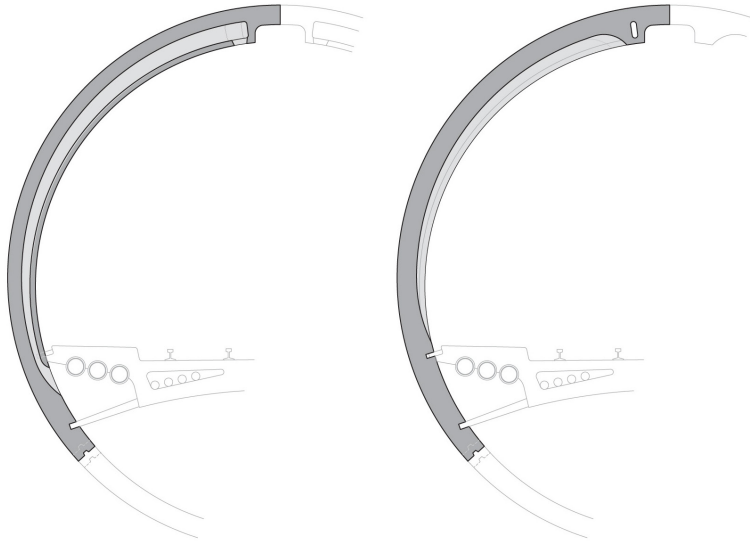


Figure 2.1:  
Drawing of tunnel lining showing hollow ribs (left) and coffers (right) in the precast concrete lining elements. (Detail of drawing 12.0 Tunnel Lining Details)

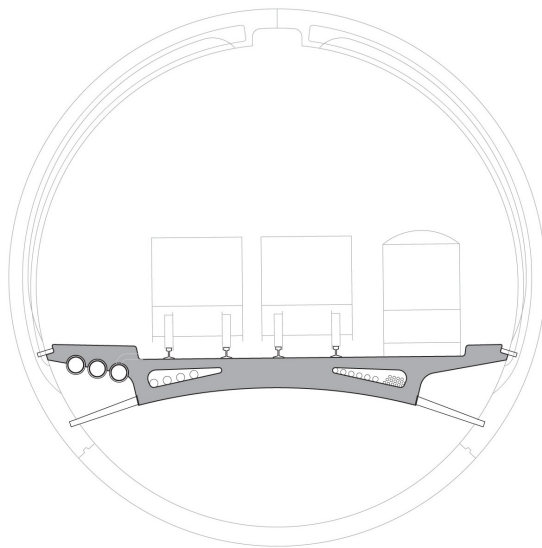


Figure 2.2:  
Drawing of suspended tunnel platform. (Detail of drawing 12.0 Tunnel Lining Details)

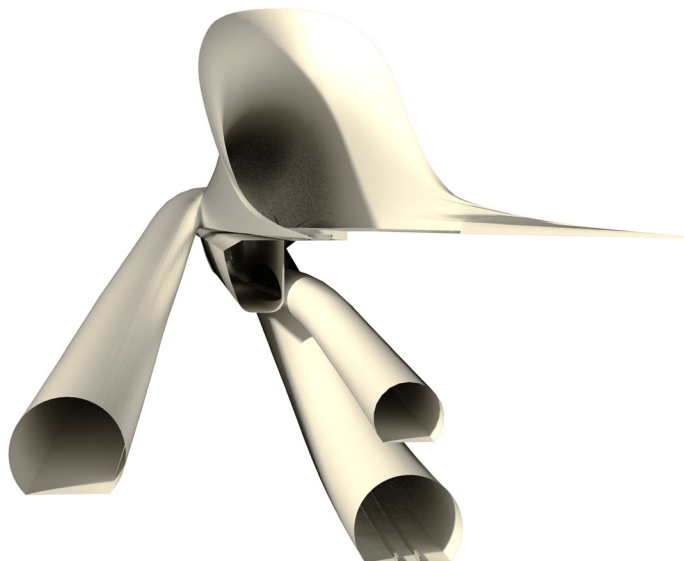


Figure 2.3:  
Image of the de-coupling and individuation of the tunnel branches as they move through the tunnel mouth from the fully integrated condition of the access tunnel to the nature centre.

tunnel environment and quality of the fresh air that flows through the tunnel to the feed the observatory. As the tunnel travels deeper into the mountain, the frequency of the ribs increases in correlation with the ambient rock temperature, effectively translating temperature information and distance into physical form. When passing through the tunnel at speed, the rhythm of the tunnel ribs subtly increases, creating a visual tempo that mirrors the latent energy in the surrounding earth.

The design of tunnel platform follows a similar approach, exploring its essential character and investing it with multiple roles. The platform is suspended within the tunnel, serving as a deck to support vehicular traffic and the electric railway tracks (see fig. 2.2). During the construction of the tunnel and excavation of the observatory, two parallel narrow gauge railways and the conveyor belt system fill out the width of the deck, ferrying workers and equipment in and out, and carrying excavation spoil back to the surface. During normal operation, a roadway takes the place of the conveyor system and the one set of railway tracks, leaving one railway line in place as the principal way to move scientists and visitors through the 7km tunnel.

The profile of the platform is adapted to its suspended position. The concrete profile is thinned at the outward edges, while remaining more massive in the centre where it needs to bridge between the tubular struts that pin the platform to the tunnel walls. Within the thickened centre portion of the platform, voids are carved out around the force paths to reduce weight. These internal voids function as raceways for small diameter piping, power and data conduit. The large pipes to carry the cooling and waste water are clamped into grooves cut into the outer wings of the platform. In its suspended position, the platform also acts as membrane that separates the fresh and exhaust air plenums. Fresh air is supplied through the main cavity of the tunnel, while exhaust air is pulled out through the space below the platform.

The tunnel mouth captures the moment of being put together and being torn apart. When travelling into the tunnel, it is here that the multiple systems, railway, road and air plenums converge and are bound into the tunnel itself (see fig 2.3). Looking the back to the surface, the coherence and integration of the tunnel splits apart. The railway bends away, and dives deeper underground towards the entrance caverns that are its terminus. The platform tightens, skirting the void left by the dropping railway, then



extending out into space as the long top deck of the nature centre. The runs of cooling pipe and conduits disengage from their niches and ducts, branching off towards the thermal transfer and power station in a separate tunnel. The fresh air is pulled through another tunnel branch that begins deep in the spoil mound – the rock mass used to moderate the air temperature through the seasons.<sup>3</sup> The compact cross section of the tunnel expands vertically, letting sunlight into the tunnel and announcing its presence.

3 The Creighton nickel mine draws its fresh air supply through a spoil pile through the year, using the rock mass to cool the hot summer air. After slowly heating up all summer, the cooling capacity of the rock is recharged all winter, effectively moderating the fresh air temperature year round.

## Neutrino Observatory

Buried beneath two kilometers of metamorphic rock in the Cottian Alps at the midpoint of Fréjus road tunnel, the neutrino observatory is situated directly below the mountain ridge that forms the geographical border of France and Italy. This subterranean location provides the shielding needed to observe the faint traces of neutrino interactions. “The most tiny quantity of reality ever imagined by a human being,”<sup>1</sup> neutrinos come in three types and are part of a group of subatomic particles called leptons. Produced during processes of radioactive decay, nuclear fission or fusion, neutrinos are nearly massless, and without electric charge. “Neutrinos by the millions fill every cubic meter of space, a ghostly, unseen matrix in which the universe has evolved.”<sup>2</sup> Despite their proliferation – there are more neutrinos in the universe than any other particle;<sup>3</sup> their lack of electric charge, and near dearth of mass, means they very rarely interact with other matter. “Nearly 100 trillion neutrinos originating in the Sun pass straight through each person on Earth each second, and statistically, only one of these solar neutrinos will interact with any subatomic particle in that person’s body during his or her entire life.”<sup>4</sup> Indeed neutrinos will pass through hundreds of light years of space and the entire earth without encountering a single subatomic particle. To see these ghostly particles, an enormous fluid-filled camera is needed. The sheer quantity and density of material increases the odds of otherwise unlikely interactions. When looking for these rare moments when the neutrino matrix interfaces with more tangible matter, shutting out background noise is critical<sup>5</sup> – a condition of nearly absolute sensory quietude.

The neutrino observatory is organized around, and extends out from, a central entrance hall that forms the end of the long access tunnel, acting as an anteroom to the observatory. This space is a narthex, mediating access to the

1 Frank Reines, Nobel Prize winner for the detection of the neutrino, quoted in Ilaria Brivio, “The ceaseless transformation of the three neutrinos,” *Invisibles*, accessed September 7, 2014, <http://invisibles.eu/outreach/entry/ceaseless-transformation-three-neutrinos>.

2 “The Neutrino Matrix,” *American Physical Society Multidivisional Study*, accessed September 21, 2013, <http://www.aps.org/policy/reports/multidivisional/neutrino/upload/main.pdf>.

3 Frank Close, *Neutrino* (Oxford: Oxford University Press, 2010), 2.

4 “Observing Neutrinos: 1663 Science and Technology Magazine | Los National Alamos Laboratory,” accessed March 24, 2014, <https://www.lanl.gov/science/1663/january2012/story2full.shtml>.

5 The noise can include high energy particles from the cosmic rays that bombard the earth, and the products of the decay of trace radioactive elements in the ground, air, water, and materials that make up and surround the observatory.

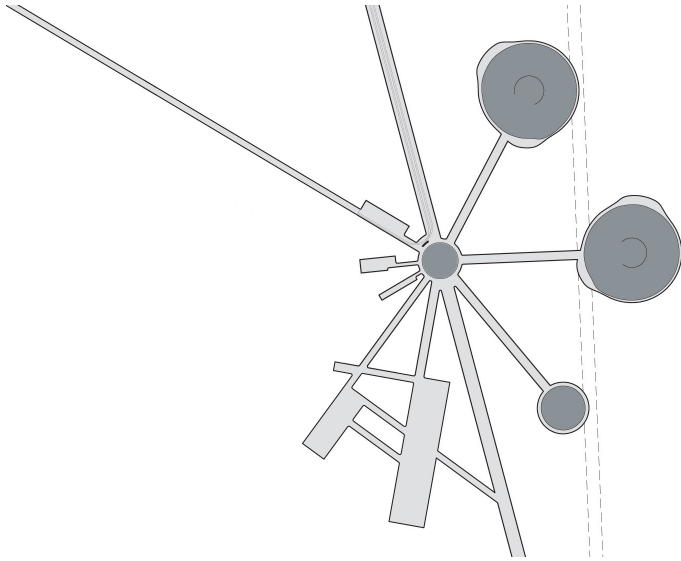


Figure 3.1:  
The narthex mediates the transition from the access tunnel to the laboratory spaces, and acts as the hub of the observatory. (Detail of drawing 14.0 Neutrino Observatory Site Plan)

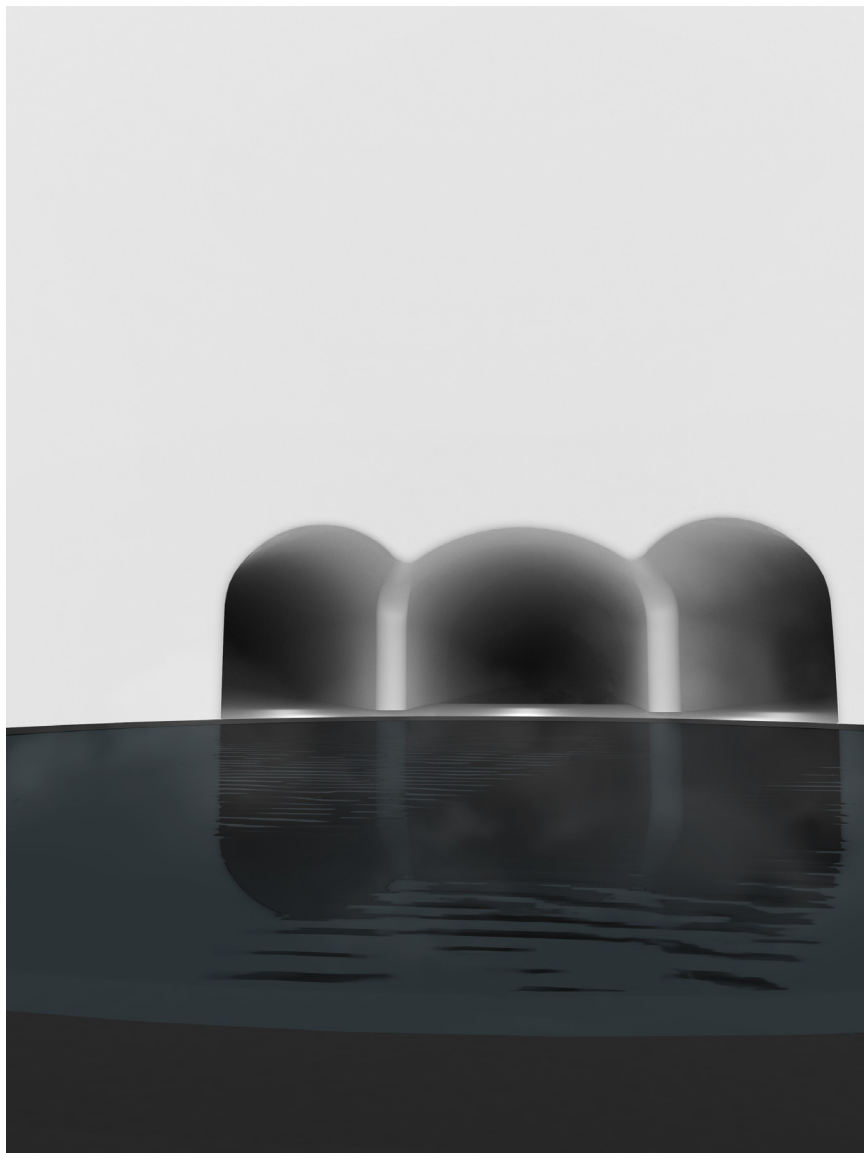


Figure 3.2:  
Image of Narthex dome and cooling reservoir. (Detail of drawing 18.0 View From the Access Tunnel Into The Entrance Hall.)

passageways and caverns beyond, and serving as space of transition between the low-level radioactive environmental contaminants of the tunnel (the outside world) and the clean laboratory spaces of the observatory. Branching immediately off this narthex is a small cavern with facilities for visitors and incoming equipment to be cleaned of radioactive trace. Staff facilities, a pair of large experiment halls, and the three immense neutrino detectors cluster around the entrance hall (fig 3.1).<sup>6</sup>

The breadth and height of the domed entrance hall offer an experiential release from the confines and blackness of the access tunnel. The strategic use of light, colour, and material in the narthex create an experiential blurring of energy and matter, and an erosion of scale that continues through the rest of the observatory. The seamless smooth finish of the dome inhibits the perception of depth, erasing indicators of scale and distance. The ceiling surface dissolves into expansive emptiness and fullness at the same time, implying the multiple and fluid nature of matter (fig 3.2). The visual effect is akin to that of artist James Turrell's ganzfeld works. Light and matter merge. Space and material cease to be solid, and energy (light) becomes tangible and massive. The delicate mixture of normal and ultraviolet light gives the space a quivering self-glow. Editor Barbara Kirschner describing a Turrell ganzfeld:

*“As a result of the even, monochrome lighting, the room is colourless, and devoid of differentiating stimuli. The eye has nothing to latch on to for orientation - nothing to make sense of. The resulting experience is like swimming in a mist of light.”*<sup>7</sup>

Mirroring this expansion, a large reservoir of cooling water sits in the middle of the entrance hall floor. The deep pool is itself a foyer. It contains the ‘focus,’ the heat source, though here it is inverted as the source of cooling. The reservoir collects and concentrates the cooling medium, operating in between the observatory cooling equipment and the long pipe runs that run to the surface of the mountains (fig 3.3). Water emanates over the back sloped reservoir edge, erasing the pool's border to create what architect Kengo Kuma describes as an “infinitely sensitive receptor, responding to the subtlest

6 The dimensions of the program elements are a synthesis of a site visit to the Sudbury Neutrino Observatory (SNOLAB), research and analysis of other neutrino laboratories, and published proposals for a possible expansion of the small existing Laboratoire Souterrain de Modane on this site.

7 Esther Barbara Kirschner “From space to surface to space: on the works of James Turrell” in *James Turrell: The Wolfsburg Project*, eds. Markus Brüderlin & Esther Barbara Kirschner (Ostfildern: Hantje Cantz, 2009), 75.

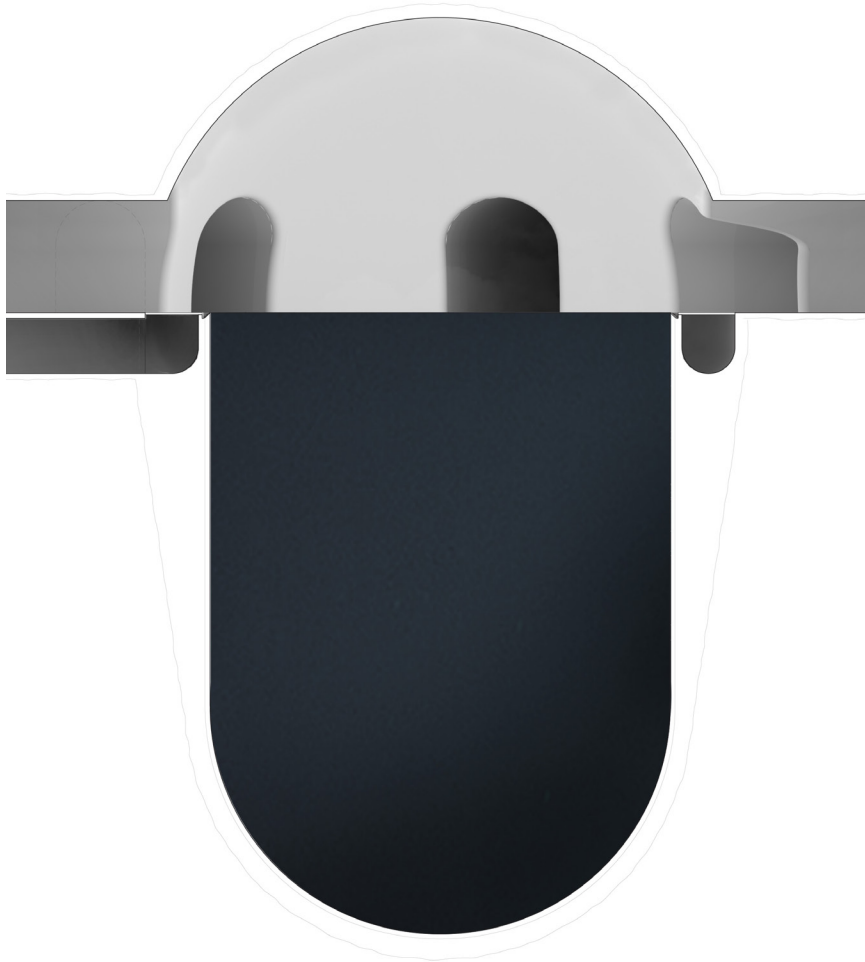


Figure 3.3: Cross section through narthex dome and cooling reservoir.  
(Detail of drawing 16.0 Neutrino Observatory Entrance Hall Section.)

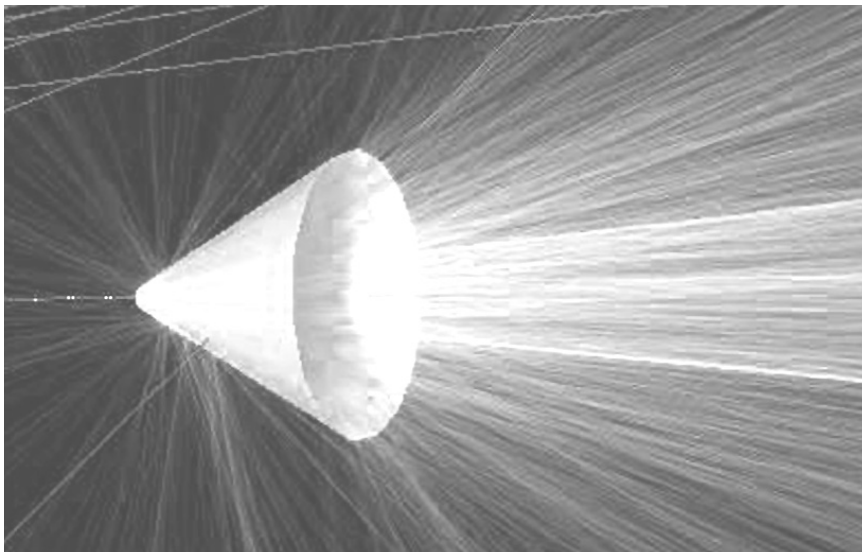


Figure 3.4:  
Image Cherenkov radiation cone-shaped light shock wave.

changes in the environment.”<sup>8</sup> The smooth reflective surface captures the expansive volume of misty light above and multiplies it within the depth of the deep pool. The stillness of the pool’s surface is broken only by the subtle registration of fresh air currents that blow in from the access tunnel (fig 3.2). The quality of light in the glowing dome above transforms the great volume of deep, dark water into a trembling mirrored plane.

Three megaton-scale detectors form the experimental core of the observatory – two water Cherenkhov detectors each containing 332,000,000 litres (332 kilotons) of ultrapure water, and one organic liquid scintillator detector that uses 53 kilotons of linear alkyl benzene. Suspended within the 30 storey-tall light-proof water tanks is a massive array of photo multiplier tubes that sense the cone-shaped flashes of dim blue light emitted by particles as they recoil from the impact of a neutrino. The flashes, called Cherenkhov radiation, are ruptures of the electromagnetic field – the optical equivalent of a sonic boom shockwaves – created as particles recoil from neutrino impacts faster than the speed of light in water (fig 3.4). The array of light sensors forms an enormous inward facing camera, the limits of which are determined only by the ultimate transparency of water. Even in an ultrapure form, free of impurities and trace ions – a form where water takes on extreme solvent-like properties and is biologically toxic – water is not completely transparent. In great enough volumes, water begins to absorb light, potentially swallowing up the faint flash of a collision. While the majority of the sensors face into the dark tank searching for the glimmer of neutrino interactions, a fraction of the sensors face out, detecting and eliminating background signals in a zone called the ‘veto area.’

A cluster of systems surround each detector: multi-stage ultra-filtration, air purification, power, cooling, data gathering, and control systems. Rather than dispersing the various systems in small caverns away from the detectors, and servicing and cooling each remotely,<sup>9</sup> the detectors and their support systems are consolidated and integrated with the detector in its cavern. By grouping the multi-stage water filtration system on platforms that cascade around the middle of the tank, it allows the detector to operate

8 Kengo Kuma, *Anti-Object : The Dissolution and Disintegration of Architecture*, translated by Hiroshi Watanabe (London: Architectural Association, 2008), 38.

9 SNOLAB operates in this manner. Filtration and other equipment is separated from the detector and located in other caverns, or at the end of tunnels. Air handlers and transformers are installed all over the lab on small mezzanines, or lined up on the side of the narrow tunnels.



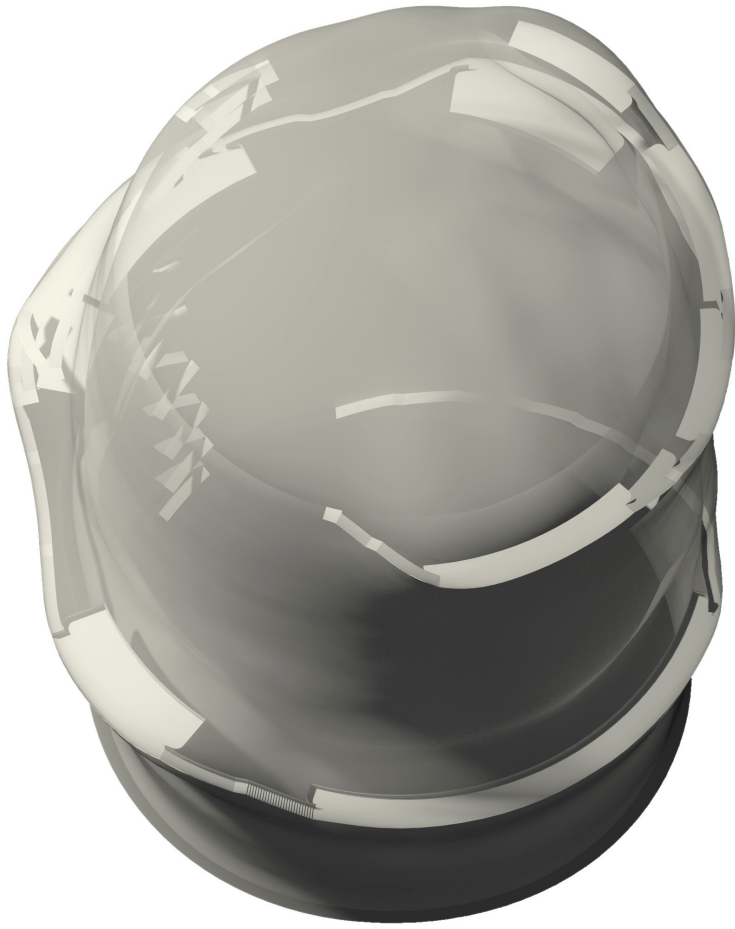


Figure 3.5:  
Isometric drawing of  
neutrino detector showing  
helical arrangement of stairs  
and systems platforms in  
ventilation airway.

like the circulatory system, pulling warmer water from the top of the tank and sending it through a series of filters, treatment stages, and cooling to then be fed back into the bottom of the tank. Other systems are located based on proximity: the equipment that purifies the small air space at the top of the tank is naturally located right next to it. Similarly, the data servers and control room are located adjacent to the wire penetrations at the top of the tank. This arrangement also makes the operation of the detector legible, wrapping the opaque body of the detector (the tank) with its organs (fig 3.5).

Cooling is critical to the operation of the detectors, and of the entire laboratory. The ambient temperature of the rock surrounding the lab is approximately 32°C, whereas the detector, and in particular the photo multiplier tubes, operate best at 12°C. In addition to this base cooling demand, the equipment, electrical systems, lights, and racks of computer servers all generate heat. To mediate the thermal pressure, the observatory forms a thermodynamic link with the Fréjus Nature Centre. Each part operates in direct thermal relationship with its immediate environment – the observatory with the warm rock, and the nature centre with the alpine atmosphere. In turn these two systems are connected and linked with the access tunnel, to form what architect and theorist Luis Fernandez-Galliano terms an open thermodynamic system, “which is able to decrease its entropy if it benefits from a relationship that allows the environment to absorb the surplus entropy of the system.” This energy flow, from the earth’s heated crust to the atmosphere, is what creates and maintains the exacting conditions for neutrino research and needs of human inhabitation.

The profiles of the detector tanks and the caverns that house them are shaped in response to the space requirements and heat flows generated by the support systems and emitted by the surrounding rock. The detector tank begins at its minimum operational diameter where support systems adjoin it, and is allowed to swell in between equipment zones to both increase the ‘veto area,’ and strengthen the tank. The precise form of the detector tank is digitally modelled using physical simulation to approximate the tensile deformation behaviour of the tank membrane around the support system zones. In turn, the form of the domed detector cavern is derived mathematically as a response to the tank shape and heat sources, varying in a factored relationship with the tank’s deformation from the minimum volume. The combined effect of the

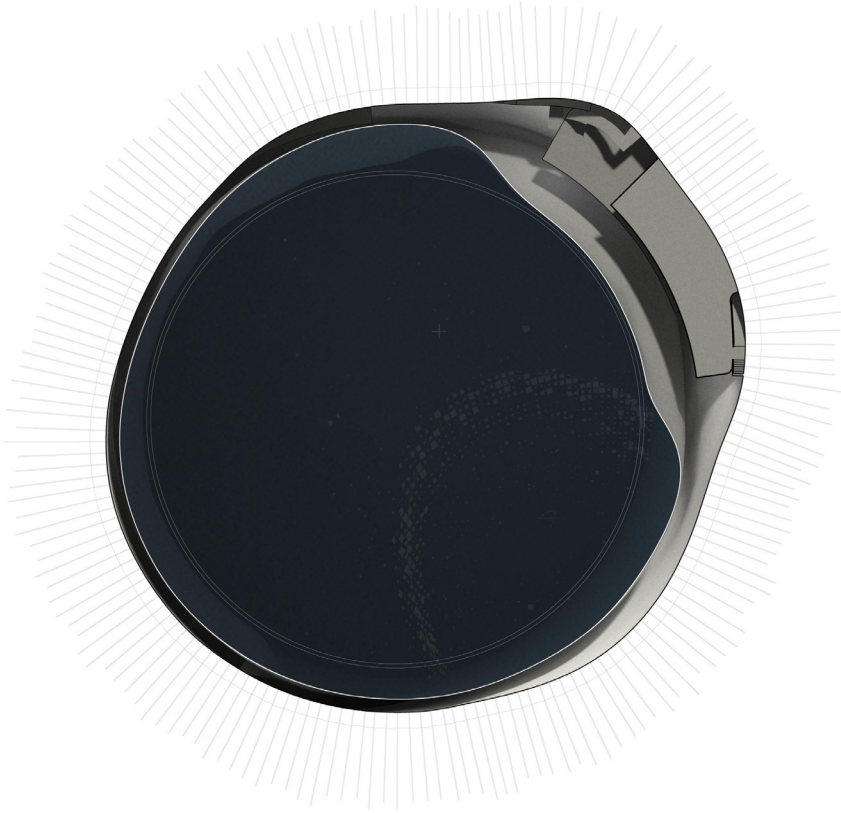


Figure 3.6:  
Rendered plan section of the neutrino detector showing the deformation of the detector tank and cavern around the equipment platforms, circulation, and heat flows.

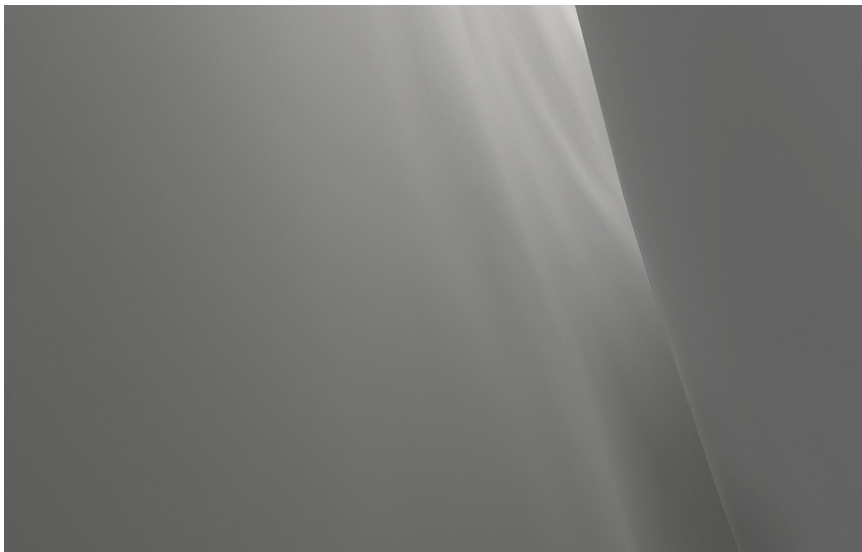


Figure 3.7:  
Light, colour and material operate in combination, dissolving distinctions between matter and light, giving light substance - a perceptible fog - that evokes the pervasive neutrino matrix. (Detail of drawing 18.3 View looking up from the base of the detector)

organic arrangement of the support systems around the deformed detector tank and the shaping of the cavern creates a helical space that links heat flows, air, physical form, and movement (fig 3.6). It recalls Fernandez-Galliano's description of architecture that "can be understood as a material organization that regulates and brings order to energy flows; and simultaneously and inseparably, as an energetic organization that stabilizes and maintains material form."<sup>10</sup>

The ring-shaped space between the walls of the tank and cavern operates as a ventilation airway that draws the heated air up and out from the cavern. The shaping of the tank and cavern around the support systems creates bulges that travel through the annular space in a branching helical pattern, focusing and concentrating the flow of heated air across cooling coils. This ring of space and the shallow domed space above the top of the tank are the extents of human experience. Within these spaces everything is painted a medium grey, allowing the objects and surfaces to blur into a seamless whole. Concealed low-intensity lighting gives the grey field a foggy quality (fig 3.7),<sup>11</sup> that continues and develops the spatial qualities first experienced in the narthex. Visitor and researcher movement traces the flow of energy by way of a series of open stairs pinned to cavern walls and to each platform. By following the winding route between the detector tank and cavern, visitors directly perceive the immensity of the 332 kiloton detector and the force of water as it seemingly pushes the tank walls out around the equipment zones. The comprehension of scalar disjunction between the visitor's body and the visible tank incites the contemplation of simultaneous magnitude and pervasiveness of the neutrino matrix, and the inversely corresponding minuteness of a neutrino particle. By walking the narrow spaces along the circumference and height of the detector – much like climbing the Duomo in Florence, Italy – visitors will experience the dimensions of the detector without seeing it fully, emphasising its dimensions in relation to muscular movement and physical experience, rather than an objective or objectifying vision. Air

10 Luis Fernandez-Galliano, *Fire and Memory: On Architecture and Energy* (Cambridge, Mass.: The MIT Press, 2000), 5.

11 For the 2012 exhibition 'Straight Jacket' at the Ydessa Hendeles Art Foundation, a large part of the gallery – floor, walls, and ceiling – was painted a medium grey and bathed in dim diffuse light. This combination of colour and light created a spatial effect that I can best describe as fog, though nothing of the sort was present.

currents move through the gaps between the stairways, platforms, tank, and cavern, blowing subtly over the skin of a visitor, making manifest the heat, energy flows, and matrix of invisible particles that fill the surrounding space.

## Conclusion

*Energy and Matter* brings together a diverse set of disciplines in science, engineering, and architecture, connecting them in a new and thoughtful way. It draws on ideas in neutrino physics, architectural theory, and observatory history to develop a design approach for a contemporary neutrino observatory. The observatory is conceived as a group of linked and interdependent buildings that engage multiple overlapping parameters – from scientific instrumentation and thermodynamics to construction technology and landscape remediation.

An examination of the history of astronomical observatories, sketches the evolution the observatory typology and the changing role of architecture. As part of this trajectory, we see the separation of scientific, public and domestic space, the increase in size and prominence of scientific space, and the diminishment of public space. The instrumentalist and functionalist paradigms that ultimately dominate the design of modern observatories, foreground technical requirements above all, leaving concerns for cultural expression and architecture at the margins. This amounts to a condition where we collectively build increasingly enormous constructions to study the frontiers of human knowledge, without apparent regard for their cultural significance.

*Energy and Matter* argues for a renewed role for architecture in the design of a contemporary neutrino observatory that enables it to fulfill its position as a cultural artefact. Drawing on ideas in neutrino physics and linking them to architecture theory, this thesis proposes an architecture that responds to fundamentally altered conceptions of matter, and engages with material culture and technology. The fluidity of energy and matter described by quantum field theory and neutrino physics, is connected with Fernández-Galliano's conceptions of energy and matter in architecture,<sup>1</sup> and is developed into an architecture that engages with thermodynamic flows and construction processes both within the buildings, and also between the buildings and their environments. An aesthetic strategy emerges from the synthesis of De Solà-Morales insights about the value of aesthetic experience in the heterogeneous

1 Luis Fernández-Galliano, *Fire and Memory: On Architecture and Energy* (Cambridge, MA: The MIT Press, 2000).



contemporary condition,<sup>2</sup> the phenomena of neutrino oscillation, and the impalpable qualities of James Turrell's light art. This strategy focuses on the precise manipulation of material, surface and light in order to dissolve the distinctions between them, implying, through aesthetic experience, the indeterminate and fluctuating nature of reality projected by neutrino physics.

Three interconnected design proposals bring together the above-mentioned syntheses and expand the narrow functionalism that characterizes observatory design to include multiple overlapping parameters. The scope of architecture is broadened to include construction processes and building services, the practice of making and operating buildings, and relationships with the cultural and physical environment – vernacular architecture, cultural heritage, meteorology, and geology. Building on the interconnections between the parasitic SNOLAB and its host mine, the nature centre, tunnel, and neutrino observatory are intrinsically linked and interdependent. These interconnected buildings are understood as parts of an observatory – an instrument building and support building – and as hybrids of these building types, interweaving public, experimental, and support spaces. Each building produces a different, but intersecting response to its environment and sub-set of parameters – the nature centre by expressing forces and energy in interwoven, individual elements; the tunnel by fully integrating and embedding the systems directly into its built form; and the observatory by seamlessly mixing movement, energy flows and form.

The Fréjus Nature Centre is conceived as a manifestation and flowering of forces – the thermal energy emitting from deep inside the Alps, the trajectory of the tunnel, and the expression of the stored construction energy in the excavation spoil. It uses the thermal energy that moves through it to create a beacon for the observatory that it actively cools, manipulating the flow of heat with openings its skin to reveal the dissipative structures that emerge when outpouring thermal energy mixes with the surrounding atmosphere. Alpine history and vernacular architecture is layered onto this thermodynamic process in the thermal baths. The cantilevered form of the nature centre makes manifest the excavation process and studies its effects. Its cable stayed structure evokes the energy stored in the excavation spoil, binding itself into the loose rock in order to study the regeneration of the

2 Ignasi de Solà-Morales, *Differences: Topographies of Contemporary Architecture*, edited by Sara Whiting, translated by Graham Thompson (Cambridge, MA: MIT Press, 1997), 60.

spoil mound. Public and private programme, service and gathering space weave together, overlapping in the theatre, exhibition space and café to bring together researchers and visitors.

The tunnel is the umbilical cord of neutrino observatory delivering air, water, power, and cooling. From their disparate sources in the nature centre, the systems fuse with the tunnel's basic tectonic elements in its mouth. The mouth of the tunnel is the moment of integration/disintegration, the zone where systems, flows, and movement converge/diverge. Conduit and piping runs embed themselves in the suspended tunnel deck, which also acts as membrane between fresh and exhaust airways. Exhaust air flows are integrated into the tunnel's lining – its skeleton and skin – cooling the tunnel with a pattern of hollow ribs. The pattern of ribs transposes distance and heat, punctuating the 7km journey to the observatory with a tempo that builds towards the observatory.

At the end of the tunnel and thermal loop sits the observatory. The design of the neutrino detectors fuse movement, energy and form – the circulation of visitors, the flow of heat and ultra-pure water, and the shaping of the massive detector tank and cavern. The systems and equipment are arranged like organs around the body of the detector, their presence effecting the tank and cavern form, and channelling heat and visitors around the enormous detector. In both the detector cavern and narthex, light and material are precisely tuned to dissolve perception, merging matter and energy, and evoking the subtle qualities of the neutrino matrix.

In each of the three design proposals, *Energy and Matter* shows how architecture can engage with science by broadening its scope to involve diverse disciplines, scientific concepts, and technology. What is presented here though, is an outline of how this deep involvement can unfold, emphasising the evocative, as well as the instrumental qualities of the buildings, components, systems and environments. To move the design proposals further would require detailed analysis: refinement of structural systems, and energy modelling for instance. Basic simulation software to accomplish this is accessible and can be incorporated in a detailed design process. This thesis is rooted in a belief that empowers architecture to take on these roles, and to fully engage, rather than exclude, the specialized disciplines on the periphery of architecture.

What emerges from this thesis is a broader definition of architecture, a general method and process that is rooted in an intense interest in site, technology, energy, and construction. This rigorous engagement with a project's physical, technical, and cultural environment can be applied equally to the design of a neutrino observatory or particle collider as it can be a library, or house. It also suggests that an awareness of the interconnections between buildings and their environments is both important and fruitful. Inversely, it implies that works of architecture should be thought of as systems, as well as, or perhaps instead of, objects.

*Energy and Matter* asks what role architecture can play in the design of huge contemporary structures for science. By investing in the design of a neutrino observatory, tunnel and nature centre, it brings together a variety of disciplines, ideas, and information, connecting them in a new and insightful way. The design proposals develop a fine-tuned architectural response that elicits a multivalent experience of subtle phenomena, and shows that architecture has the power to imply, unveil, and influence our understanding of the universe.

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*The above listed drawings are reproduced at one half scale in this document.*



Savoie has a varied history, having been populated, fought over, and occupied by numerous kingdoms and people: The Kingdom of the Burghundians (Scandinavian origin); The Frankish Empire (Germanic tribes); The Kingdom of Lower Burghundy and the Kingdom of Arelat (both parts of the Holy Roman Empire); and the Duchy of Savoy. Later it passed between allegiances to Italian and French powers. Finally, after a period under the rule of the Kingdom of Sardinia, in 1860, the Duchy of Savoy was annexed by France. Indeed a small minority of present day Savoyard separatists who wish to secede from France.

## Legend

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- ① Project Location  
*Col du Fréjus & Fréjus Road Tunnel*  
*Modane, France – Bardonecchia, Italy*
- ② Grenoble, France
- ③ Lyon, France
- ④ Chambéry, France
- ⑤ Albertville, France
- ⑥ Geneva, Switzerland
- ⑦ CERN (Meyrin, Switzerland)
- ⑧ Bern, Switzerland
- ⑨ Turin, Italy
- ⑩ Milan, Italy
- ⑪ Genoa, Italy

Opposite: Drawing 0.1  
Cottian Alps Region



FRANCE

SWITZERLAND

ITALY

Settlements, transportation and energy infrastructure line the alpine valleys. Roads and rail lines follow the valley floor connecting small towns, rail yards, and a transonic wind tunnel facility at Avrieux. Aqueducts and power lines connect hydroelectric dams and reservoirs. Gondolas and lifts climb up from the ski stations at Valfréjus and La Norma. The borders between France and Italy, and between the communes follow the ridge lines of the mountains.

### Legend

①	Fréjus Railway Tunnel
②	Fréjus Road Tunnel
③	Fréjus Safety Tunnel
④	Neutrino Observatory Tunnel
⑤	Fréjus Nature Centre
⑥	Neutrino Observatory
—————	Motorways & Highways
- - - - -	Motorway Tunnel
—————	Roadways
- - - - -	Paths & Trails
+++++	Railway
++ ++ ++ ++ +	Railway Tunnel
■   ■   ■   ■	International Border
— — — — —	Commune Border
■	La Vanoise National Park
▨	Nat. Park Peripheral Zone

Opposite: Drawing 0.2  
Context Plan: Built Environment







The peaks and ridges of the Cottian Alps form the border between France and Italy, dividing La Vallée de le Maurienne from La Val di Susa.

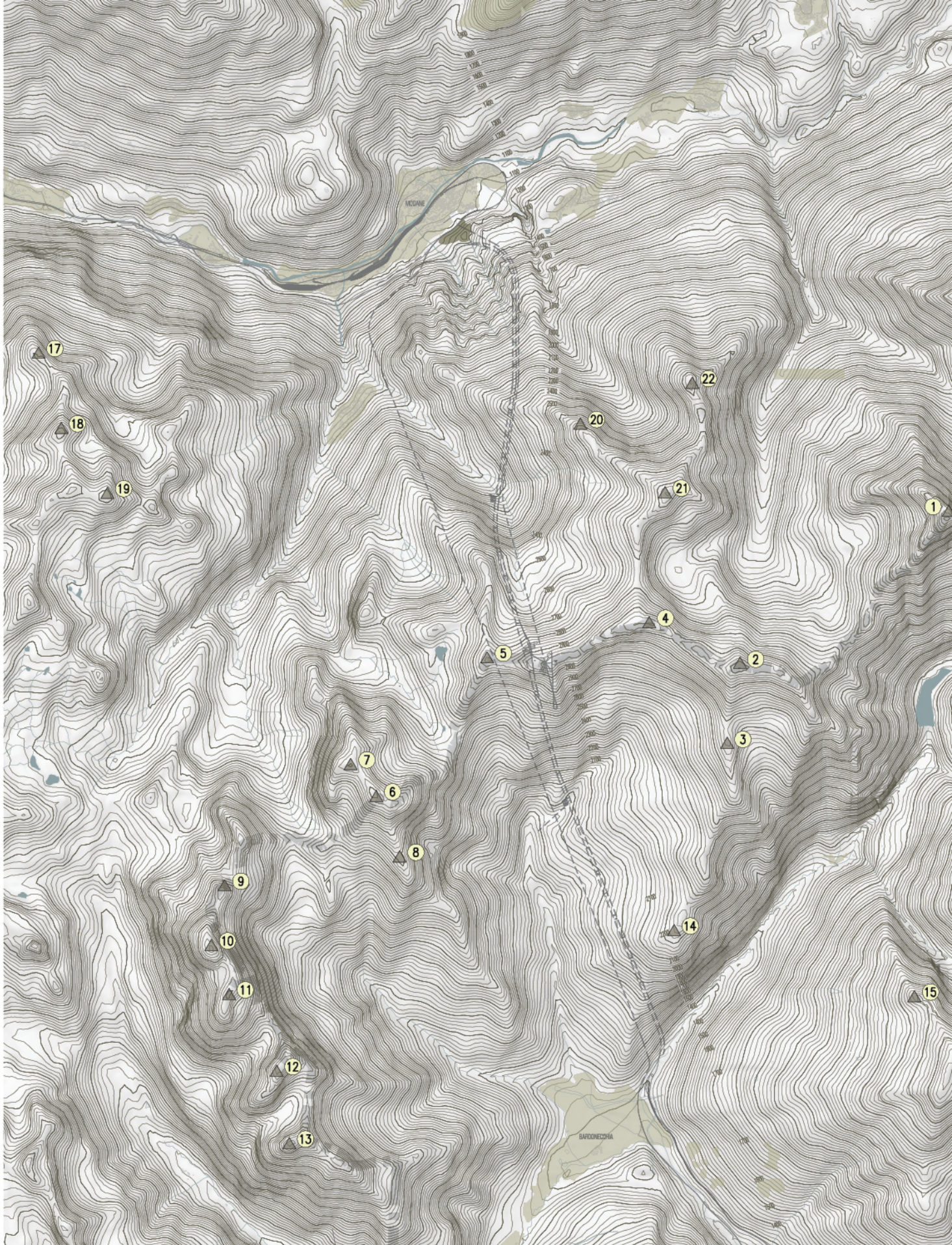
#### Legend

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①	Aiguille de Scolette	3506m
②	Pointe de Peumont	3171m
③	Cime du Grand Vallon	3129m
④	Rocchia Verde	2852m
⑤	Pointe de Fréjus	2934m
⑥	Punta Nera	3046m
⑦	Le Grand Argentier	3042m
⑧	Cima del Blave	2667m
⑨	Cime de la Planette	3103m
⑩	Roche Bernaude	3222m
⑪	Punta Baldassarre	3156m
⑫	Punta Melchiorre	2952m
⑬	Pointe Gaspard	2807m
⑭	Punta Melmise	2310m
⑮	Testa del Ban	2652m
⑯	Monte Jafferau	2815m
⑰	Roche Fleurie	2573m
⑱	Pic Noir	2874m
⑲	Pointe des Sarrasins	2963m
⑳	Mont Rond	2272m
㉑	Le Belle Plinier	3086m
㉒	La Norma	2918m

Opposite: Drawing 0.3  
Context Plan: Topography







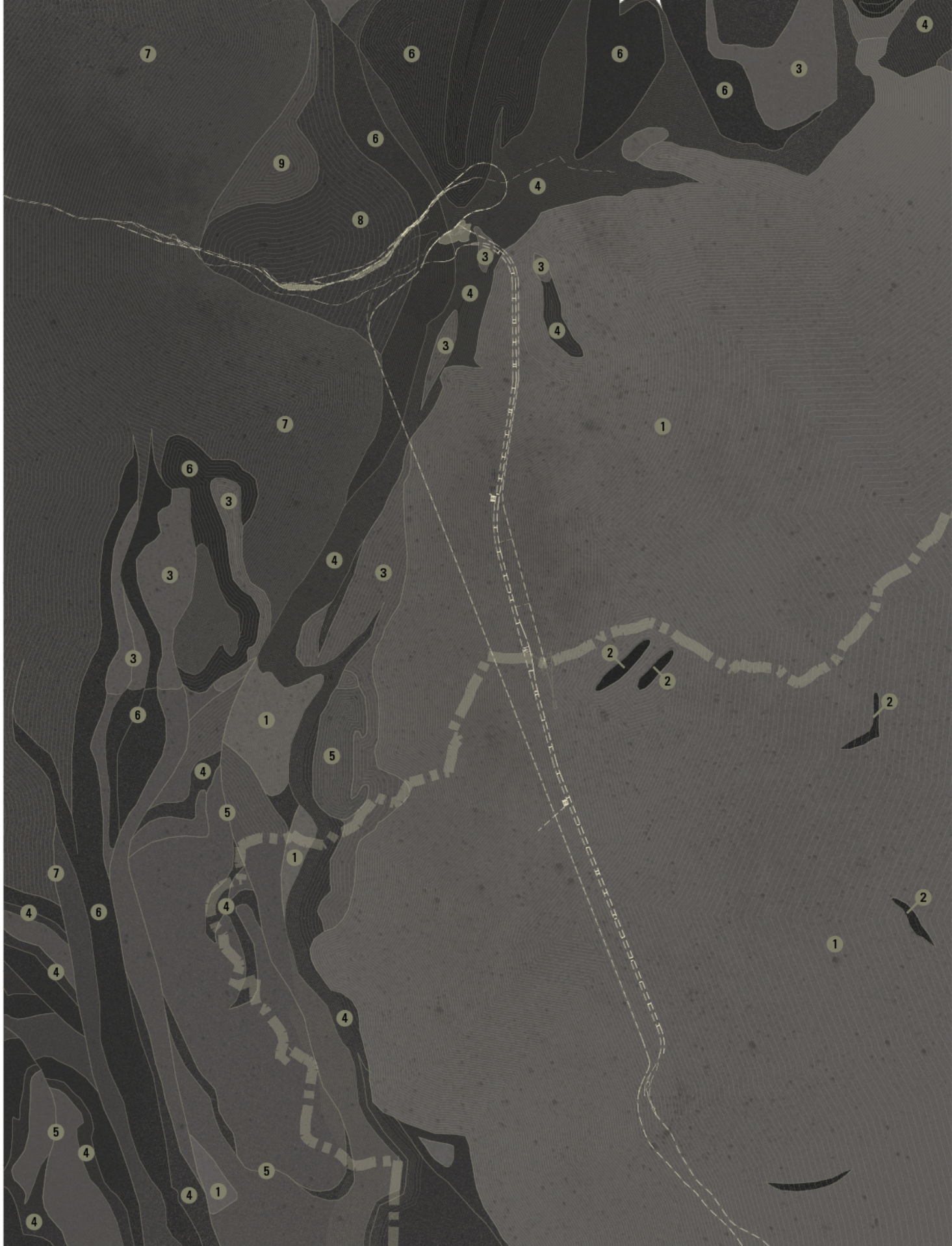
This region of the Cottian Alps is composed of metamorphic rock - layered schists, limestones, and sandstones made of sediments laid down on the bottom ancient oceans. These striated sedimentary rocks were transformed into their present form by the pressure and heat as tectonic plates collided, heaving them into the wrinkled the nappes of rock. Glaciers and erosion scraped the surface of the sheets of rocks unevenly, leaving behind a marbled disposition of geological formations.

### Legend

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- ① Lustrous Schist
- ② Gabbro
- ③ Limestone
- ④ Gypsum & Cargneules
- ⑤ Dolomite
- ⑥ Quarzite
- ⑦ Sandstone & Bituminous Schist
- ⑧ Gneiss
- ⑨ Conglomerate Schist

Opposite: Drawing 0.4  
Context Plan: Geology



This map of avalanches in the vicinity of Modane is taken from La Carte de Localisation des Phénomènes d'Avalanche (CLPA). The CLPA maps are a composite of collected physical evidence of avalanches, the interpretation of aerial photography, and terrain analysis that inventories the extents of historical avalanches. It shows the significant role avalanches play in the transformation of surface geology and ecology in this area of the Cottian Alps.

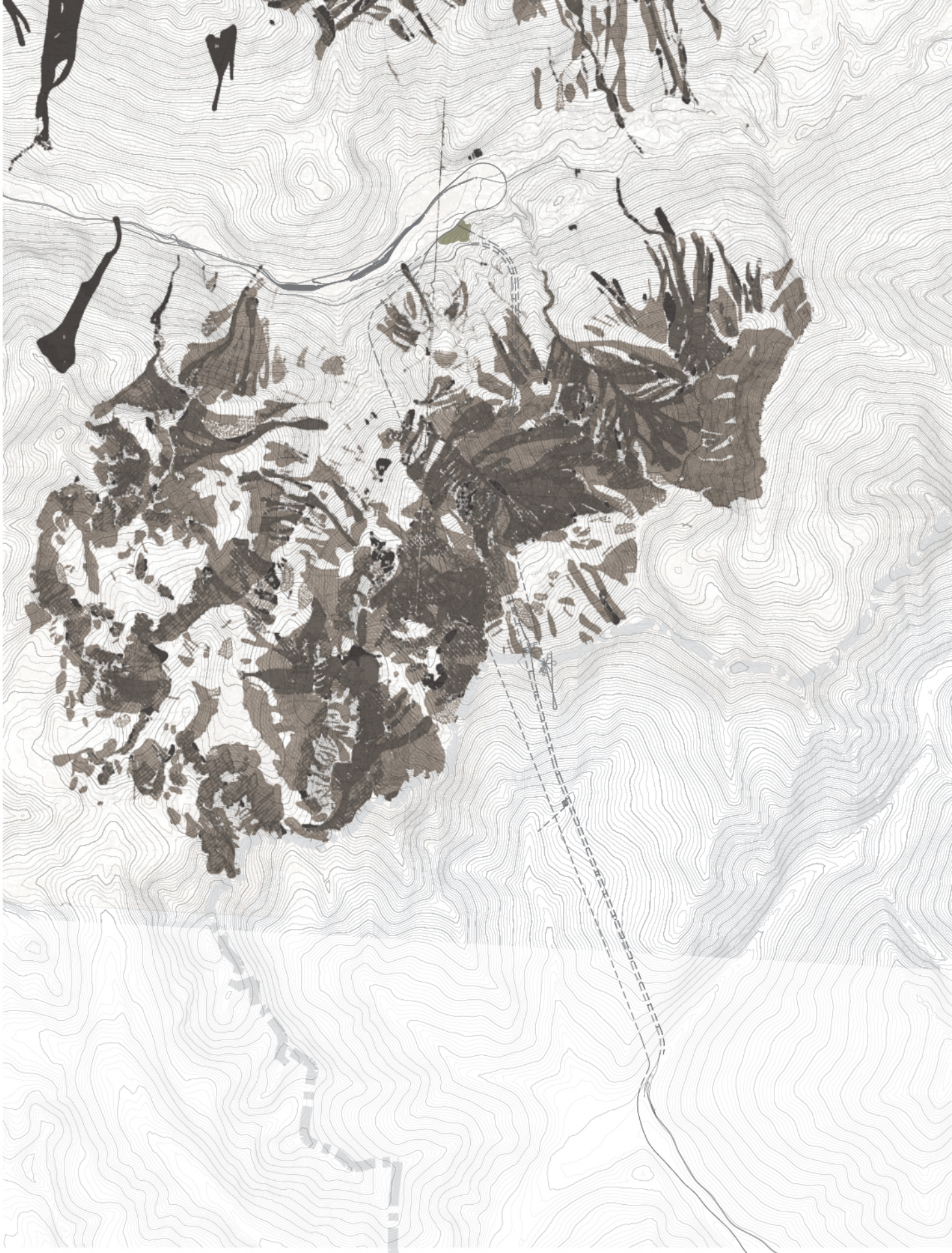
#### **Legend**

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- Photo-interpretation & Terrain Analysis
- Collection Of Physical Evidence
- Combination Of Interpretive & Physical Evidence

Opposite: Drawing 0.5  
Context Plan: Avalanche







Prevailing winds, weather systems, and air currents driven by mountain topography and urban settlement all overlap and interact in the atmosphere above and around Modane. This simulation traces the force and movement of these fields, visualizing the high and low pressure vortices, eddies, and varying flows that emerge as the fields meet.

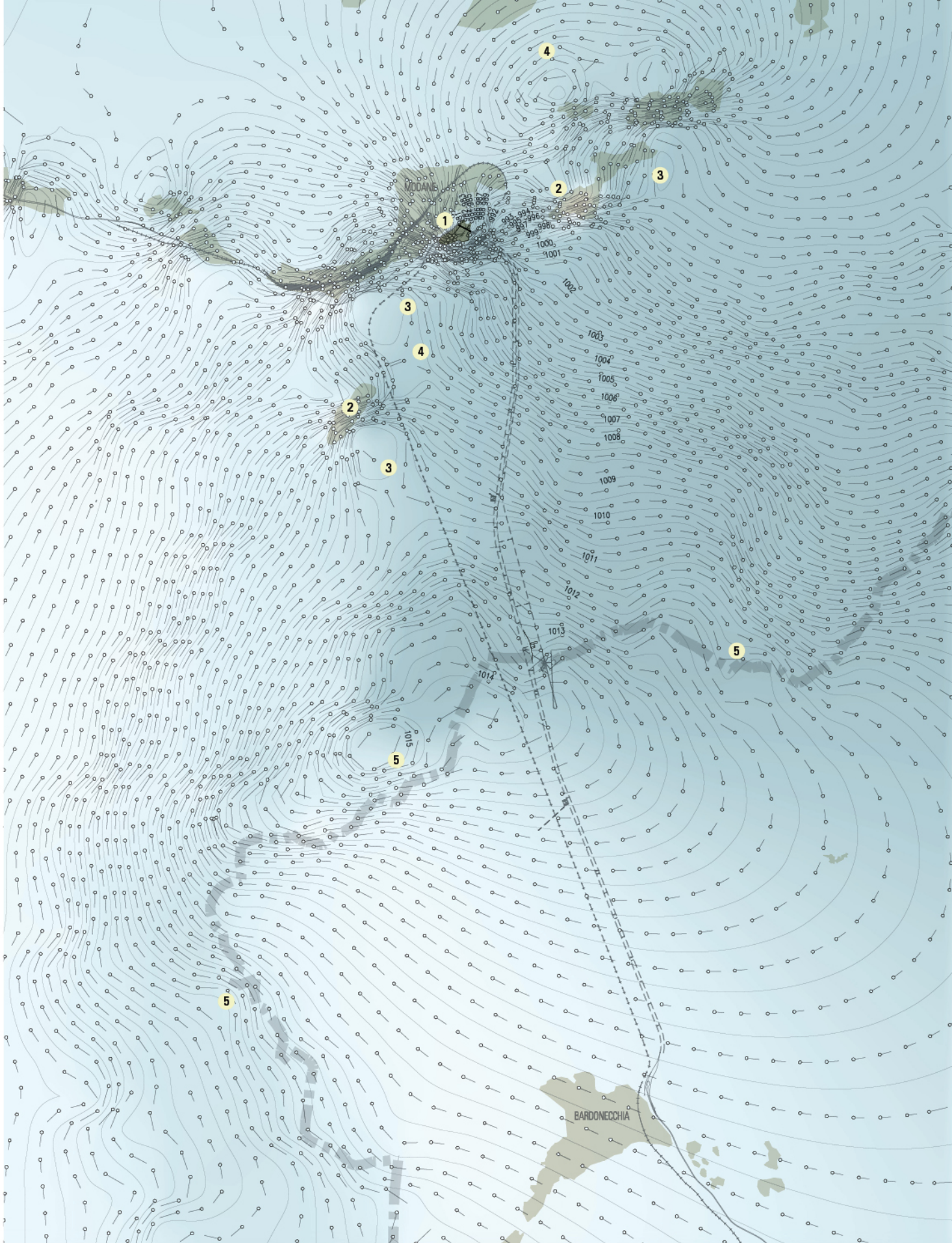
### Legend

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- ① Low pressure system created by Fréjus Nature Centre and Access Tunnel thermal dissipation
- ② Low pressure system created urban areas
- ③ Resultant high pressure region generated by convection downdrafts
- ④ Interaction of prevailing north west winds with low pressure systems (counter clockwise air flow) and high pressure systems (clockwise air flows) to create patterns of varying wind intensity
- ⑤ Turbulence and eddies form as lifting warmed surface air on mountain slopes and prevailing winds meet along the ridges

Opposite: Drawing 0.6  
Context Plan: Meteorology





MODANE

BARDONECCHIA

A Series of tunnel perforate this regions of the Cottain Alps – the Fréjus or Mont Cenis Railway tunnel (1857-1871, 12.2km), the Fréjus Motorway tunnel (1975 -1978, 12.8 km), and the Fréjus Road Tunnel safety tunnel (2006-2017, 12.8km). Each operates at full capacity, and so to faciliate the construction and operation of a massive new underground neutrino observatory, a fourth tunnel is planned to reach 7km into the thickest part of the mountain.

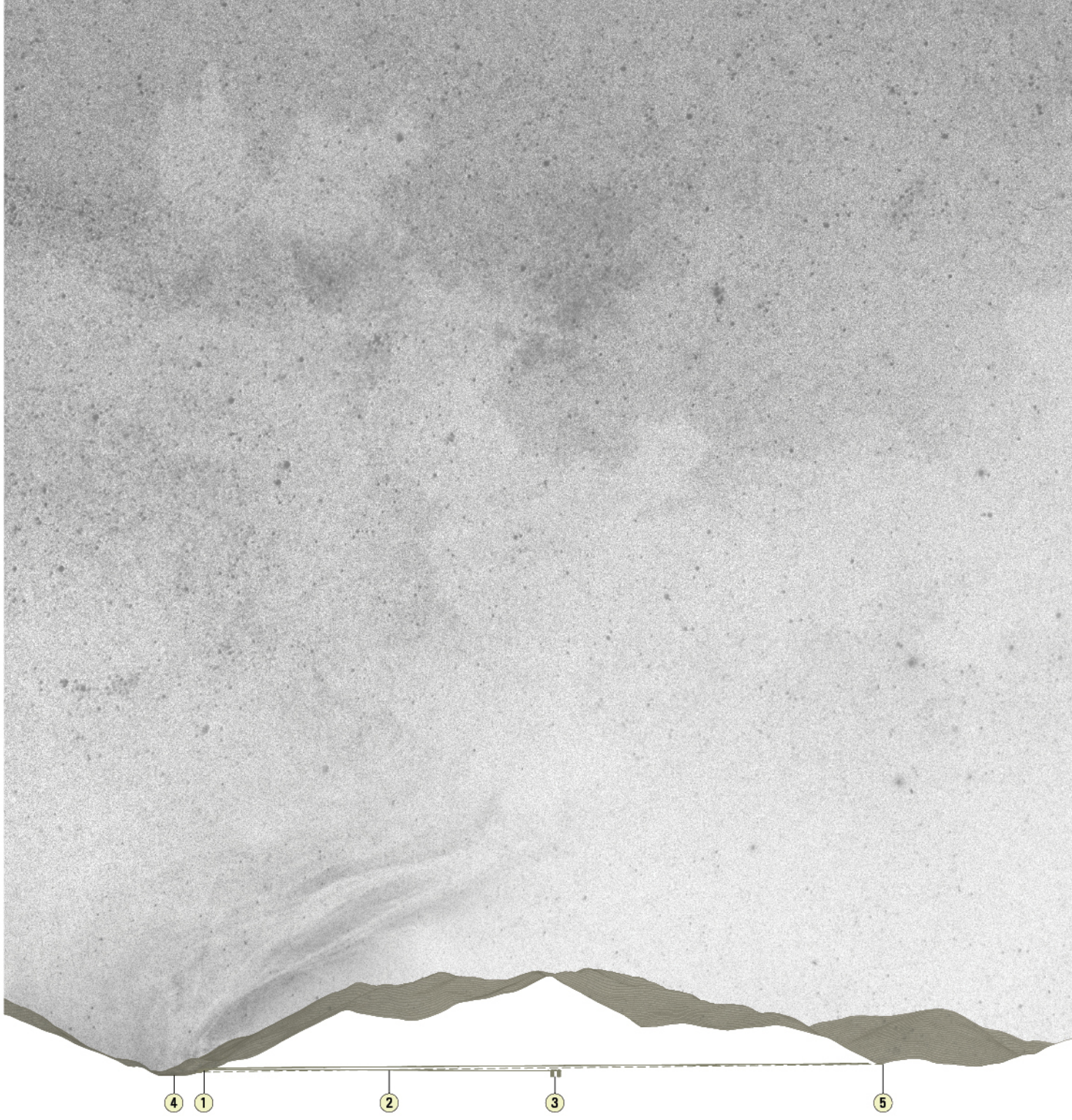
#### Legend

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- ① Fréjus Nature Centre & Spoil Mound
- ② Access Tunnel
- ③ Neutrino Observatory
- ④ Modane, France
- ⑤ Bardonecchia, Italy

Opposite: Drawing 0.7  
Context Section





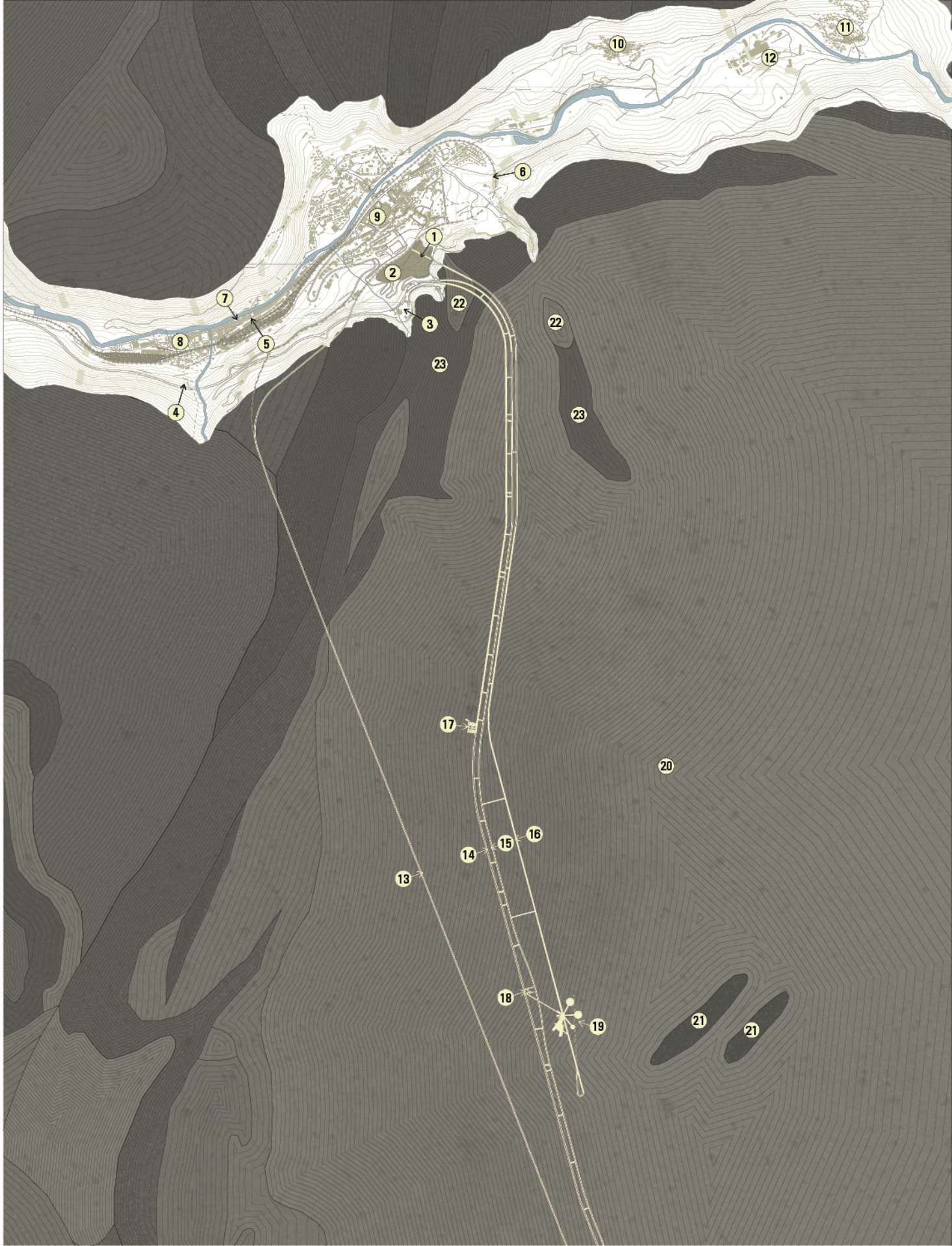
## Legend

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- ① Fréjus Nature Centre
- ② Excavaton Spoil Mound
- ③ Fréjus Road Tunnel Toll Station & Vehicle Heat Detectors
- ④ Highway A43 - Autoroute De La Maurienne
- ⑤ Modane Tgv Train Trainstation
- ⑥ Helical Railway Ramp Viaducts And Tunnels
- ⑦ Arc River
- ⑧ Fourneaux
- ⑨ Modane
- ⑩ Villarodin-bourget
- ⑪ Avrieux
- ⑫ Onera Transonic Wind Tunnel Facility
- ⑬ Fréjus (Mont Cenis) Railway Tunnel
- ⑭ Fréjus Road Tunnel
- ⑮ Safety Tunnel
- ⑯ Neutrino Observatory Access Tunnel
- ⑰ Ventilation Plant
- ⑱ Laboratoire Souterrain de Modane (LSM)
- ⑲ Neutrino Observatory
- ⑳ Lustrous Schist
- ㉑ Gabbro
- ㉒ Limestone
- ㉓ Gypsum & Cargneules

Opposite: Drawing 1.0  
Overall Site Plan





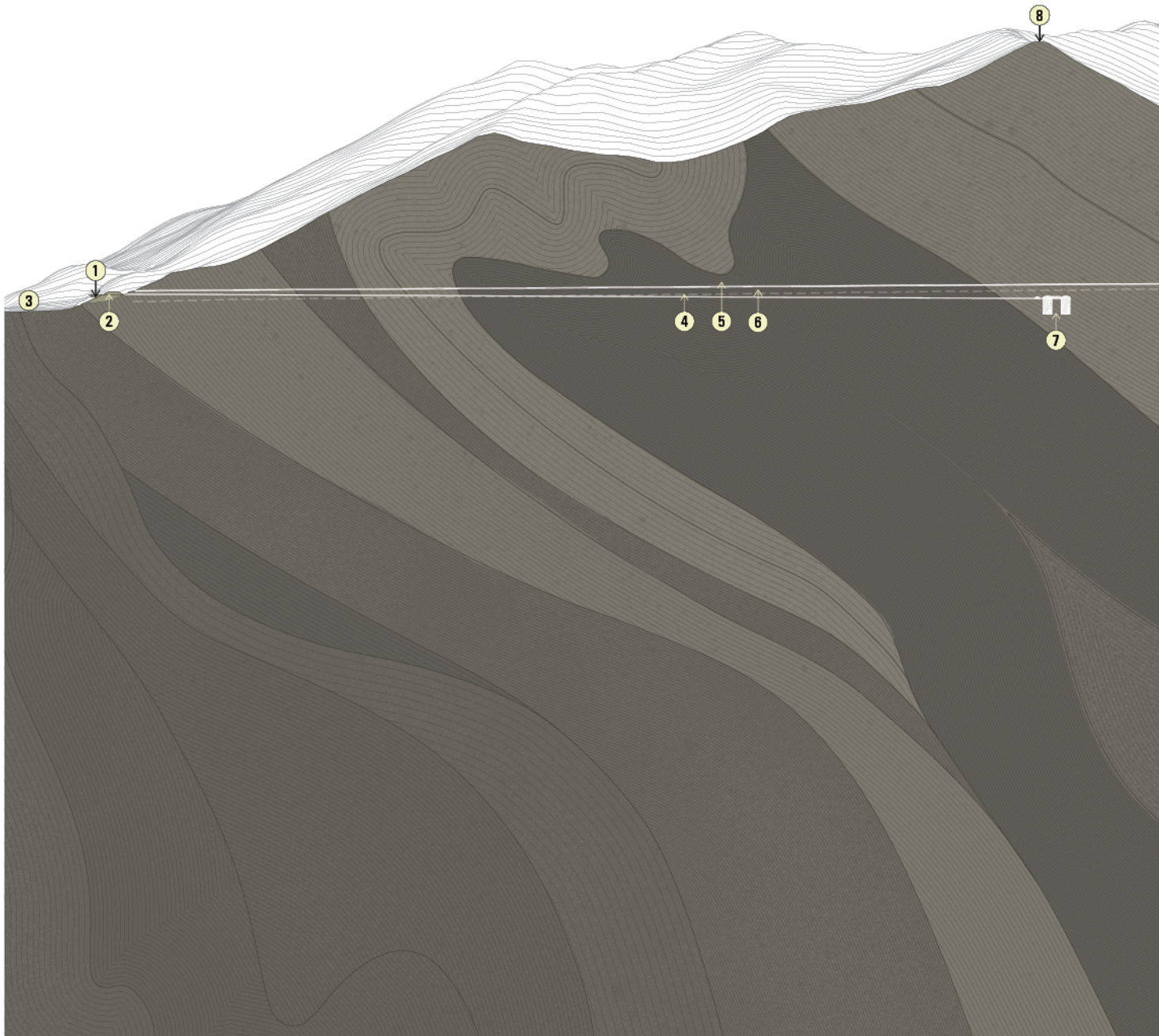
## Legend

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- ① Fréjus Nature Centre
- ② Excavaton Spoil Mound
- ③ Modane
- ④ Neutrino Observatory Access Tunnel
- ⑤ Fréjus Road & Safety Tunnels
- ⑥ Fréjus (Mont Cenis) Rail Tunnel
- ⑦ Neutrino Observatory
- ⑧ Col du Fréjus - Border of France and Italy

Opposite: Drawing 1.1  
Overall Site Section









# FRÉJUS NATURE CENTRE

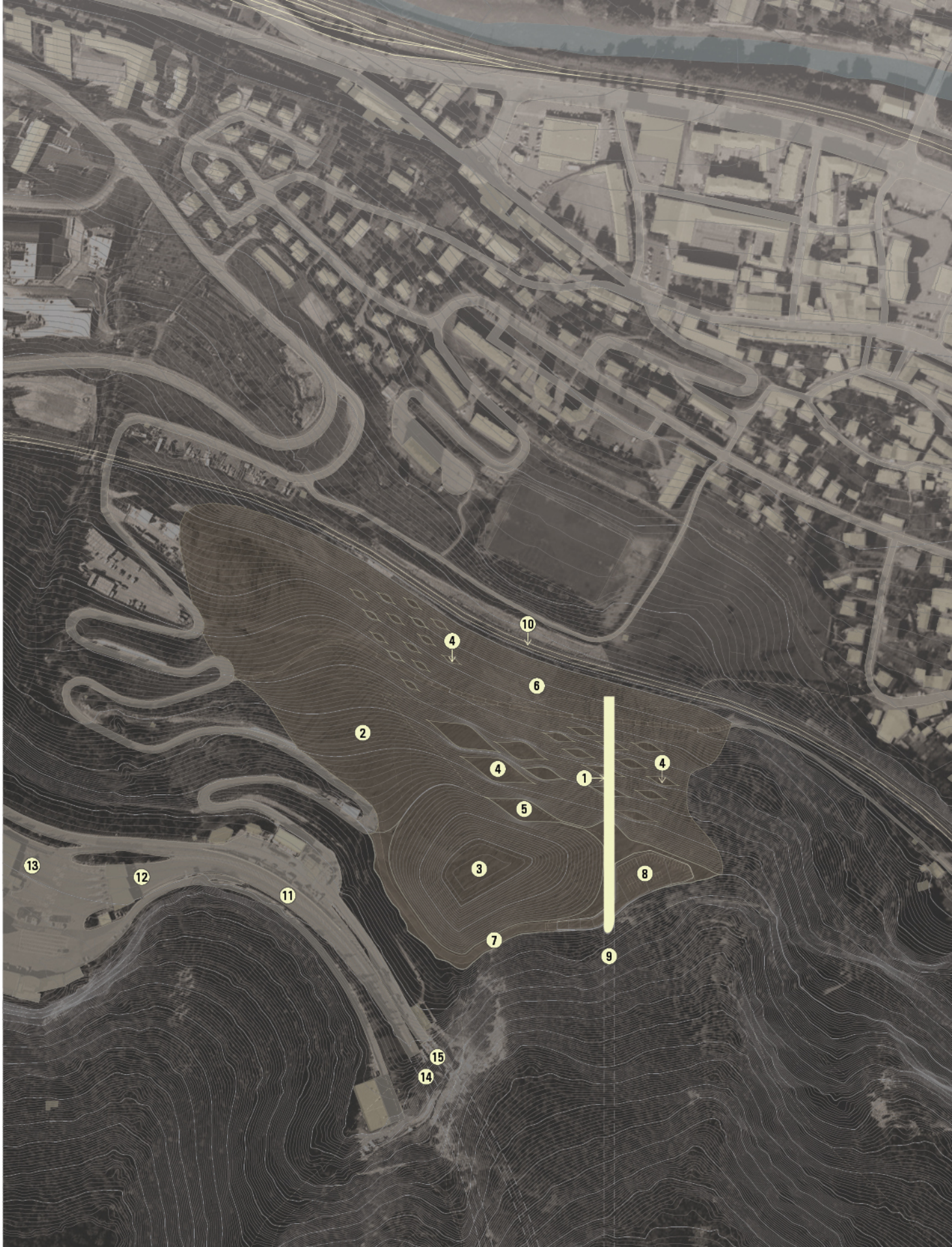
## Legend

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- ① Fréjus Nature Centre
- ② Spoil Mound
- ③ Upper Spoil Mound
- ④ Terraces
- ⑤ Main Lookout Terrace
- ⑥ Walking Trail
- ⑦ Nature Centre Access Road
- ⑧ Parking Area
- ⑨ Access Tunnel to Neutrino Observatory
- ⑩ Railway Line - Tgv, Passenger & Freight
- ⑪ Highway A43 - Autoroute de la Maurienne
- ⑫ Toll Station
- ⑬ Fire Detector & Thermal Scanner
- ⑭ Fréjus Road Tunnel
- ⑮ Safety Tunnel

Opposite: Drawing 2.0  
Fréjus Nature Centre  
Site Plan





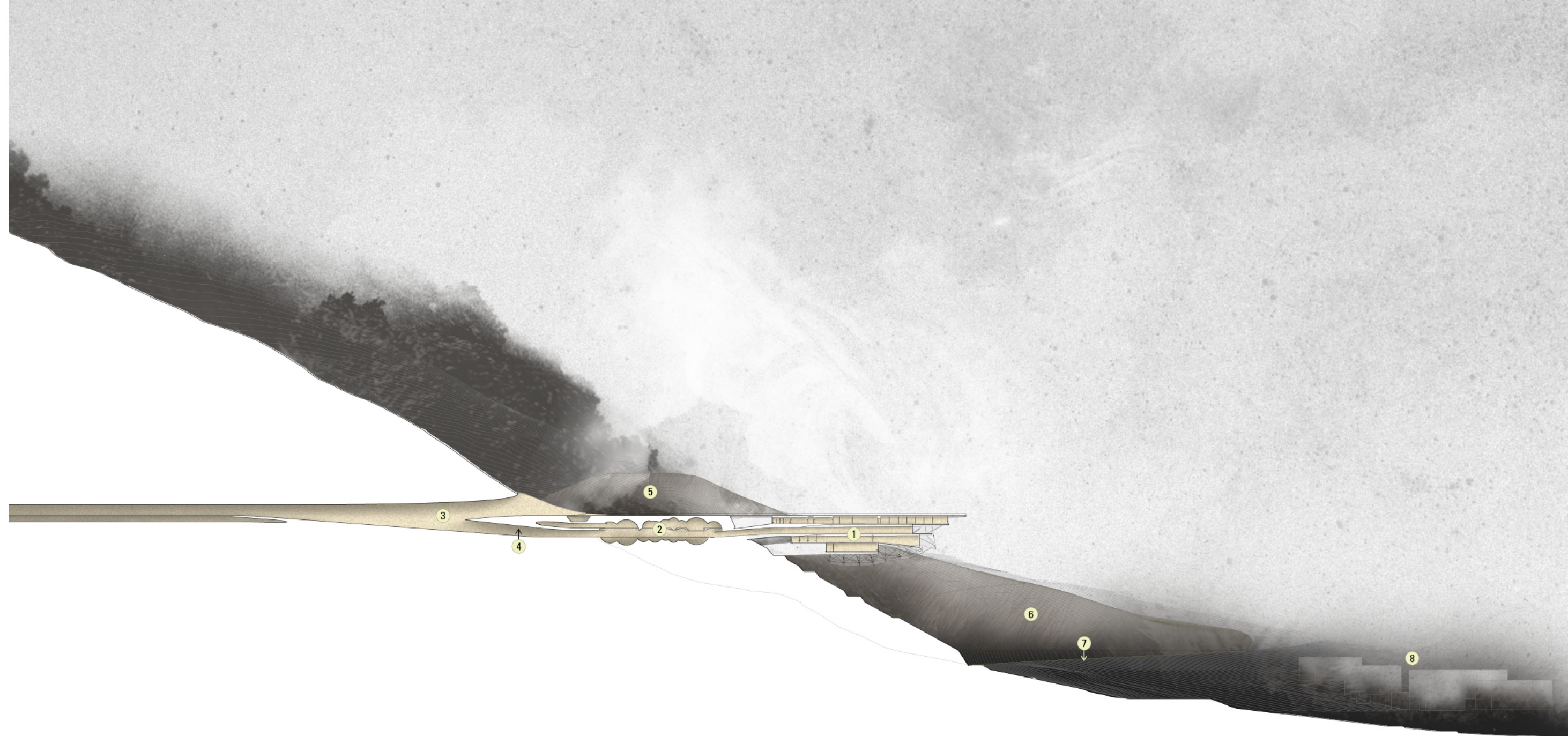


## Legend

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- ① Fréjus Nature Centre
- ② Thermal Baths
- ③ Tunnel Mouth
- ④ Observatory Rail Access
- ⑤ Upper Spoil Mound
- ⑥ Spoil Mound
- ⑦ TGV Railway track
- ⑧ City of Modane

Opposite: Drawing 2.1  
Fréjus Nature Centre  
Site Section





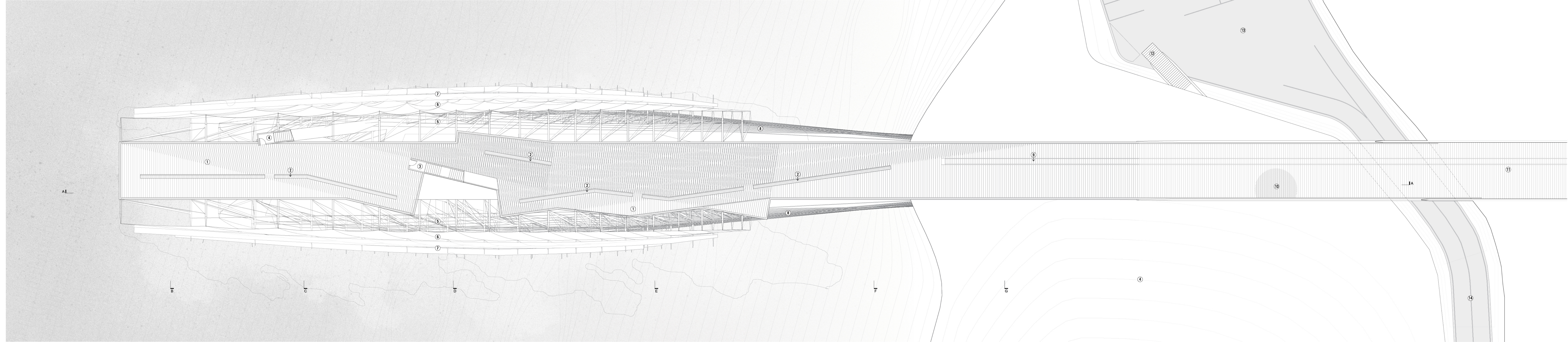
### Legend

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- ① Observation Deck
- ② Benches
- ③ Public Stair
- ④ Staff & Reseracher Stair
- ⑤ Structural Matrix
- ⑥ Cooling Mesh
- ⑦ Exterior Maintenance Catwalks (below)
- ⑧ Main Cable Stays
- ⑨ Railway Track
- ⑩ Ventiation Louvres to Thermal Transfer Station Below
- ⑪ Tunnel Mouth
- ⑫ Main Entrance Stair
- ⑬ Parking Area
- ⑭ Access Road

Opposite: Drawing 3.0  
Fréjus Nature Centre  
Plan: Observation Deck









## Legend

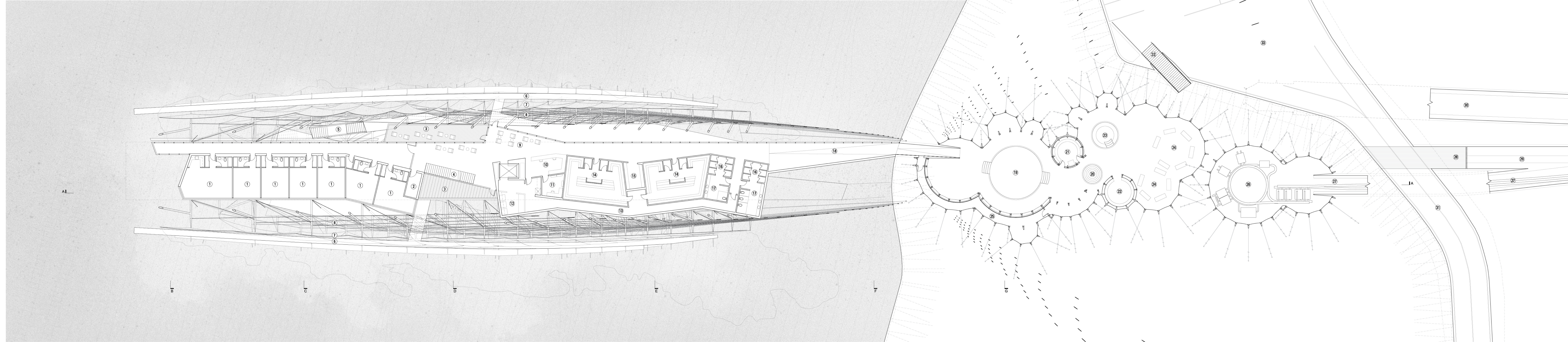
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- ① Hotel Room
- ② Housekeeping
- ③ Terrace
- ④ Public Stair
- ⑤ Staff & Researcher Stair
- ⑥ Exterior Maintenance Catwalk
- ⑦ Cooling Mesh
- ⑧ Structural Matrix
- ⑨ Lounge Waiting Area
- ⑩ Thermal Bath Reception
- ⑪ Office
- ⑫ Laundry
- ⑬ Service Corridor
- ⑭ Locker Room
- ⑮ Grooming Area
- ⑯ Showers
- ⑰ Washroom
- ⑱ Connection to Thermal Baths  
(Hollow Structural Concrete Strut)
- ⑲ Warm Bath (32°)
- ⑳ Cold Bath (12°)
- ㉑ Sauna
- ㉒ Steam Room
- ㉓ Hot Bath (42°)
- ㉔ Resting Area
- ㉕ Service Corridor
- ㉖ Thermal Transfer Loop
- ㉗ Services Tunnel
- ㉘ Exhaust Air Vent
- ㉙ Exhaust Air Tunnel
- ㉚ Fresh Air Tunnel
- ㉛ Access Road
- ㉜ Main Entrance Stair
- ㉝ Parking Area
- ㉞ Helical Tie-back
- ㉟ Cable Stay
- ㊱ Excavation Spoil
- ㊲ Geotextile Slope Stabilization
- ㊳ Rock Face

Following Pages: Drawing 3.1  
Fréjus Nature Centre  
Plan: Hotel and Thermal Baths











## Legend

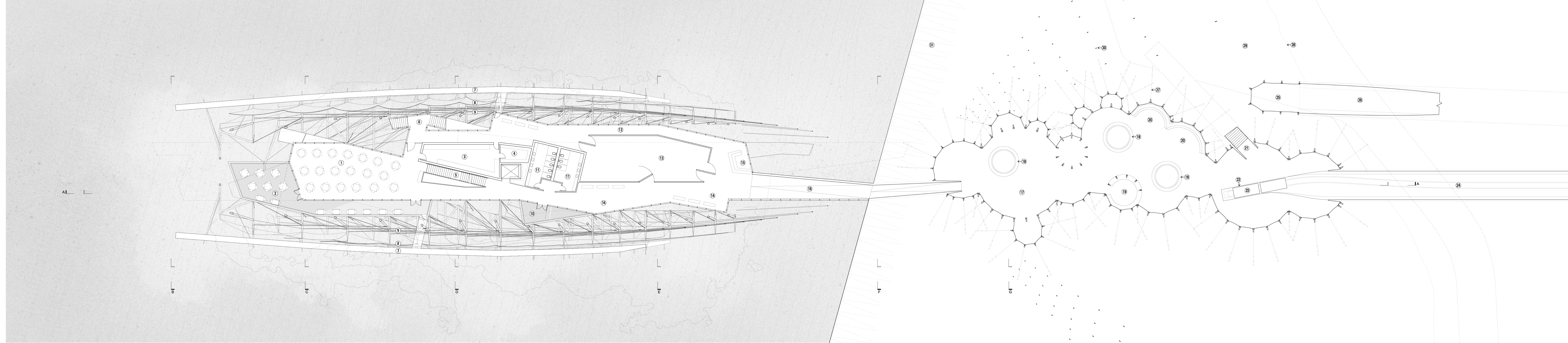
---

- ① Café
- ② Café Terrace
- ③ Kitchen
- ④ Kitchen Storage
- ⑤ Public Stair
- ⑥ Staff & Researcher Stair
- ⑦ Exterior Maintenance Catwalk
- ⑧ Cooling Mesh
- ⑨ Structural Matrix
- ⑩ Terrace
- ⑪ Washroom
- ⑫ Staff & Researcher Corridor
- ⑬ Exhibition Space
- ⑭ Lounge/Event Crush Space
- ⑮ Main Reception/Information Desk
- ⑯ Entrance Bridge  
(Hollow Structural Concrete Strut)
- ⑰ Entrance Caverns
- ⑱ Bench
- ⑲ Information Desk
- ⑳ Locker Area
- ㉑ Main Entrance Stair
- ㉒ Sunken Train Platform
- ㉓ Electric Passenger & Freight Railway
- ㉔ Train Tracks
- ㉕ Fresh Air Grille (Within Spoil Rock)
- ㉖ Fresh Air Tunnel
- ㉗ Helical Tie-back
- ㉘ Rock Face
- ㉙ Excavation Spoil
- ㉚ Cable Stay
- ㉛ Geotextile Slope Stabilization

Following Pages: Drawing 3.2  
Fréjus Nature Centre  
Plan: Entrance, Exhibition, and Café











## Legend

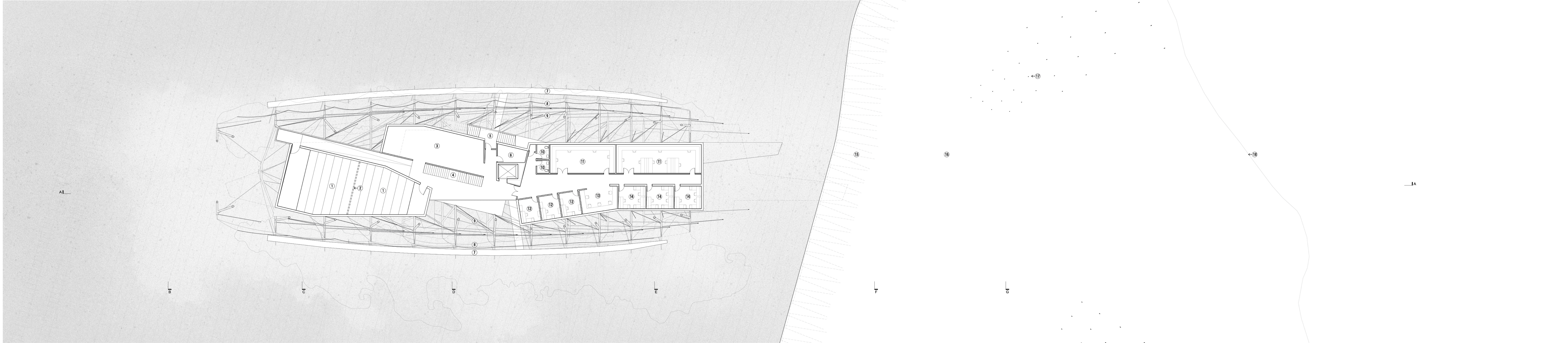
---

- ① Theatre (Tiered Classrooms)
- ② Moveable Dividing Wall
- ③ Multi-purpose Space
- ④ Public Stair
- ⑤ Staff & Researcher Stair
- ⑥ Storage
- ⑦ Exterior Maintenance Catwalk
- ⑧ Cooling Mesh
- ⑨ Structural Matrix
- ⑩ Washroom
- ⑪ Laboratory
- ⑫ Reseracher Office
- ⑬ Open Work Area (Visiting Reserachers)
- ⑭ Group Office
- ⑮ Geotextile Slope Stabilization
- ⑯ Excavation Spoil
- ⑰ Cable Stay
- ⑱ Rock Face

Following Pages: Drawing 3.3  
Fréjus Nature Centre  
Plan: Theatre and Research Offices











## Legend

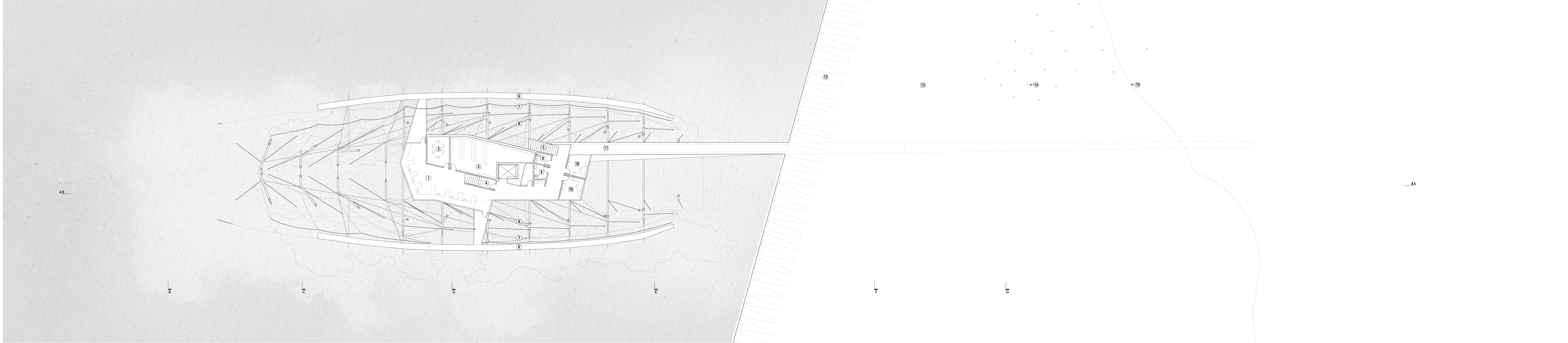
---

- ① Nature Centre Administration Area
- ② Meeting Room
- ③ Sample Storage & Archives
- ④ Public Stair
- ⑤ Staff & Researcher Stair
- ⑥ Exterior Maintenance Catwalk
- ⑦ Cooling Mesh
- ⑧ Structural Matrix
- ⑨ Washroom
- ⑩ Nature Centre Administration Office
- ⑪ Service Connections  
(Hollow Structural Concrete Strut)
- ⑫ Geotextile Slope Stabilization
- ⑬ Excavation Spoil
- ⑭ Cable Stay
- ⑮ Rock Face

Following Pages: Drawing 3.4  
Fréjus Nature Centre  
Plan: Administration











## Legend

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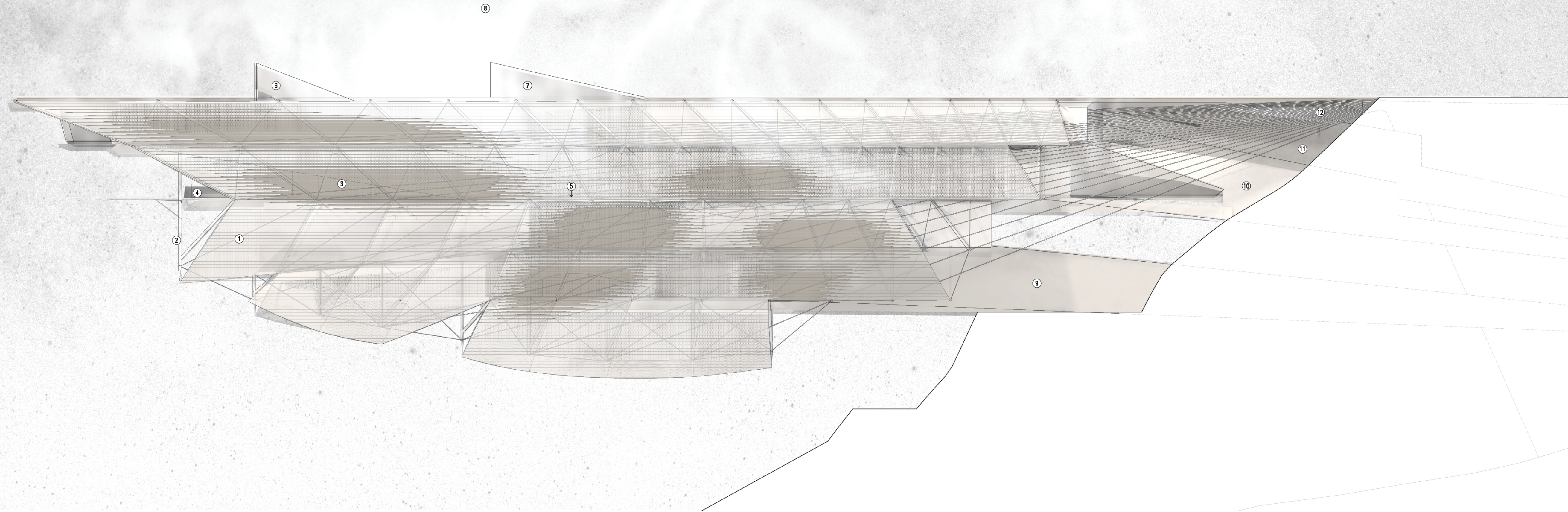
- ① Cooling Mesh
- ② Structural Matrix
- ③ Mesh Opening
- ④ Café Terrace
- ⑤ Exterior Maintenance Catwalk
- ⑥ Staff & Researcher Stair (beyond)
- ⑦ Public Stair (beyond)
- ⑧ Vapour Plumes
- ⑨ Service Strut
- ⑩ Entrance Strut
- ⑪ Thermal Bath Strut
- ⑫ Cable Stay Bundle

Following Pages: Drawing 4.0  
Fréjus Nature Centre  
South Elevation















## Legend

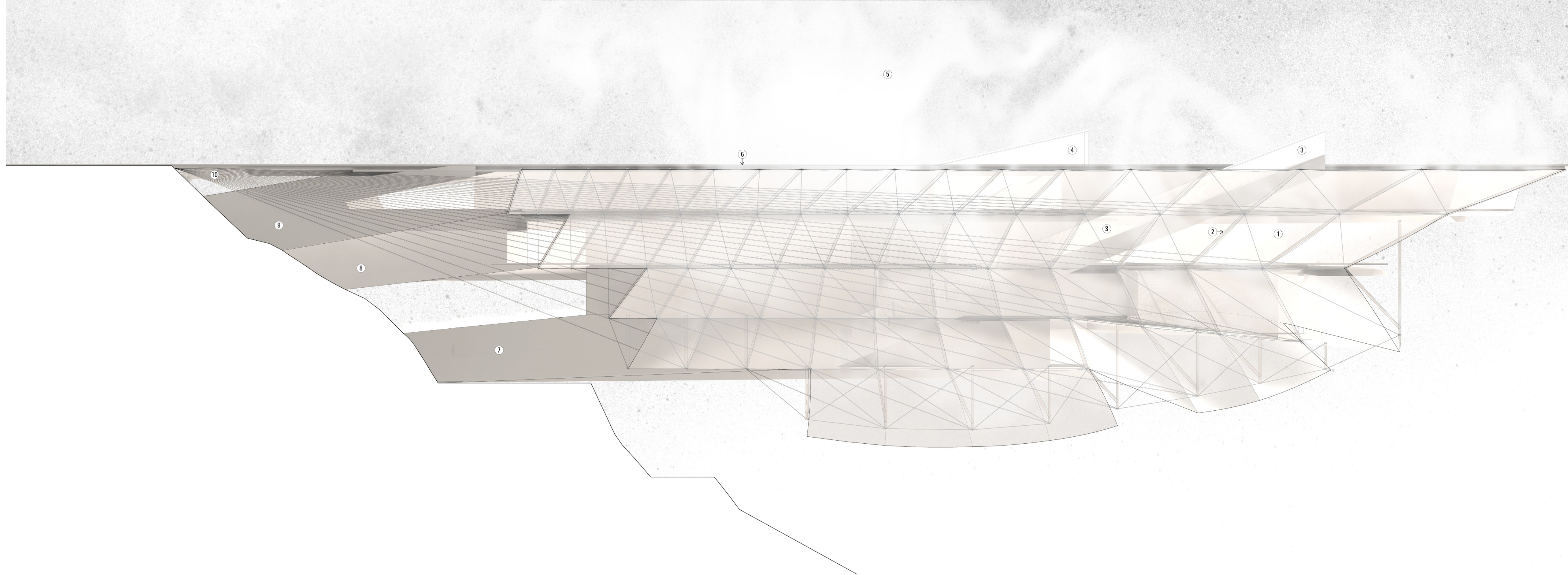
---

- ① Cooling Mesh
- ② Structural Matrix
- ③ Staff & Researcher Stair (beyond)
- ④ Public Stair (beyond)
- ⑤ Vapour Plumes
- ⑥ Observation Deck
- ⑦ Service Strut
- ⑧ Entrance Strut
- ⑨ Thermal Bath Strut
- ⑩ Cable Stay Bundle

Following Pages: Drawing 4.1  
Fréjus Nature Centre  
North Elevation

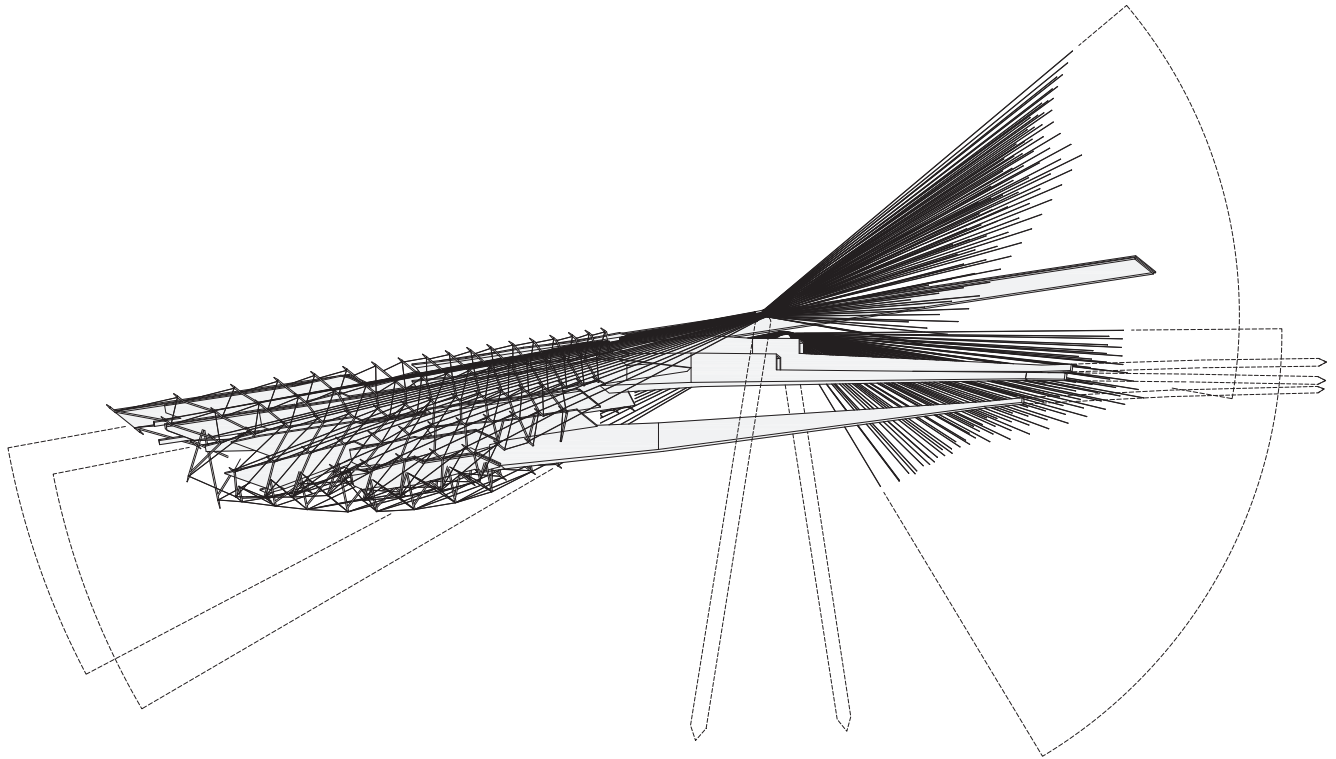












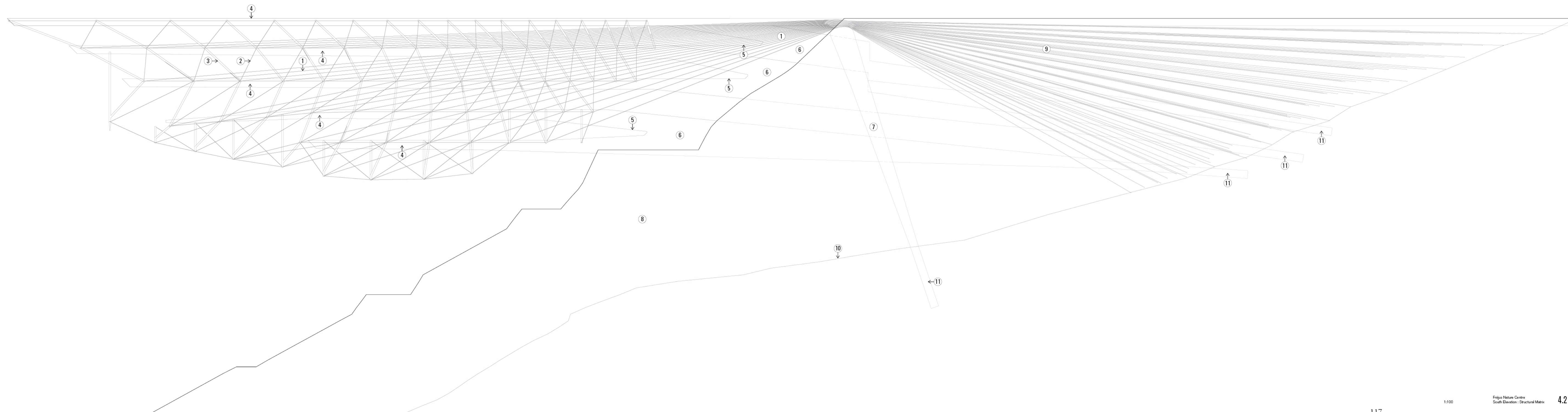
### Legend

- ① Cable Stay Network
- ② Matrix - Steel Cable Tension Members
- ③ Matrix - Steel Tube Compression Members
- ④ Floor Platform - Precast Concrete Box Girders
- ⑤ Merging of Box Girders into Compressive Struts
- ⑥ Hollow Structural Concrete Struts (Movement & Services)
- ⑦ Concrete Pylon
- ⑧ Excavation Spoil
- ⑨ Cable Anchoring in Spoil (helical anchor plates omitted for clarity)
- ⑩ Rock Face
- ⑪ Strut Socketted into Rock

Following Pages: Drawing 4.2  
Fréjus Nature Centre  
South Elevation: Structural Matrix









## Legend

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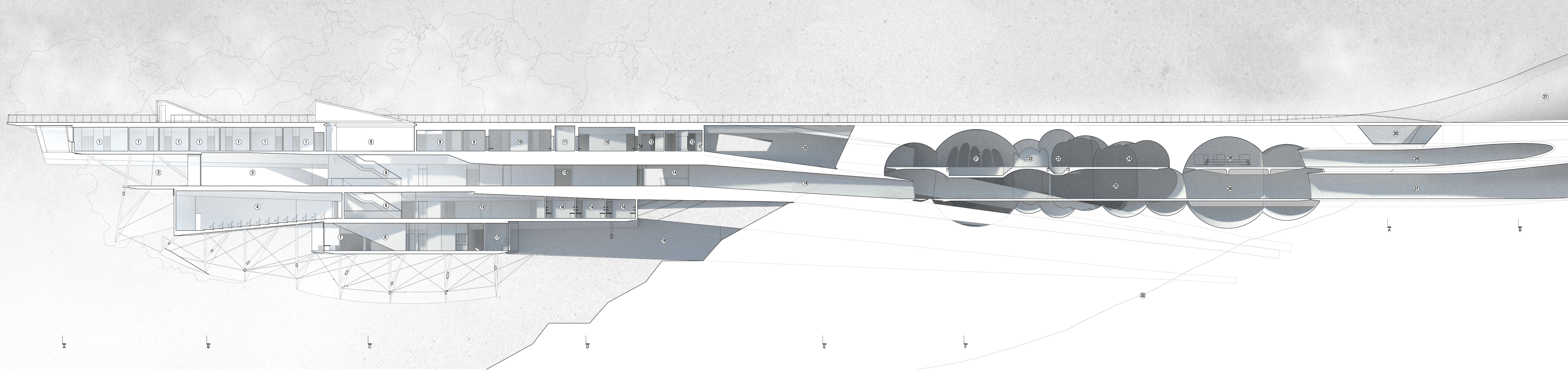
- ① Hotel Room
- ② Café Terrace
- ③ Café
- ④ Theatre/Classrooms
- ⑤ Terrace
- ⑥ Public Stair
- ⑦ Nature Centre Administration
- ⑧ Thermal Bath Reception
- ⑨ Office
- ⑩ Locker Room
- ⑪ Grooming Area
- ⑫ Washroom
- ⑬ Corridor (Exhibition Space Beyond)
- ⑭ Main Reception & Information Desk
- ⑮ Corridor (Laboratory Beyond)
- ⑯ Researcher Office
- ⑰ Nature Centre Office
- ⑱ Service Connections (Hollow Structural Concrete Strut)
- ⑲ Entrance Connection (Hollow Structural Concrete Strut)
- ⑳ Thermal Bath Connection (Hollow Structural Concrete Strut)
- ㉑ Warm Bath
- ㉒ Sauna (beyond)
- ㉓ Hot Bath
- ㉔ Resting Area
- ㉕ Entrance Caverns, Reception & Lockers
- ㉖ Electric Tunnel Railway Platform
- ㉗ Railway Tunnel
- ㉘ Thermal Transfer Loop & Equipment
- ㉙ Services Tunnel
- ㉚ Access Road Underpass
- ㉛ Tunnel Mouth
- ㉜ Rock Face

Following Pages: Drawing 5.0  
Fréjus Nature Centre  
Longitudinal Section















## Legend

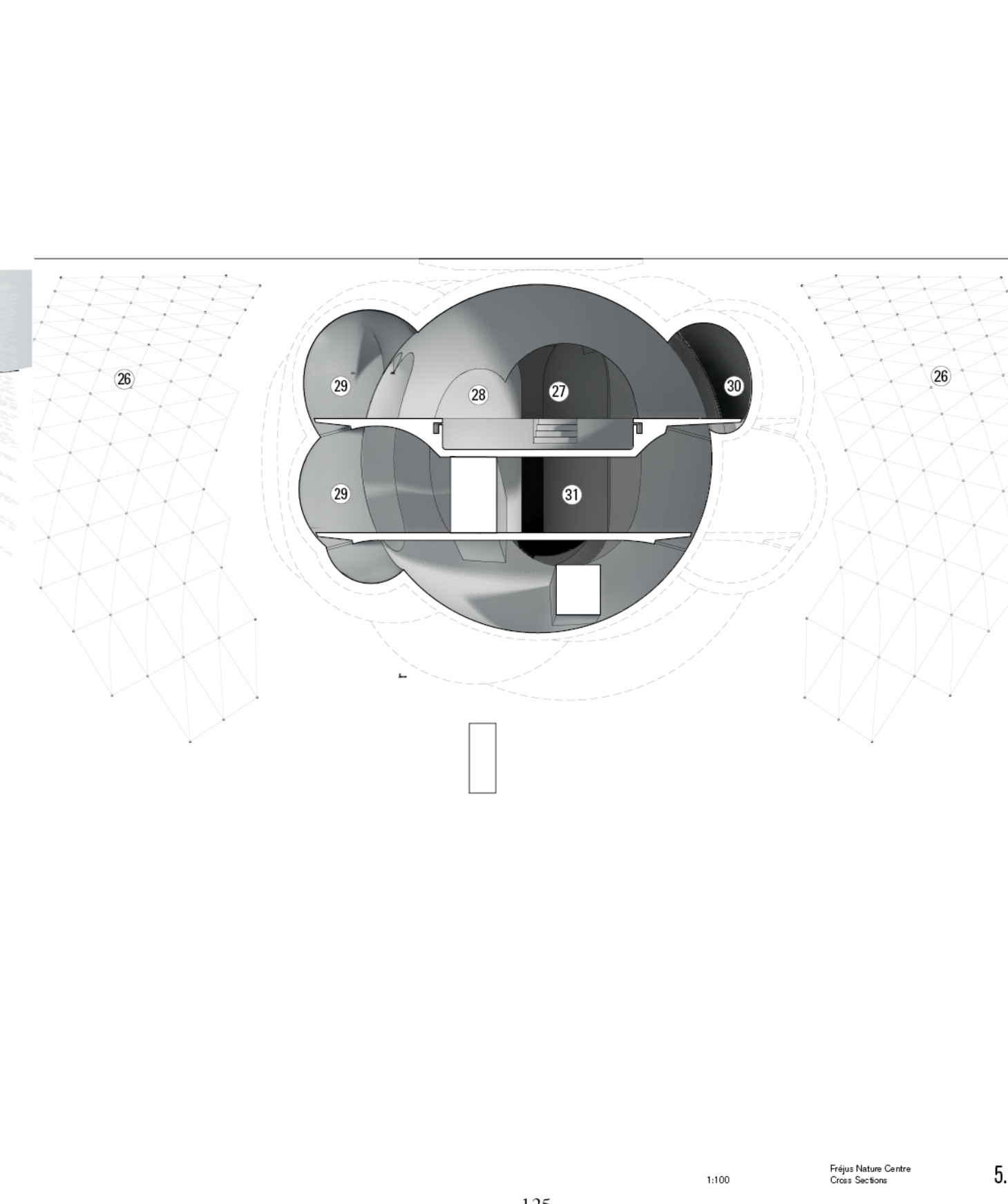
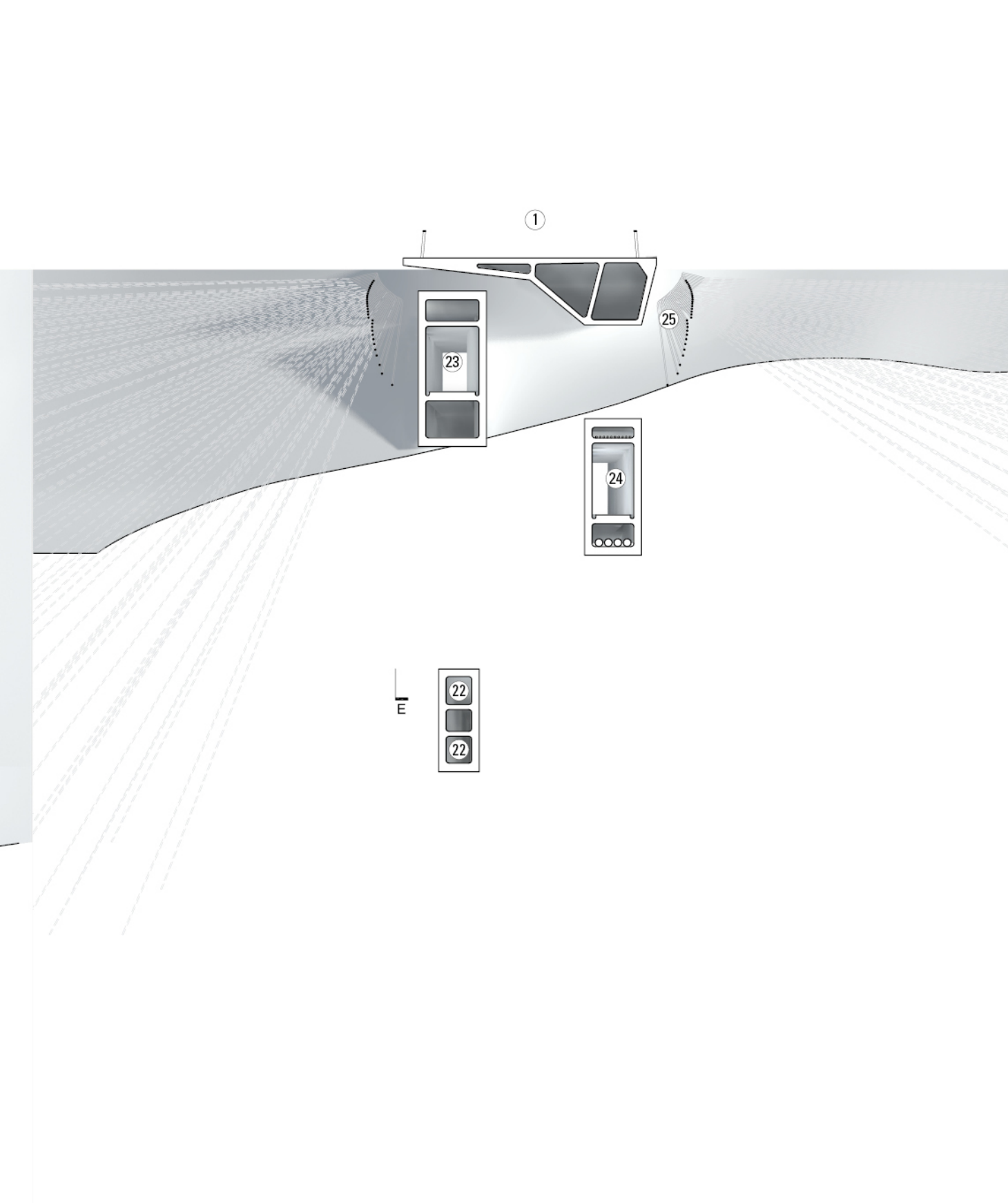
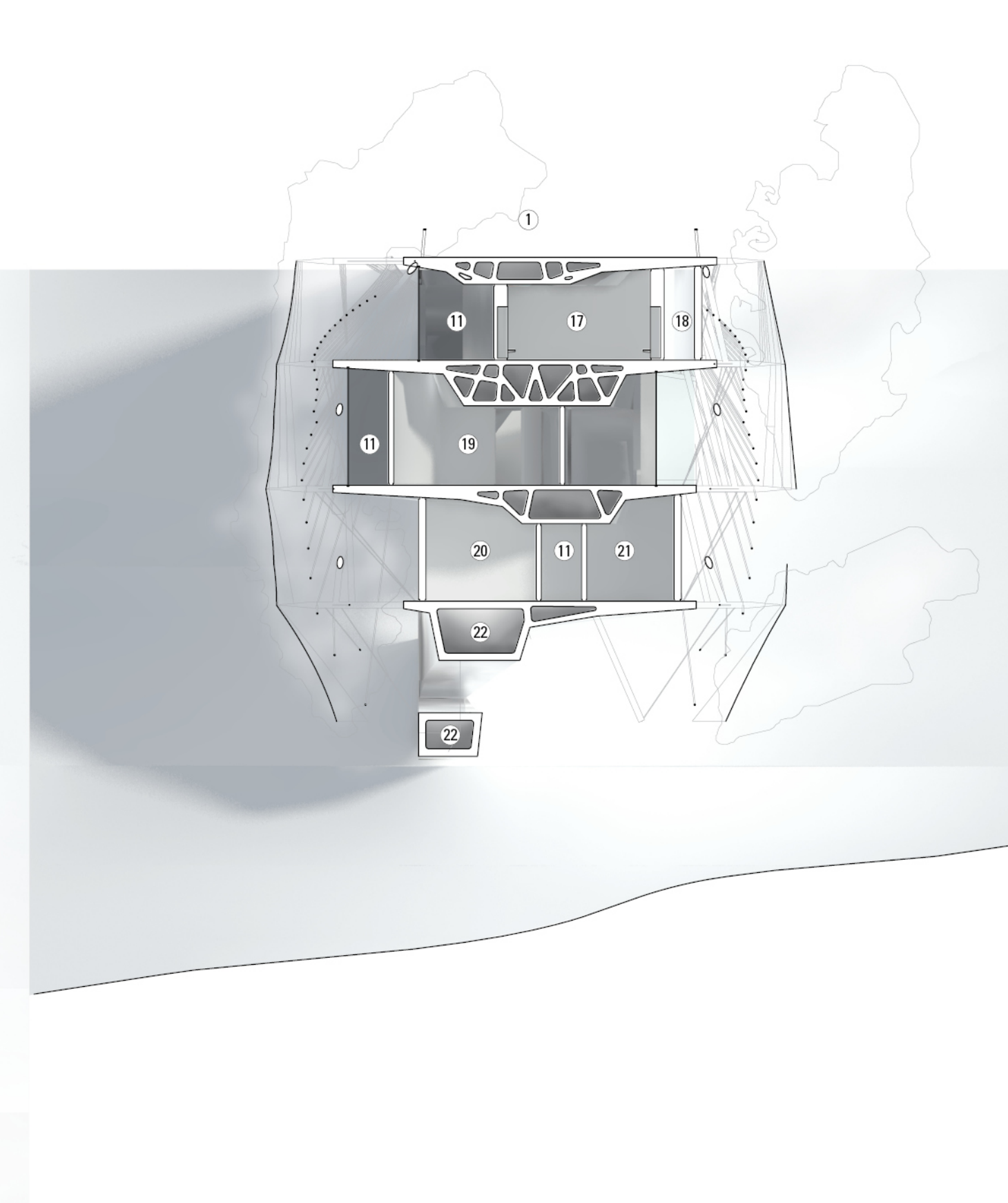
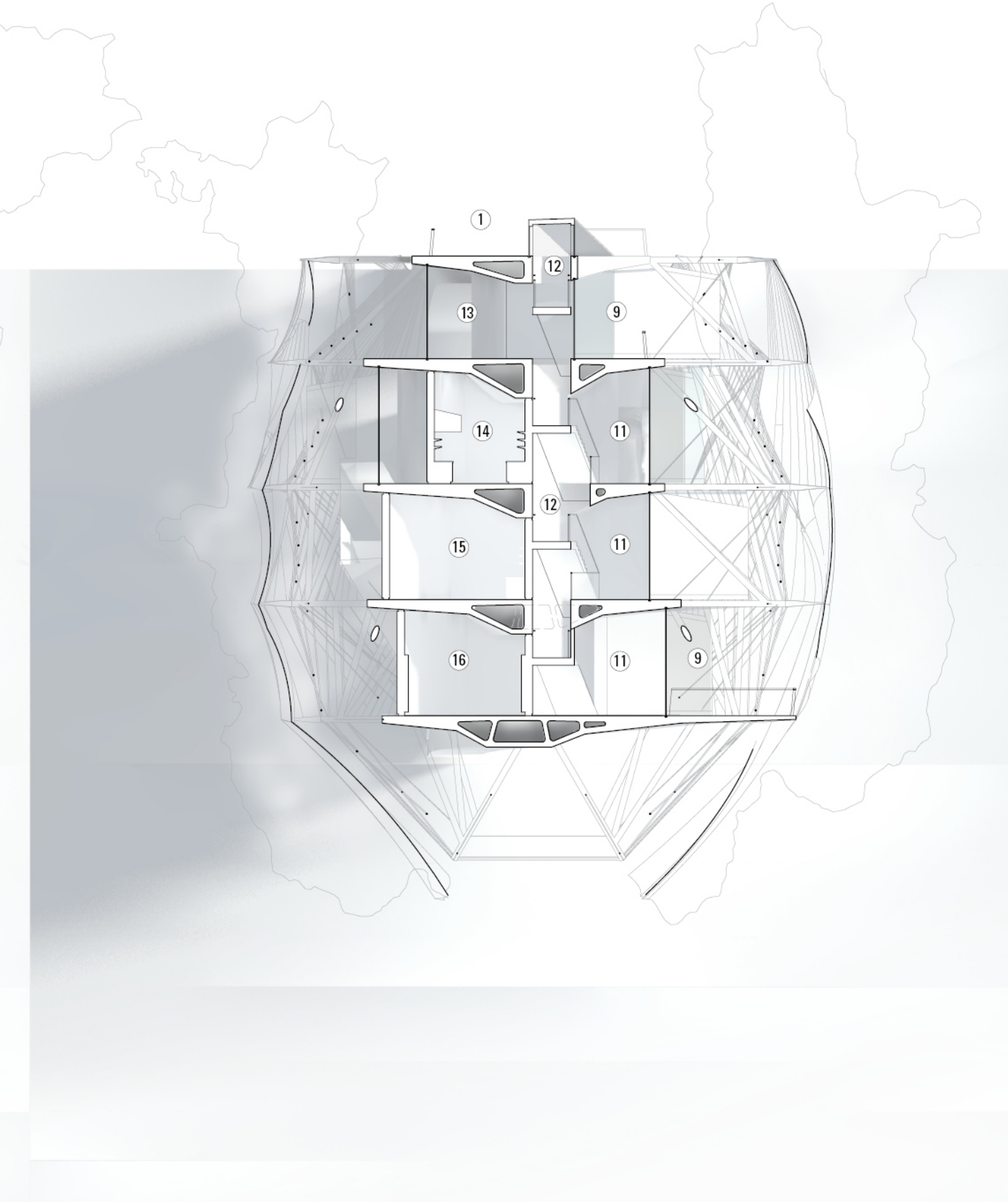
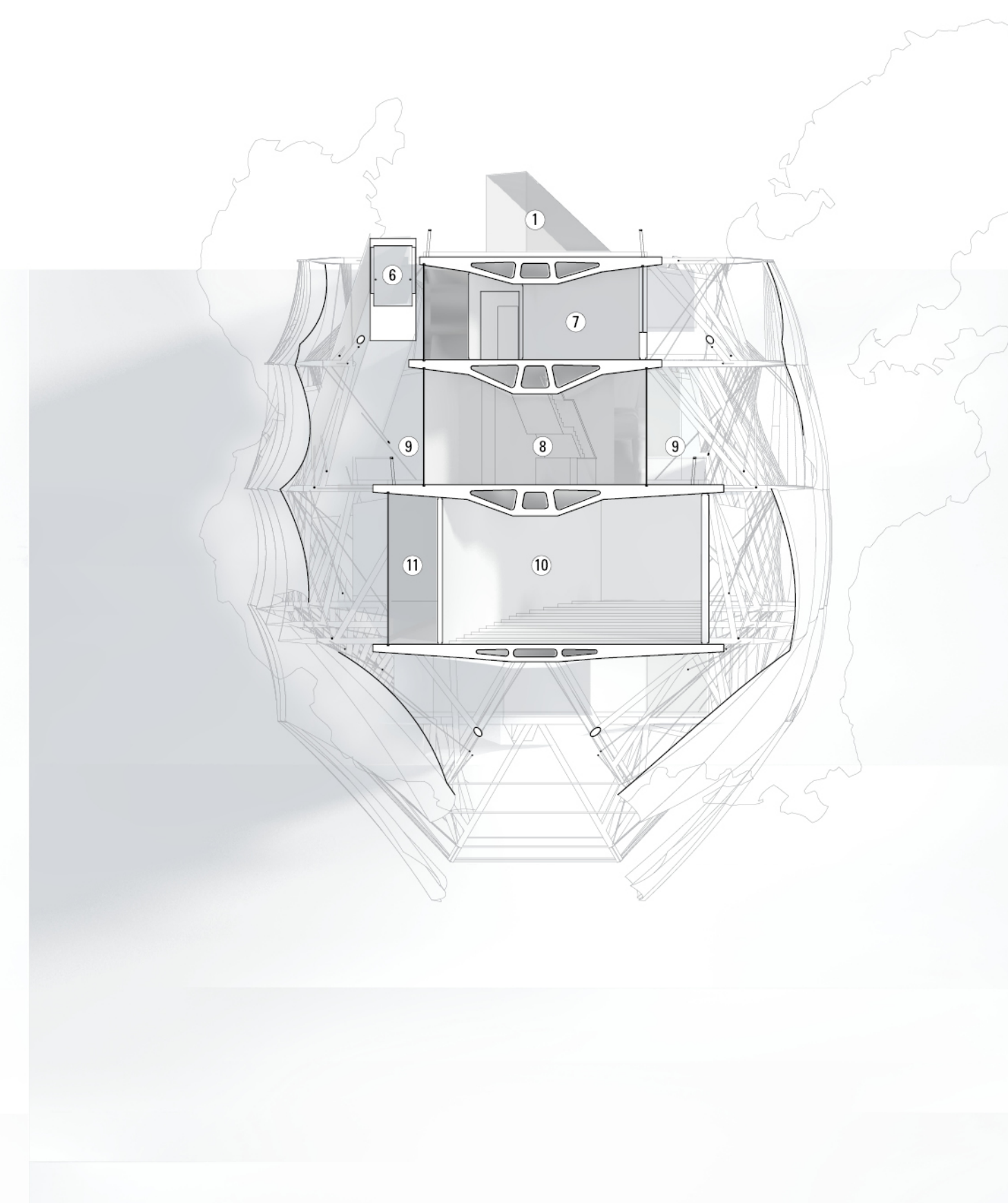
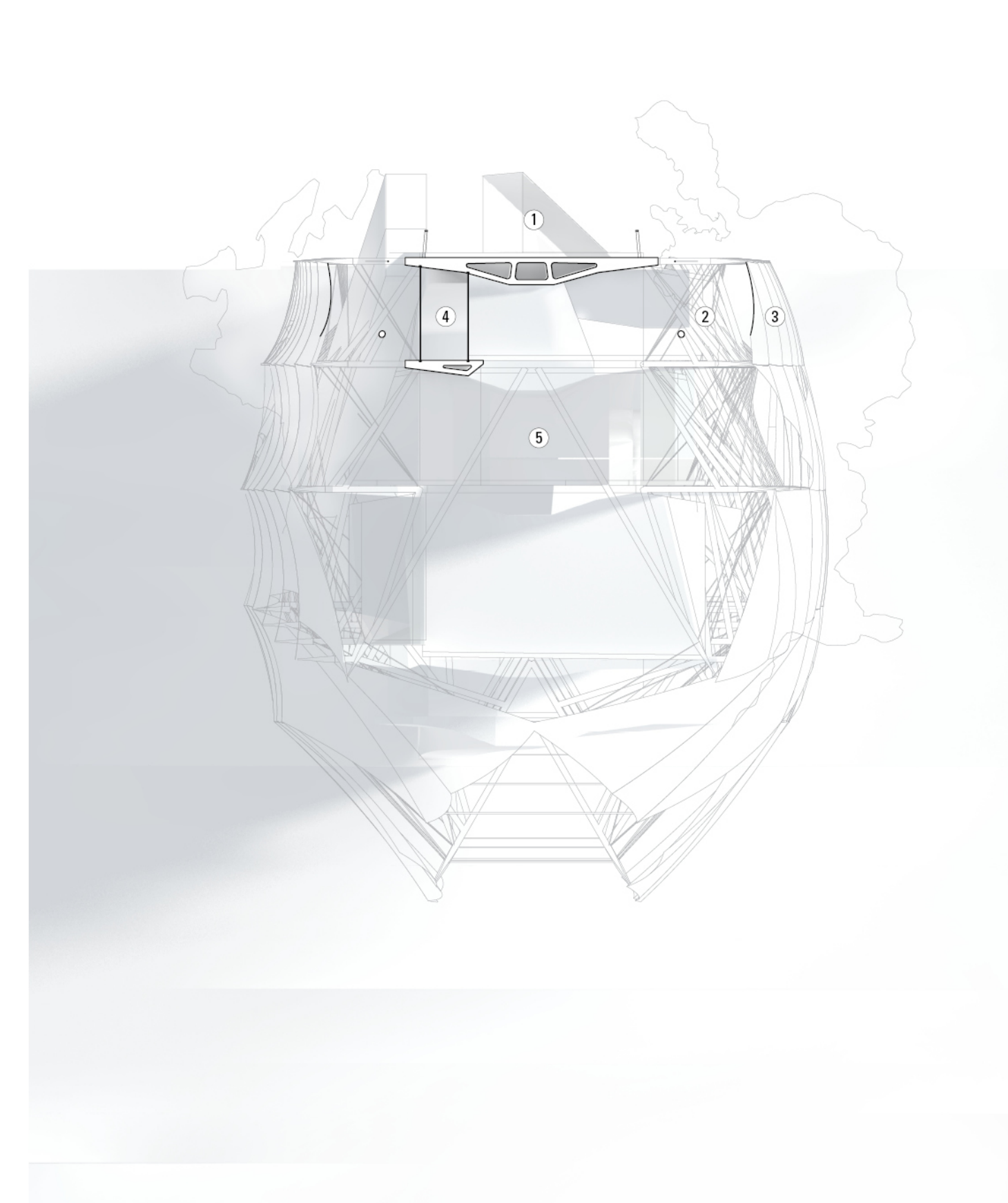
---

- ① Observation Deck
- ② Structural Matrix
- ③ Cooling Mesh
- ④ Hotel Corridor
- ⑤ Café Terrace
- ⑥ Staff & Researcher Stair
- ⑦ Hotel Room
- ⑧ Café
- ⑨ Terrace
- ⑩ Theatre
- ⑪ Corridor
- ⑫ Public Stair
- ⑬ Lounge/Waiting for Thermal Bath
- ⑭ Kitchen
- ⑮ Multi-Purpose Room
- ⑯ Nature Centre Sample Archives & Storage
- ⑰ Thermal Bath Locker Room
- ⑱ Service Corridor
- ⑲ Exhibition Space
- ⑳ Research Laboratory
- ㉑ Research Office
- ㉒ Service Duct in Hollow Structural Concrete Strut
- ㉓ Connection to Thermal Bath in Hollow Structural Concrete Strut
- ㉔ Connection to Entrance in Hollow Structural Concrete Strut
- ㉕ Gathered Cable Stays
- ㉖ Cable Stay Network
- ㉗ Warm Bath (32°)
- ㉘ Sauna (Beyond)
- ㉙ Alcove
- ㉚ Service Corridor
- ㉛ Entrance Caverns

Following Pages: Drawing 5.1  
Fréjus Nature Centre  
Cross Sections











## Legend

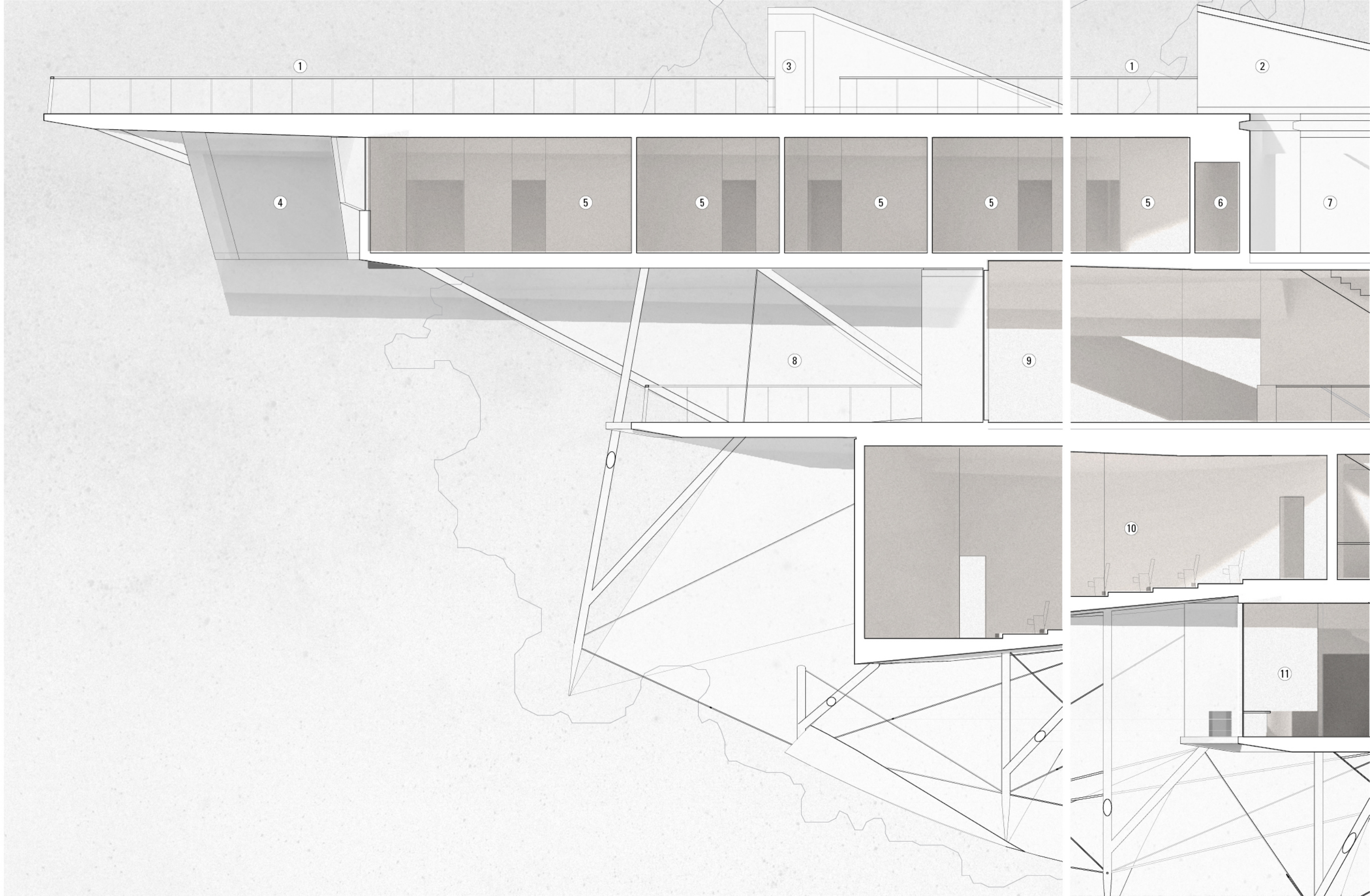
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- ① Observation Deck
- ② Public Stair (beyond)
- ③ Staff & Researcher Stair
- ④ Hotel Lookout
- ⑤ Hotel Room
- ⑥ Housekeeping
- ⑦ Terrace
- ⑧ Café Terrace
- ⑨ Café
- ⑩ Theatre/Classrooms
- ⑪ Nature Centre Administration Work Area

Following Pages: Drawing 6.0  
Fréjus Nature Centre  
Wall Section: Tip of the Nature Centre







1

3

1

2

4

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5

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5

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10

11

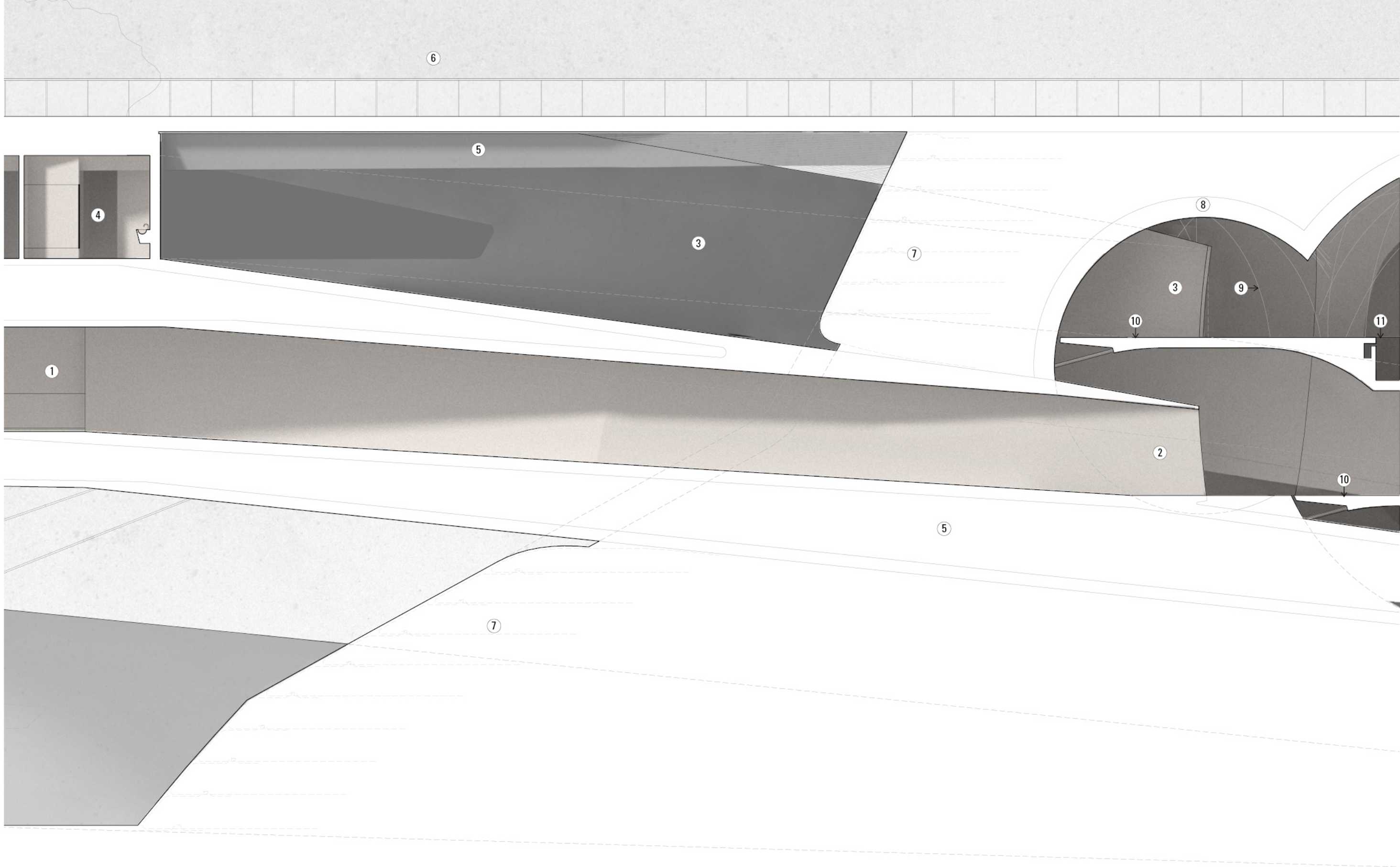
**Legend**

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- ① Reception & Information Desk
- ② Opening into Hollow Structural Strut
- ③ Thermal Bath Strut Beyond
- ④ Thermal Bath Changing Area
- ⑤ Thickening of Platform Box Girder Beyond
- ⑥ Observation Deck
- ⑦ Geotextile Mat Slope Stabilization
- ⑧ Zone of Spoil Cavern Reinforcement
- ⑨ Steel Rib Reinforcement
- ⑩ Suspended Slab
- ⑪ Warm Thermal Bath

Opposite: Drawing 6.1  
Fréjus Nature Centre  
Wall Section: Struts and Spoil Surface





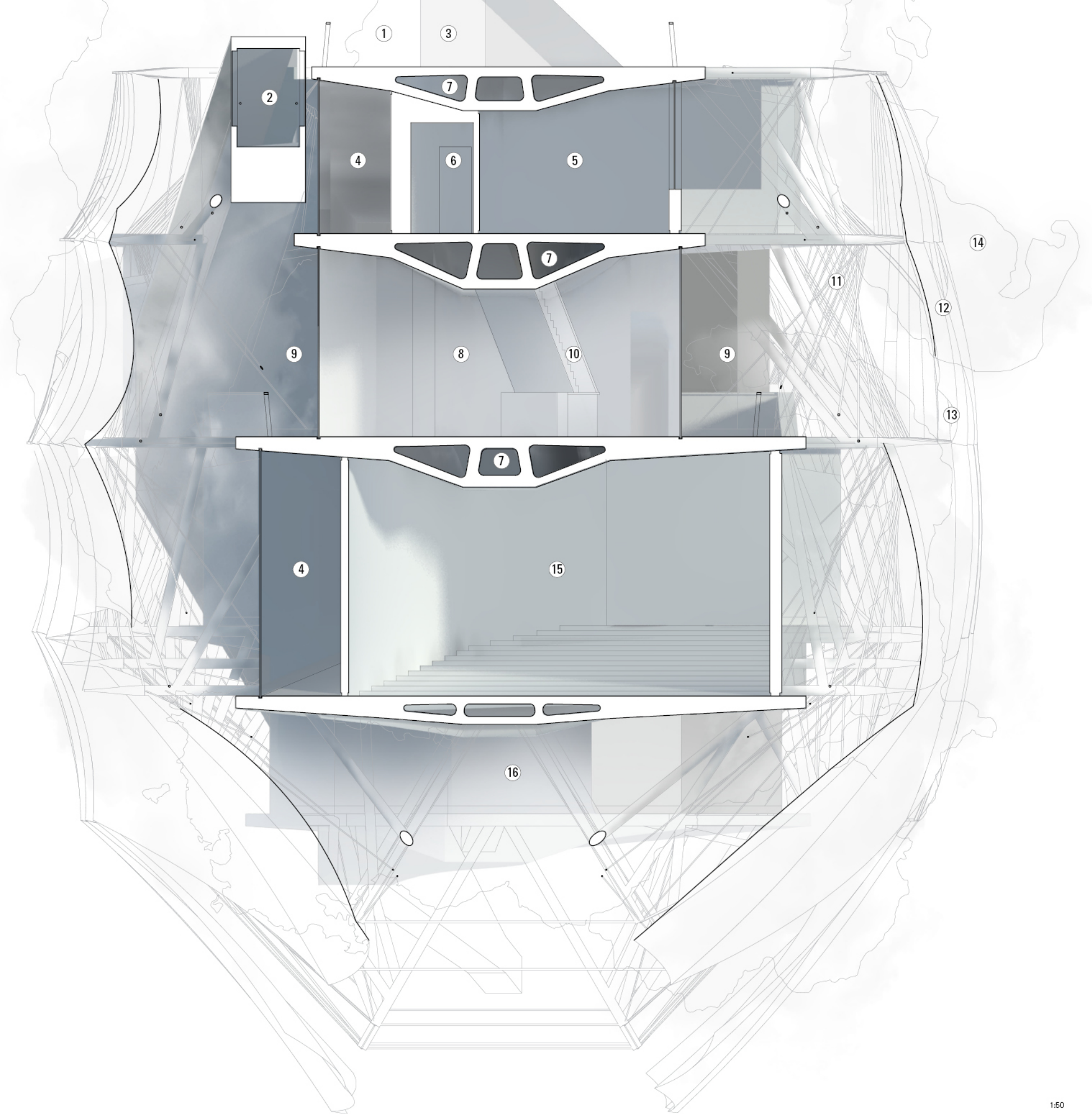


### Legend

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- ① Observation Deck
- ② Staff & Researcher Stair
- ③ Glass Enclosure of Public Stair Beyond
- ④ Corridor
- ⑤ Hotel Room
- ⑥ Hotel Washroom
- ⑦ Platform Box Girder Voids (duct, piping, and conduit raceway)
- ⑧ Café
- ⑨ Terrace
- ⑩ Open Public Stair
- ⑪ Structural Matrix
- ⑫ Cooling Mesh
- ⑬ Opening in Cooling Mesh (increased air flow maintains clear views)
- ⑭ Vapour Plumes
- ⑮ Theatre
- ⑯ Nature Centre Administration Beyond

Opposite: Drawing 6.2  
Fréjus Nature Centre  
Wall Section: Hotel, Café, and Theatre



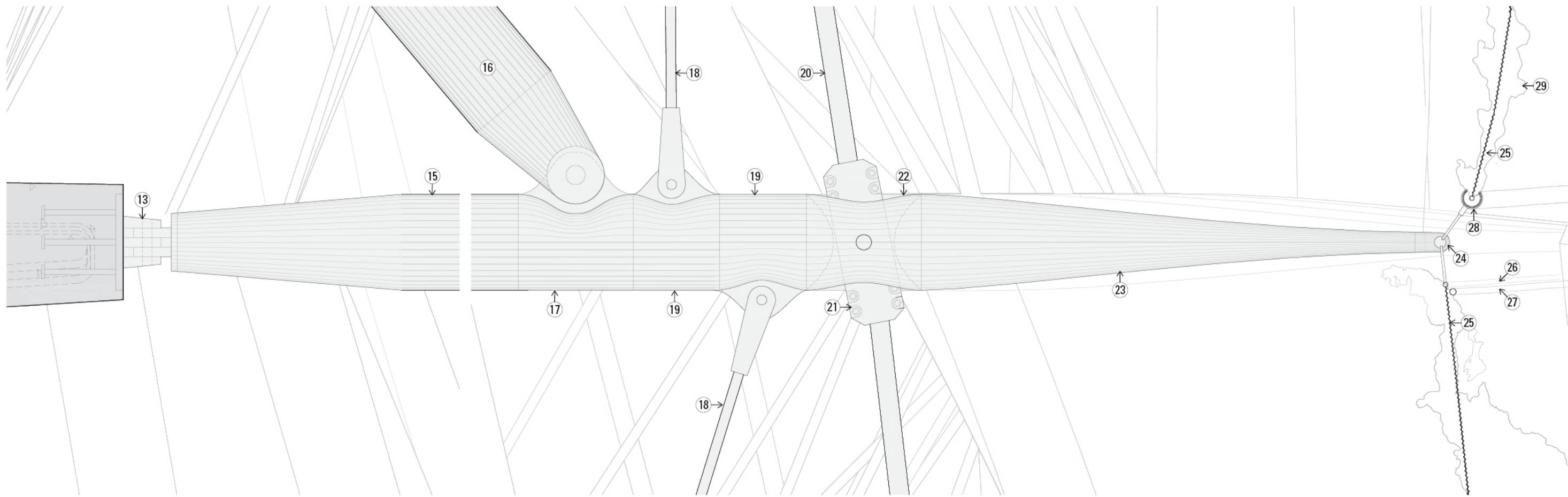
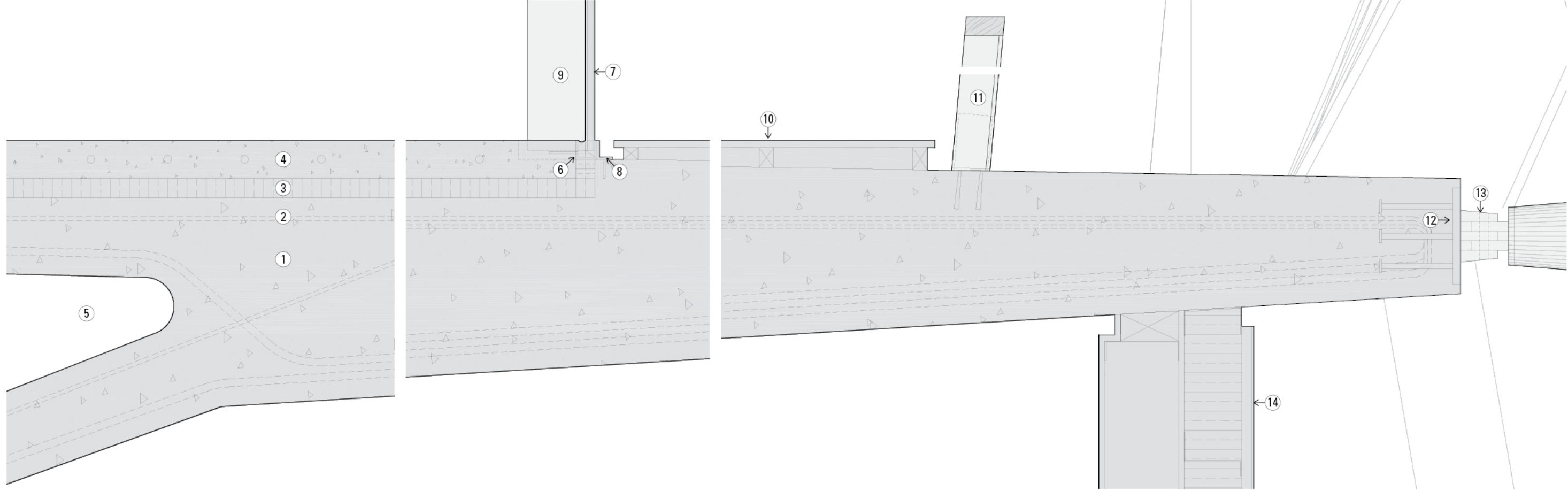
## Legend

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- ① Precast Concrete Box Girder Platform
- ② Reinforcing
- ③ Insulation
- ④ Concrete Topping with Radiant Heating
- ⑤ Void (raceway for ducts, piping, and conduit)
- ⑥ Steel Angle Embed to Receive Glazing
- ⑦ Insulated Double-Glazing
- ⑧ Stainless Steel Clip Angle (with neoprene thermal break)
- ⑨ Polished Stainless Steel Plate Mullion
- ⑩ Raised Ipe Slat Deck
- ⑪ Glass Guard on Stainless Steel Posts
- ⑫ Steel Plate Embed
- ⑬ Hinged Connection to Structural Matrix
- ⑭ Rainscreen Wall
- ⑮ Steel HSS Horizontal Strut
- ⑯ Steel HSS Compression Strut with Cast Steel Fork End
- ⑰ Cast Module to Receive Compression Connection
- ⑱ Steel Tension Cable with Swaged Fork End
- ⑲ Cast Module to Receive Tension Connection
- ⑳ Steel Cable Stay
- ㉑ Cable Clamp with Pin Connection
- ㉒ Cast Module to Receive Cable Stay Clamp
- ㉓ Tapered Flexible Struct End (to buffer wind gusts)
- ㉔ Cast Cable Eye Insert
- ㉕ Expanded Stainless Steel Cooling Mesh
- ㉖ Cable Mesh Edge Reinforcing
- ㉗ Cooling Water Distribution Piping
- ㉘ Cooling Water Collection Trough
- ㉙ Vapour Plume

Opposite: Drawing 7.0  
Fréjus Nature Centre  
Details: Slab, Glazing, Wall and Matrix



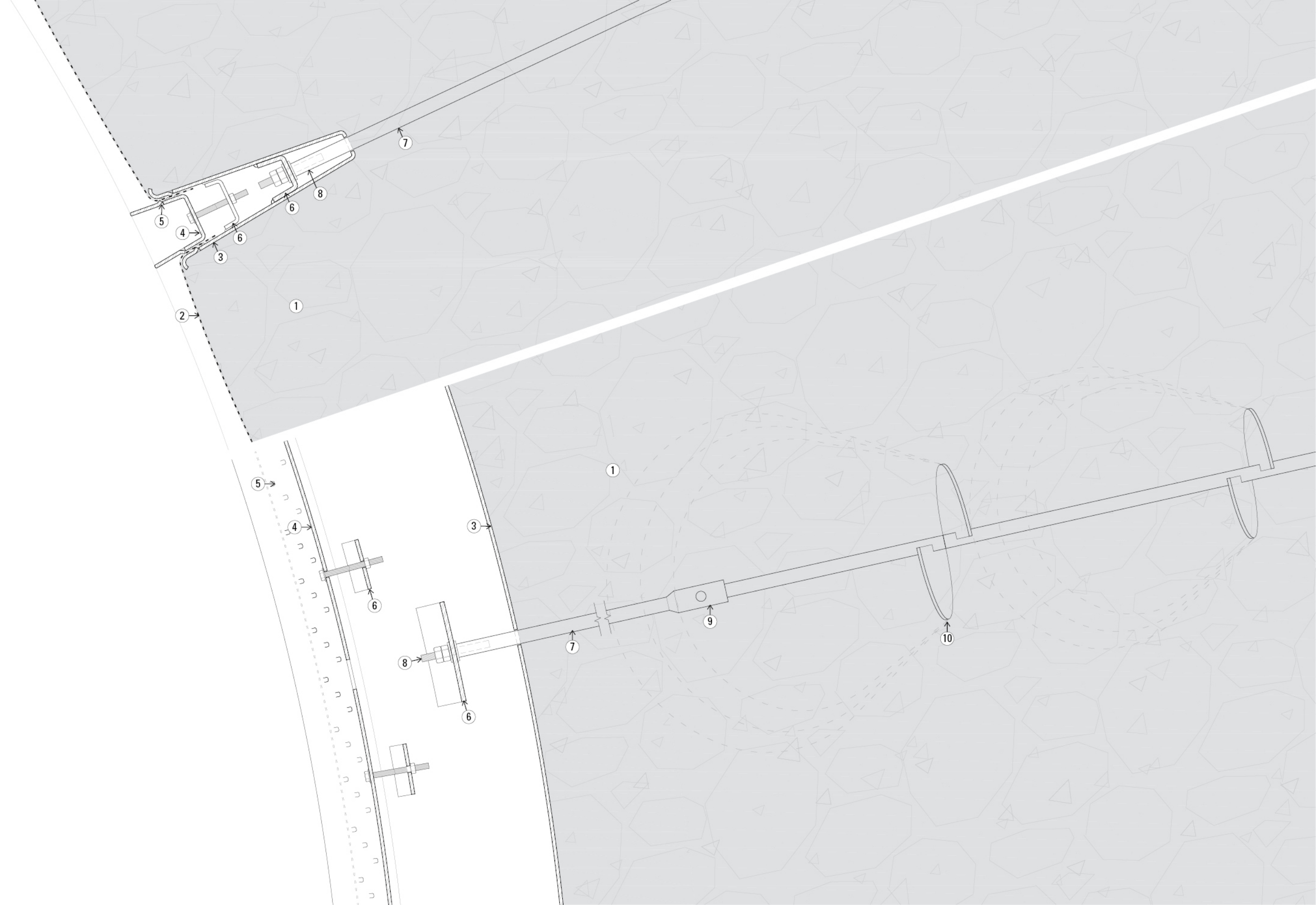


**Legend**

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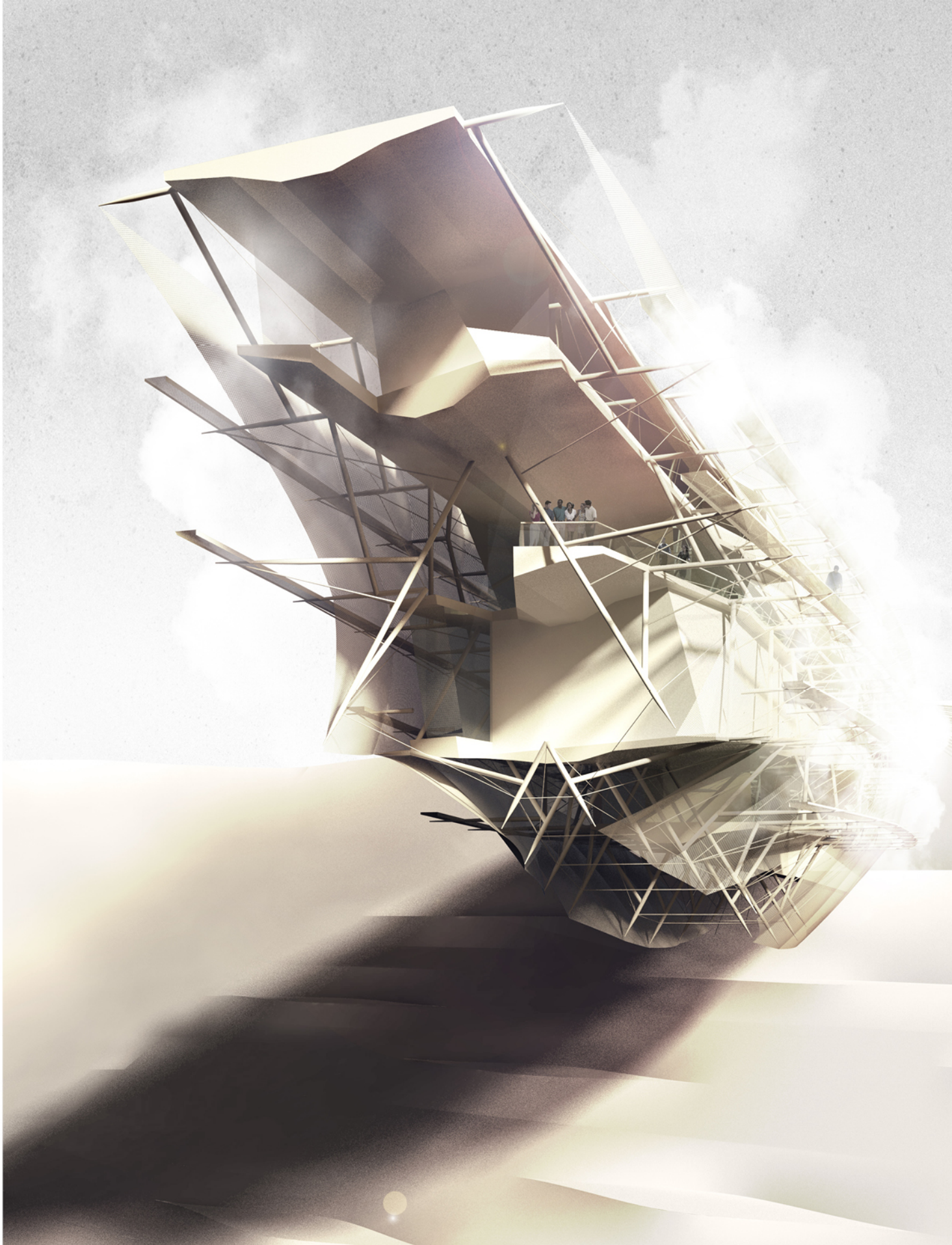
- ① Loose Excavation Spoil
- ② Expanded Metal Mesh
- ③ Bent Steel Reinforcing Rib
- ④ Bent Steel Clamping Plate
- ⑤ Bent Die-Cut Tabs (to grip expanded mesh)
- ⑥ Anchor Plate (welded to rib)
- ⑦ Helical Anchor
- ⑧ Threaded Rod Insert
- ⑨ Helical Anchor Shaft Splice
- ⑩ Helical Anchor Plate

Opposite: Drawing 7.1  
Fréjus Nature Centre  
Details: Spoil Cavern Plan & Section





Opposite: Drawing 8.0  
Fréjus Nature Centre  
View of Nature Centre from Below



View of Nature Centre From Below

Opposite: Drawing 8.1  
Fréjus Nature Centre  
View of Café, Structural Matrix &  
Cooling Skin





Opposite: Drawing 8.2  
Fréjus Nature Centre  
View from the Entrance Bridge into the  
Nature Centre





View From Entrance Bridge Into  
Nature Centre



Opposite: Drawing 8.3  
Fréjus Nature Centre  
View of Nature Centre and Spoil Mound







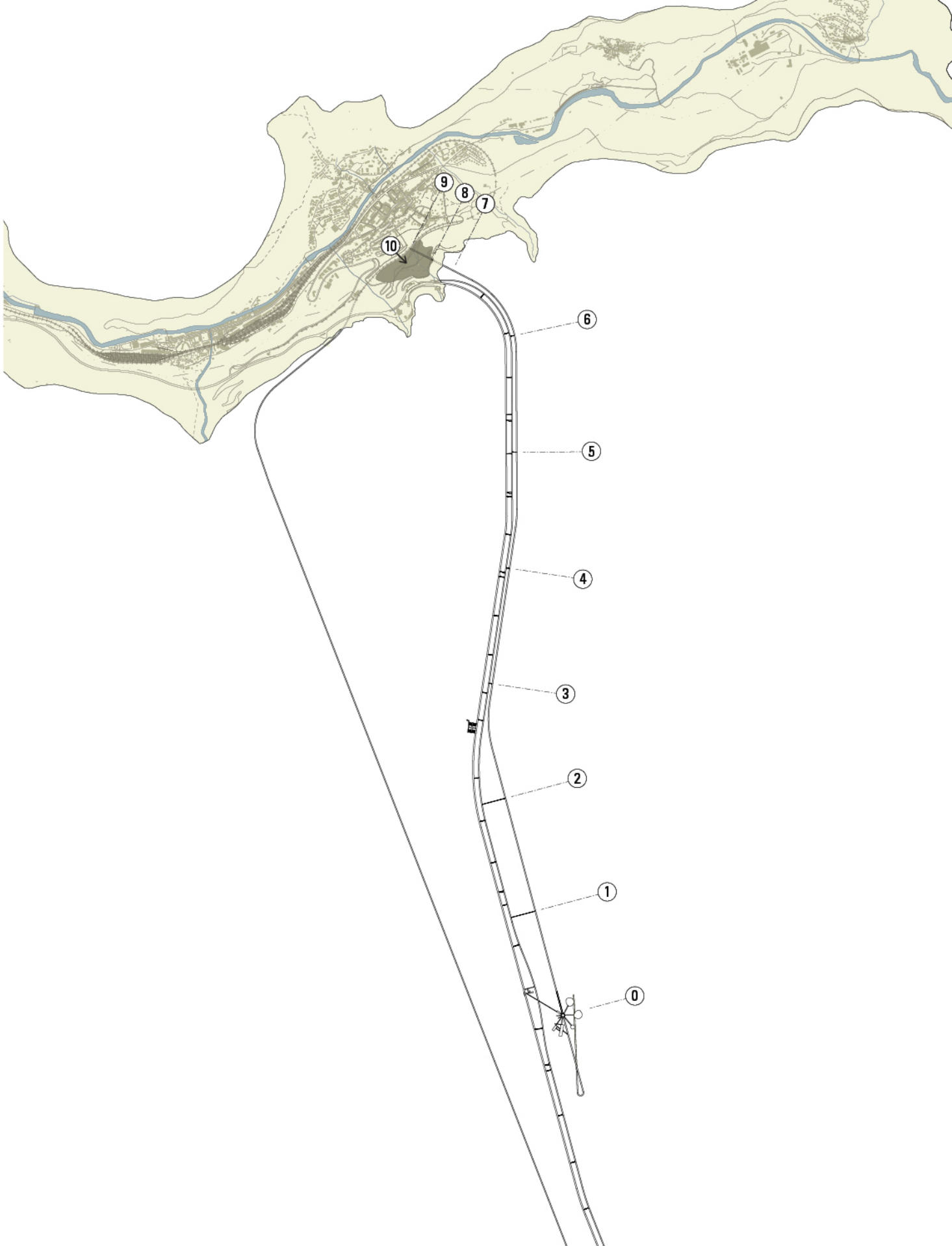
TUNNEL

## Legend

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- ① Observatory Entrance
- ② Interconnection with Safety Tunnel (1km)
- ③ Interconnection with Safety Tunnel (2km)
- ④ Interconnection with Safety Tunnel (3km)
- ⑤ Interconnection with Safety Tunnel (4km)
- ⑥ Interconnection with Safety Tunnel (5km)
- ⑦ Interconnection with Safety Tunnel (6km)
- ⑧ Zone of Systems Intergration/Disintegration
- ⑨ Tunnel Mouth (7km)
- ⑩ Fréjus Nature Centre
- ⑪ Spoil Mound

Opposite: Drawing 9.0  
Tunnel Site Plan



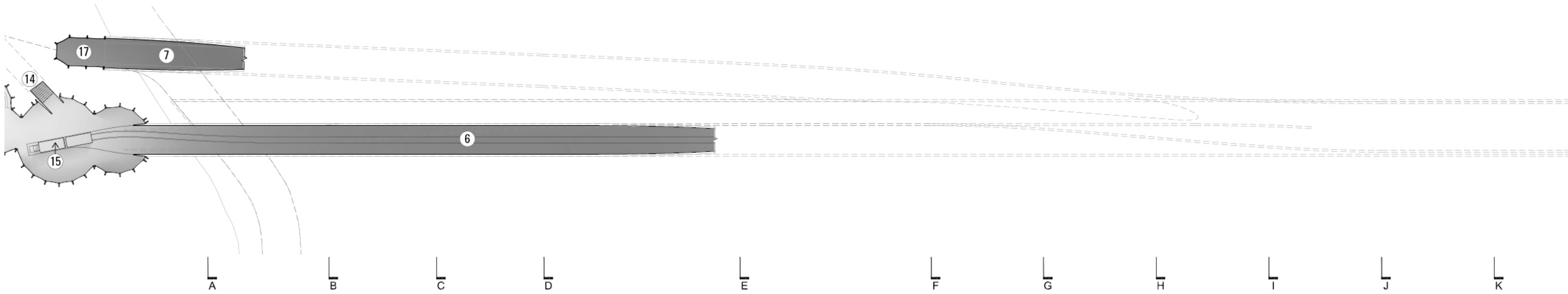
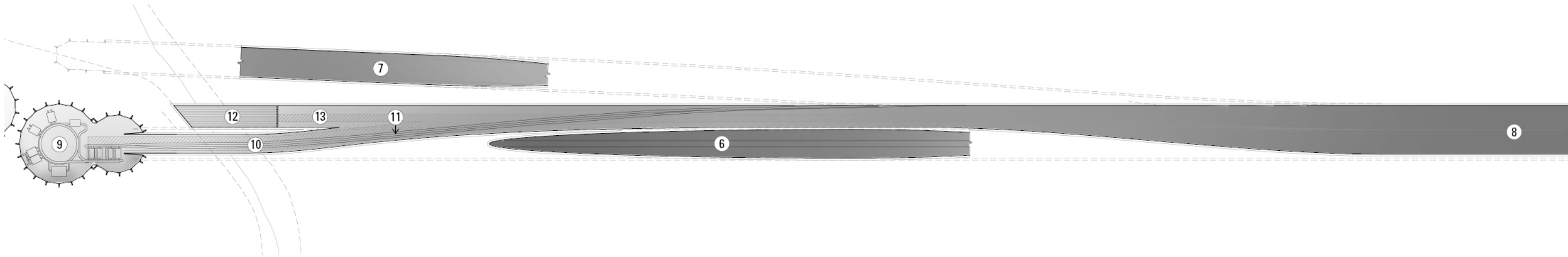
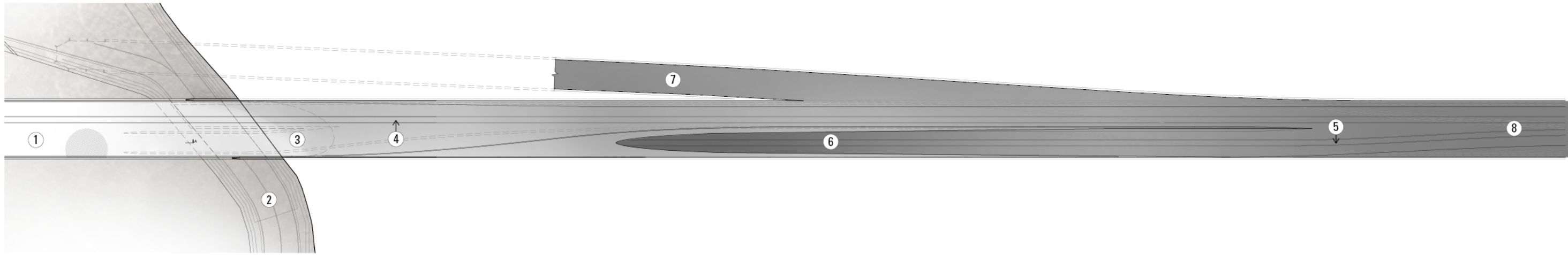


## Legend

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- ① Observation Deck
- ② Access Road
- ③ Tunnel Mouth
- ④ Railway Track (large equipment transport; spoil removal during construction)
- ⑤ Railway Track (visitor, staff, and equipment transport)
- ⑥ Railway Tunnel Branch
- ⑦ Fresh Air Intake Tunnel Branch
- ⑧ Full Integration of Systems (beginning of tunnel boring machine and precast lining modules)
- ⑨ Thermal Transfer Equipment (heat exchangers and pumps)
- ⑩ Service Tunnel Branch
- ⑪ Cooling Water Loop Supply & Return Mains
- ⑫ Exhaust Grille
- ⑬ Exhaust Air Tunnel Branch
- ⑭ Entrance Stair
- ⑮ Sunken Railway Platform

Opposite: Drawing 10.0  
Tunnel Mouth Plans



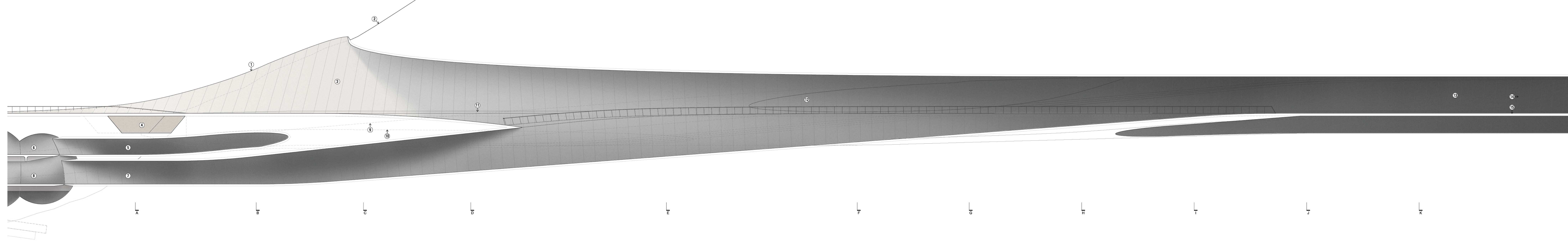
### Legend

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- ① Edge of Tunnel Lining (projecting past rock face to deflect rock slides)
- ② Rock Face
- ③ Tunnel Mouth
- ④ Access Road Underpass
- ⑤ Services Tunnel Branch
- ⑥ Thermal Transfer Equipment
- ⑦ Railway Tunnel Branch
- ⑧ Railway Platform
- ⑨ Fresh Air Intake Tunnel Branch Beyond
- ⑩ Exhaust Air Tunnel Branch Beyond
- ⑪ Roadway & Railway Track Beyond
- ⑫ Fresh Air Inlet
- ⑬ Full Integration of Systems and Tunnel Elements
- ⑭ Precast Concrete Tunnel Lining Module
- ⑮ Precast Concrete Tunnel Platform Module

Opposite: Drawing 11.0  
Tunnel Mouth Longitudinal Section







## Legend

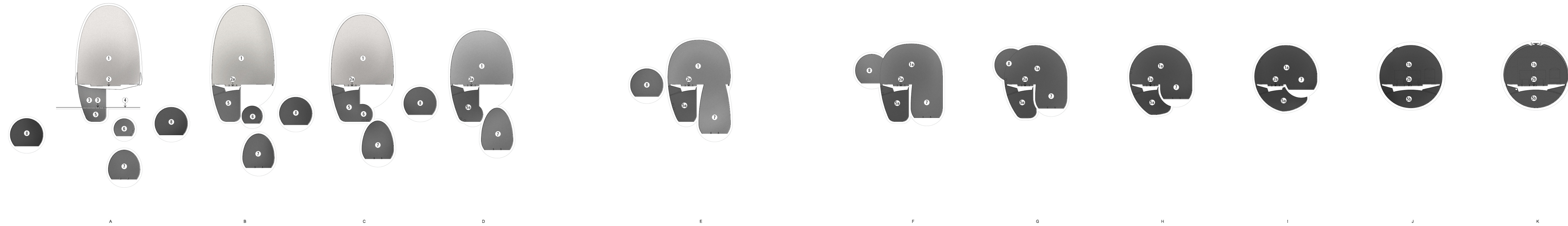
---

- ① Tunnel Mouth
- ①a Combined Tunnel Mouth and Fresh Air Intake
- ①b Combined Tunnel Mouth and Fresh Air Intake with Integration of Surface Cooling in Precast Concrete Tunnel Lining Ribs (transition to excavation by tunnel boring machine)
- ② Observtion Deck
- ②a Hybrid Tunnel Platform (rail tracks for large equipment transport; spoil removal during construction)
- ②b Precast Concrete Tunnel Platform
- ③ Exhaust Grille
- ④ Access Road
- ⑤ Exhaust Air Tunnel Branch
- ⑤a Combined Exhaust Air and Services Tunnel
- ⑤b Combined Exhaust Air and Services Tunnel with Full Integration of Systems, Cooling Water Loop Supply & Return Mains
- ⑥ Services Tunnel Branch
- ⑦ Railway Tunnel Branch (visitor, staff, and equipment transport)
- ⑧ Fresh Air Intake Tunnel Branch

Following Pages: Drawing 11.1  
Tunnel Mouth Cross Sections











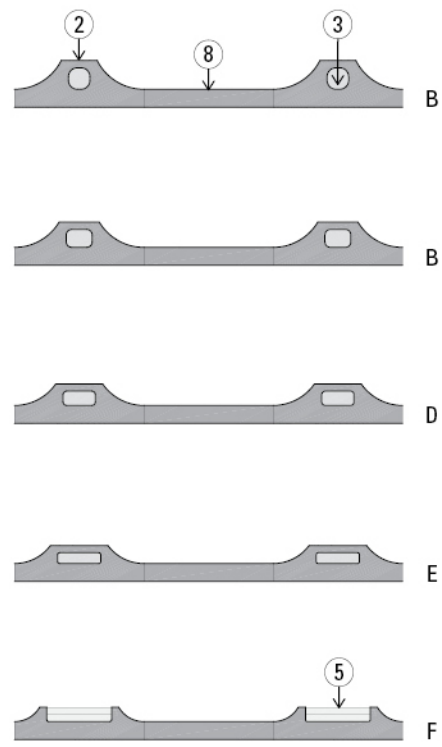
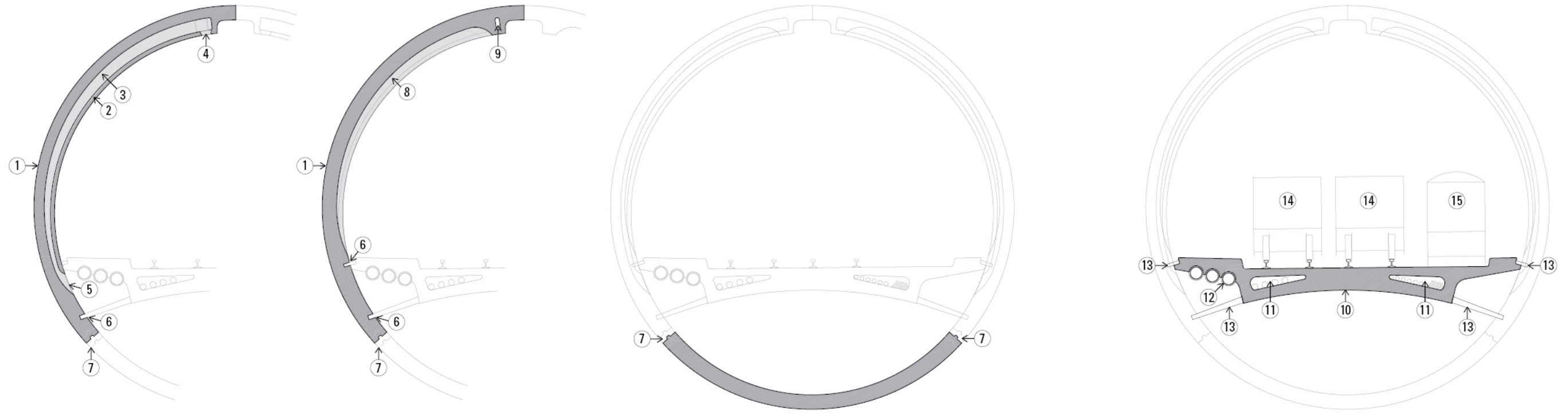
## Legend

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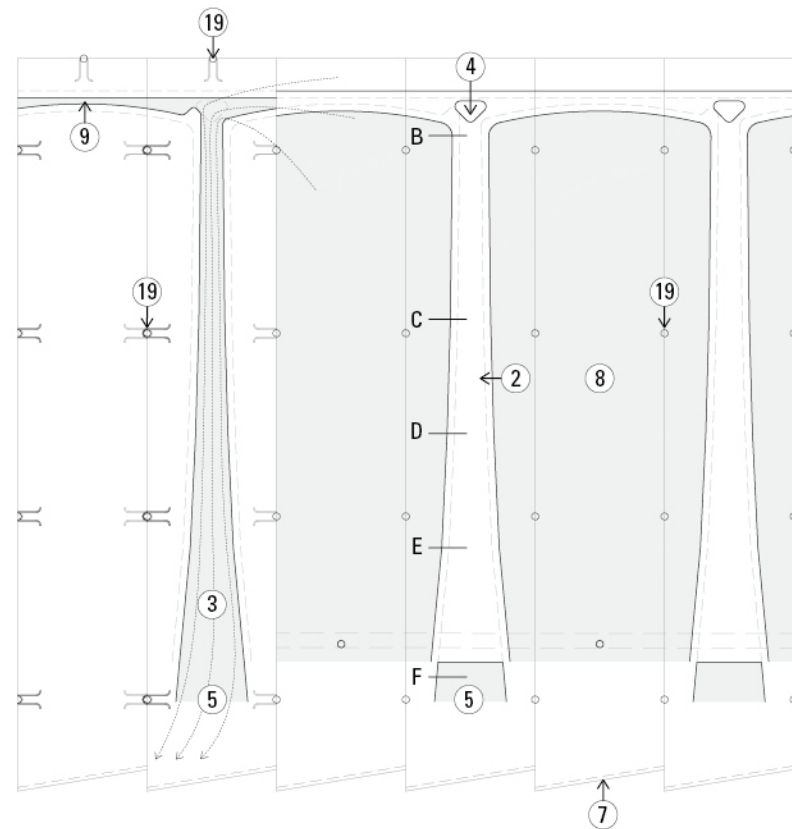
- ① Precast Concrete Tunnel Lining
- ② Rib
- ③ Cooling Airway
- ④ Air Inlet
- ⑤ Air Outlet (into exhaust air plenum)
- ⑥ Socket to Receive Platform Pins
- ⑦ Tapering Slotted Lining Element Connection (lower lining element is driven into place with hydraulic rams like a keystone)
- ⑧ Coffer/Un-ribbed Lining Element
- ⑨ Duct Interconnecting Cooling Airways
- ⑩ Precast Concrete Platform
- ⑪ Void Space (structural optimization and raceway for conduits & piping)
- ⑫ Grooves for Observatory Cooling Supply & Return, and Water Mains
- ⑬ Steel Struts Pin the Platform to the Lining
- ⑭ Bi-Directional Electric Construction Railway
- ⑮ Conveyor System (connected to tunnel boring machine)
- ⑯ Staff, Visitor, and Maintenance Railway
- ⑰ Oversize Vehicle Profile (for large equipment transport)
- ⑱ Recess for Future Bundled Conduit & Piping
- ⑲ Lining Element Pin Connection
- ⑳ Tapered Steel Pin
- ㉑ Cast-in Stirrups (pin is threaded through stirrups, pulling the lining elements together)
- ㉒ Waterproof Gasket (compression seal at joints)

Following Pages: Drawing 12.0  
Tunnel Lining Details

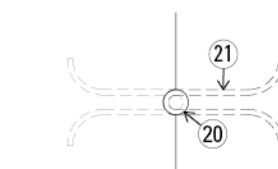




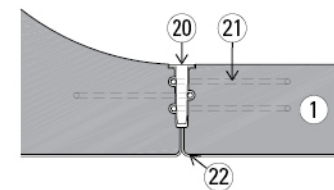
Sections Through Ribs and Coffers in Tunnel Lining Elements



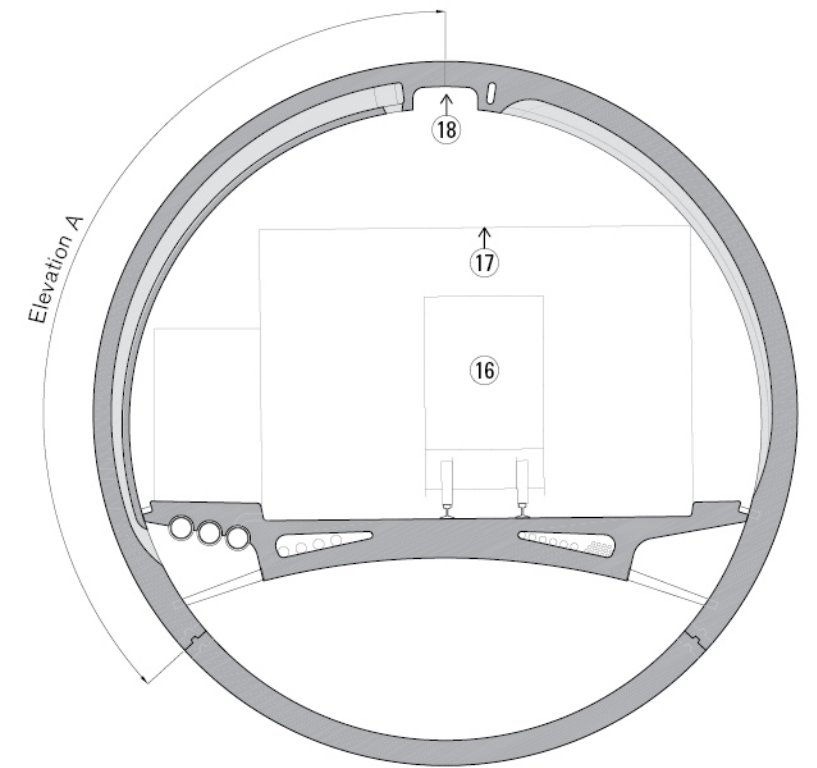
A - Unrolled Elevation of Tunnel Lining Elements



G - Plan Detail of Lining Connection

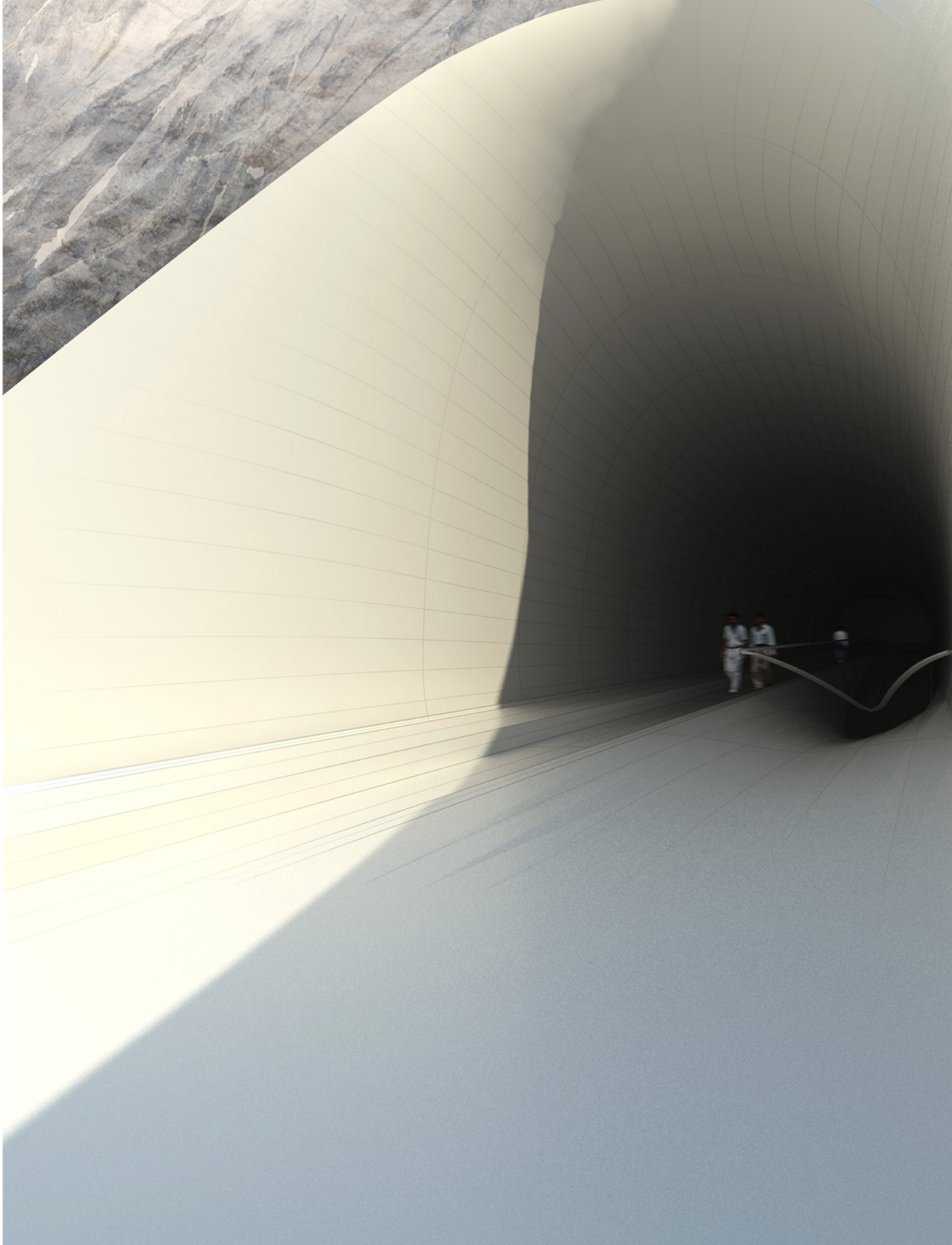


H - Section Detail of Lining Connection





Opposite: Drawing 13.0  
View of Looking into the Tunnel Mouth



Opposite: Drawing 13.1  
View of Tunnel Systems Disintegration







# OBSERVATORY

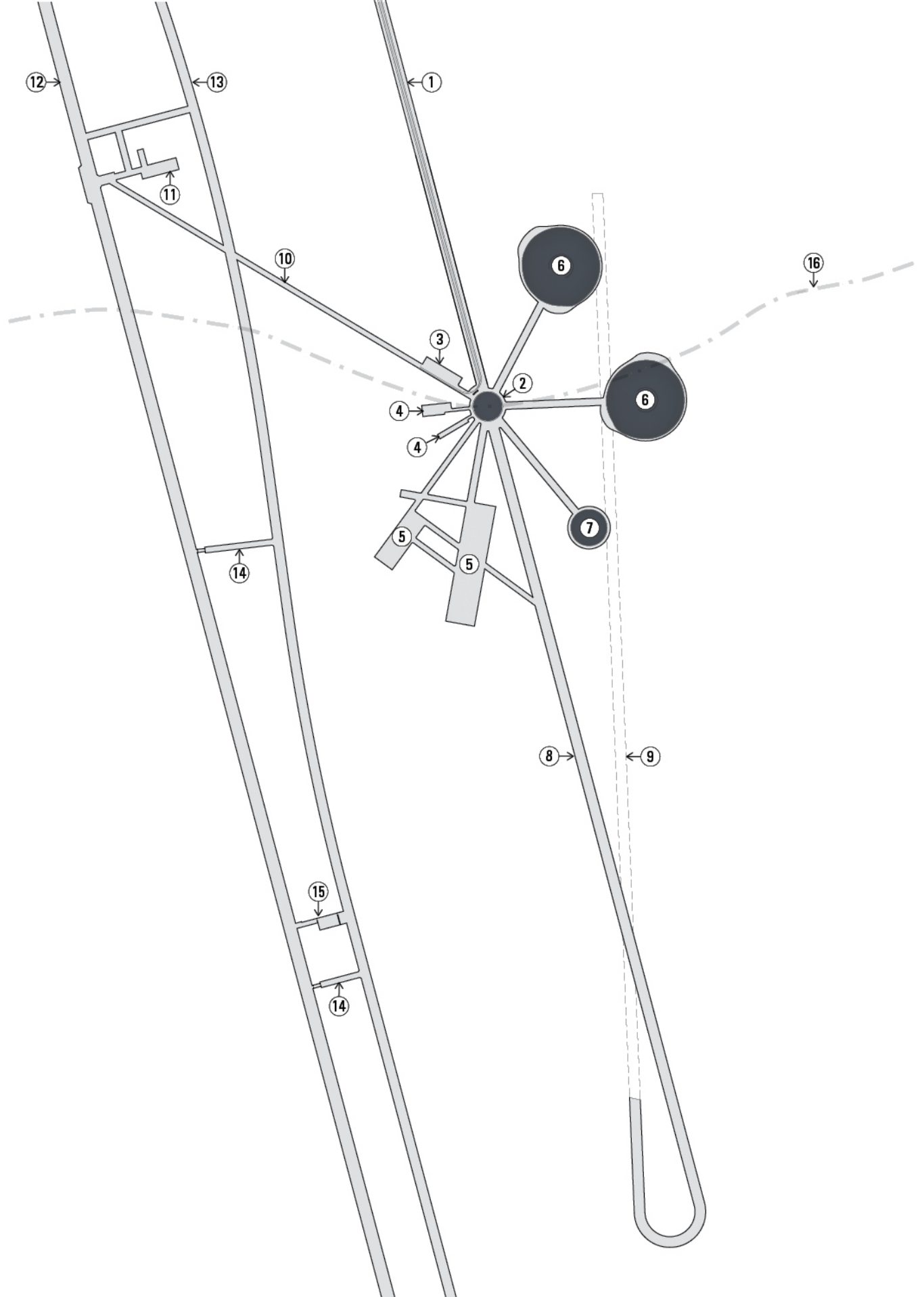


## Legend

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- ① Observatory Access Tunnel
- ② Entrance Cavern - Narthex
- ③ Staging & Cleaning
- ④ Support Spaces
- ⑤ Experiment Halls
- ⑥ Water Cherenkov Neutrino Detector
- ⑦ Organic Liquid Scintillator Neutrino Detector
- ⑧ Detector Base Access Tunnel (means of excavation spoil removal)
- ⑨ Detector Base Access Tunnel Below
- ⑩ Connection to Existing Laboratoire Souterrain de Modane
- ⑪ Existing Laboratoire Souterrain de Modane
- ⑫ Fréjus Road Tunnel
- ⑬ Fréjus Safety Tunnel
- ⑭ Safety Shelter (connecting road & safety tunnels)
- ⑮ Technical Station (for emergency response)
- ⑯ Border of France & Italy

Opposite: Drawing 14.0  
Neutrino Observatory  
Site Plan



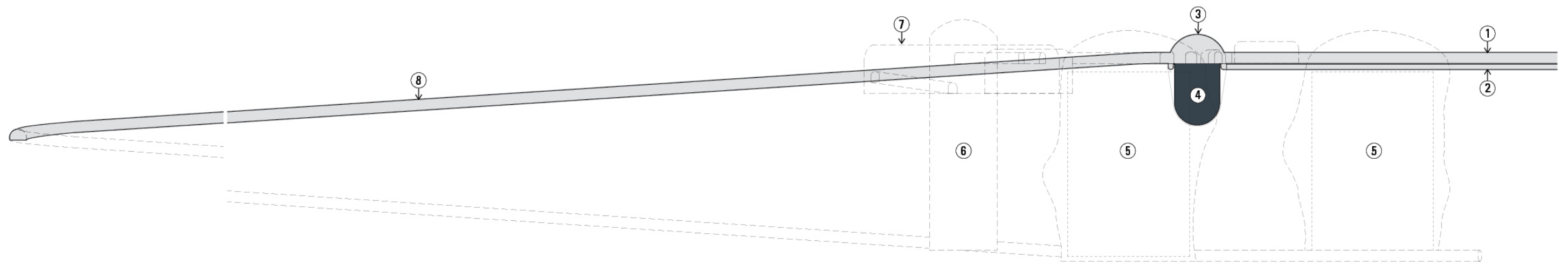
## Legend

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- ① Observatory Access Tunnel (fresh air plenum)
- ② Observatory Access Tunnel (exhaust air plenum)
- ③ Entrance Cavern - Narthex
- ④ Cooling Water Reservoir
- ⑤ Water Cherenkov Neutrino Detector (in front)
- ⑥ Organic Liquid Scintillator Neutrino Detector (in front)
- ⑦ Experiment Halls (beyond)
- ⑧ Dectector Base Access Tunnel (means of excavation spoil removal)
- ⑨ Dectector Base Access Tunnel Below

Opposite: Drawing 14.1  
Neutrino Observatory  
Site Section



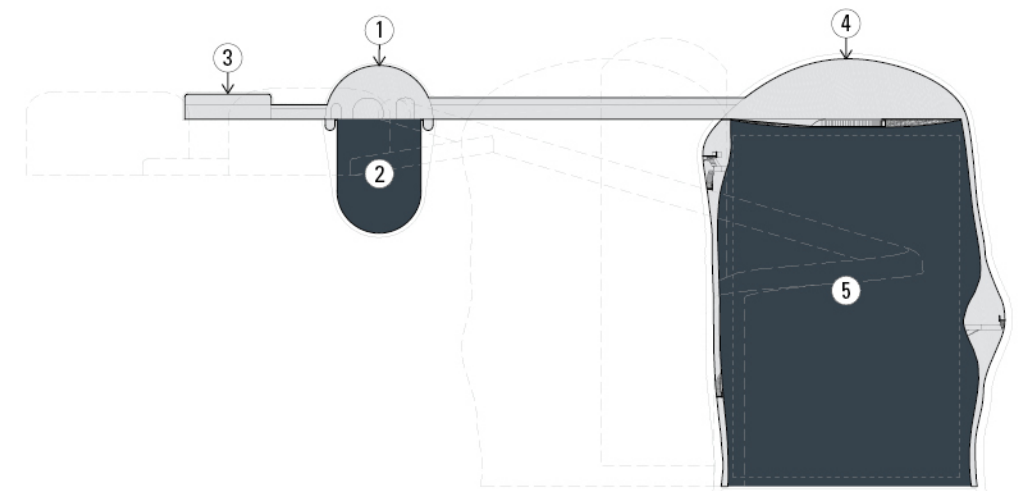


**Legend**

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- ① Entrance Cavern - Narthex
- ② Cooling Water Reservoir
- ③ Service Cavern
- ④ Neutrino Detector Cavern
- ⑤ Water Cherenkov Neutrino Detector
- ⑥ Fréjus Safety Tunnel
- ⑦ Fréjus Road
- ⑧ Fréjus Railway Tunnel

Opposite: Drawing 14.2  
Neutrino Observatory  
Site Section



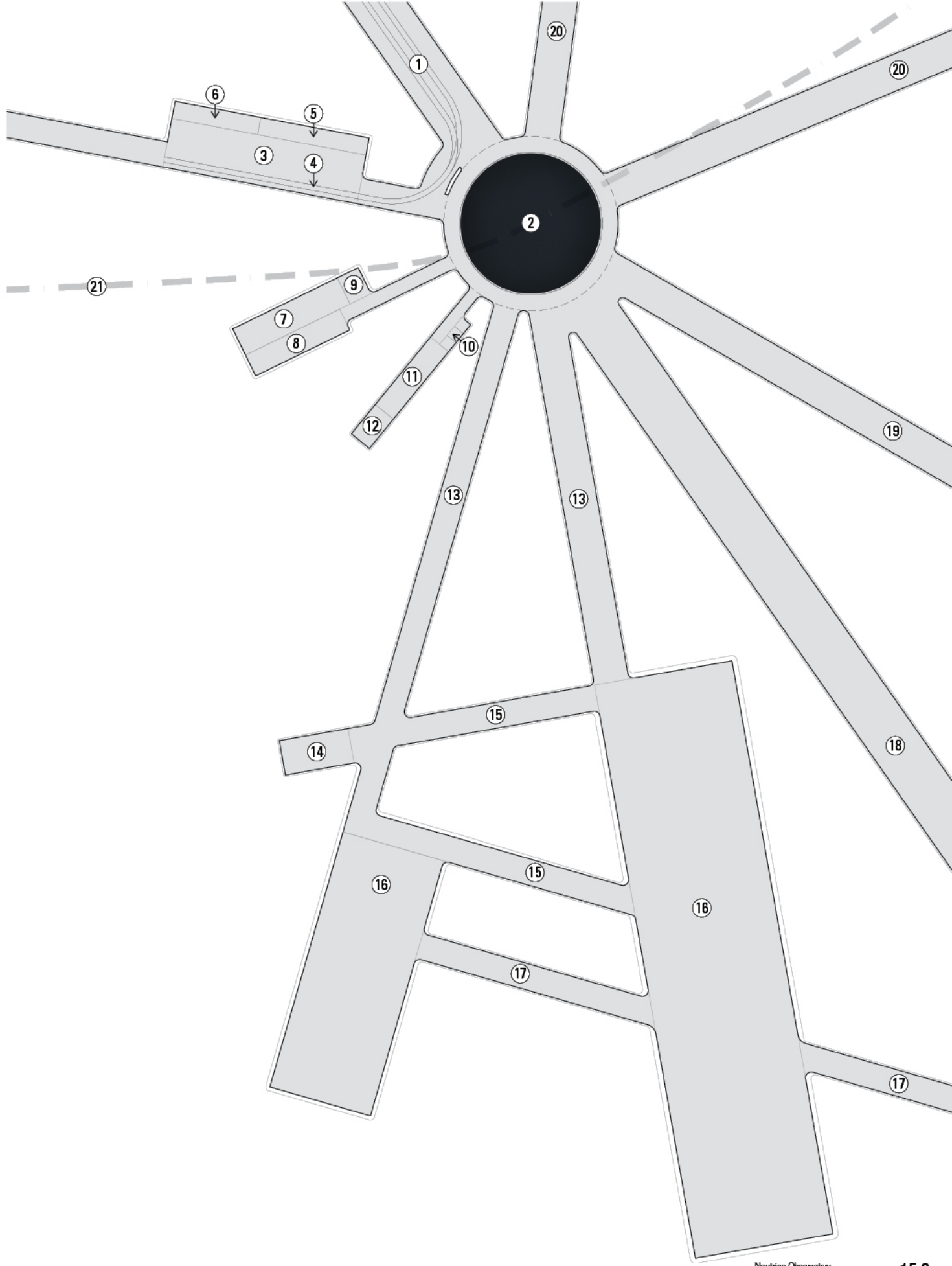


### Legend

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- ① Observatory Access Tunnel
- ② Entrance Hall - Narthex (cooling reservoir below)
- ③ Loading/Staging Area
- ④ Railway Tracks
- ⑤ Washdown Area
- ⑥ Cleaning Facility
- ⑦ Men's Changeroom & Showers
- ⑧ Women's Changeroom & Showers
- ⑨ Laundry
- ⑩ Washrooms
- ⑪ Staff Room (emergency refuge area)
- ⑫ Meeting Room
- ⑬ Experiment Hall Tunnel (high level)
- ⑭ Workshop & Testing Area
- ⑮ Linear Lab Space & Experiment Hall Connection
- ⑯ Large Experiment Hall
- ⑰ Experiment Hall Tunnel (low level) & Low Level Connection
- ⑱ Tunnel to Base of Neutrino Dectector Caverns (means of excavation spoil removal)
- ⑲ Tunnel to Liquid Scintillator Neutrino Detector
- ⑳ Tunnel to Water Cherenkhov Neutrino Detector
- ㉑ Border of France & Italy

Opposite: Drawing 15.0  
Neutrino Observatory  
Plan: Central Cluster



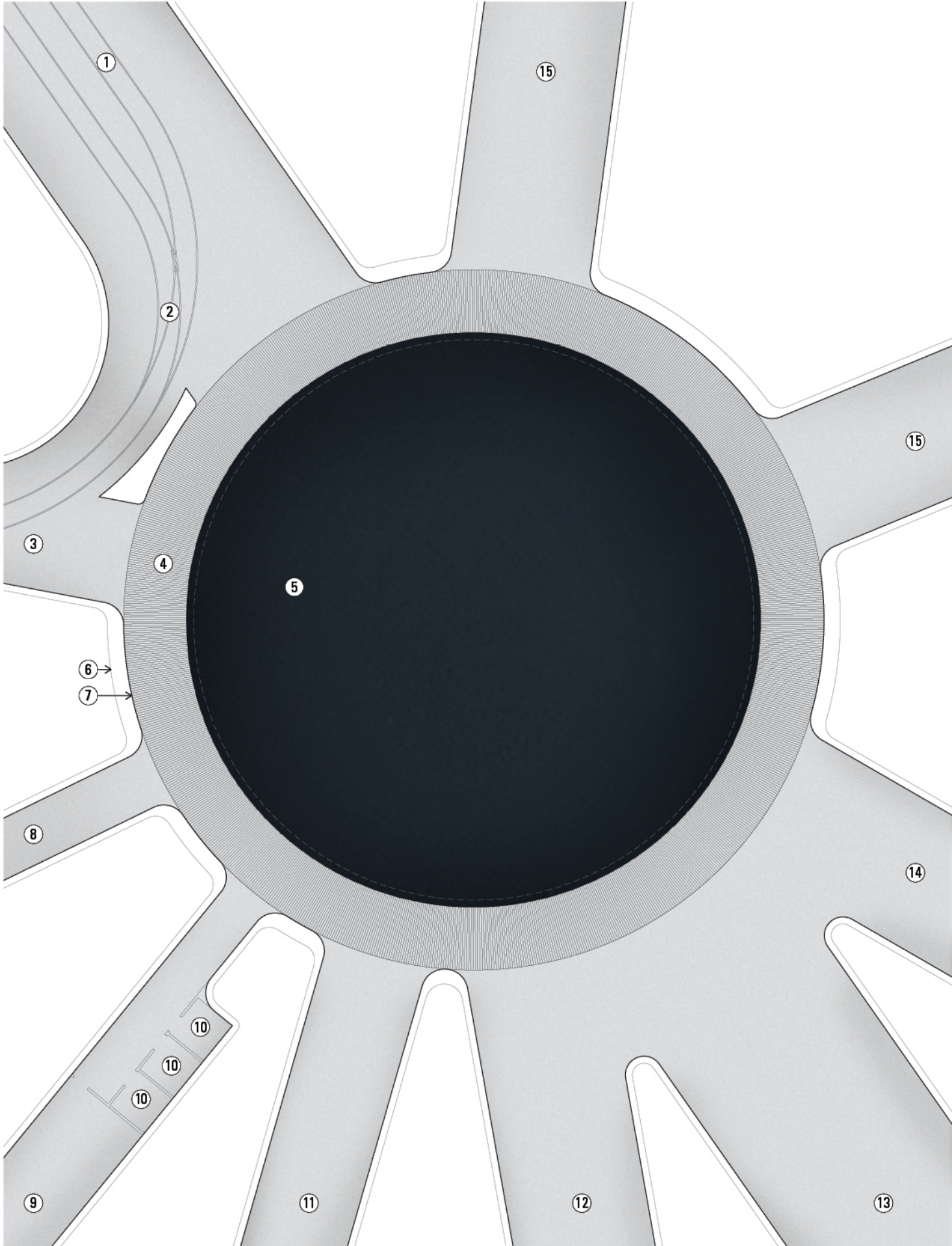
## Legend

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- ① Observatory Access Tunnel
- ② Railway Tracks
- ③ Cleaning & Staging Area
- ④ Perimeter Walkway
- ⑤ Cooling Water Reservoir
- ⑥ Excavation Profile
- ⑦ Final Profile of Trowelled Reinforced Shotcrete Lining
- ⑧ Tunnel to Changerooms & Laundry
- ⑨ Staff Room & Refuge Area
- ⑩ Washroom
- ⑪ Tunnel to Experiment Small Hall
- ⑫ Tunnel to Experiment Large Hall
- ⑬ Tunnel to Bases of Neutrino Detector Caverns
- ⑭ Tunnel to Liquid Scintillator Neutrino Detector
- ⑮ Tunnel to Water Cherenkov Neutrino Detector

Opposite: Drawing 15.1  
Neutrino Observatory  
Plan: Entrance Hall - Narthex





1:100

Neutrino Observatory  
Plan : Entrance Hall - Narthex

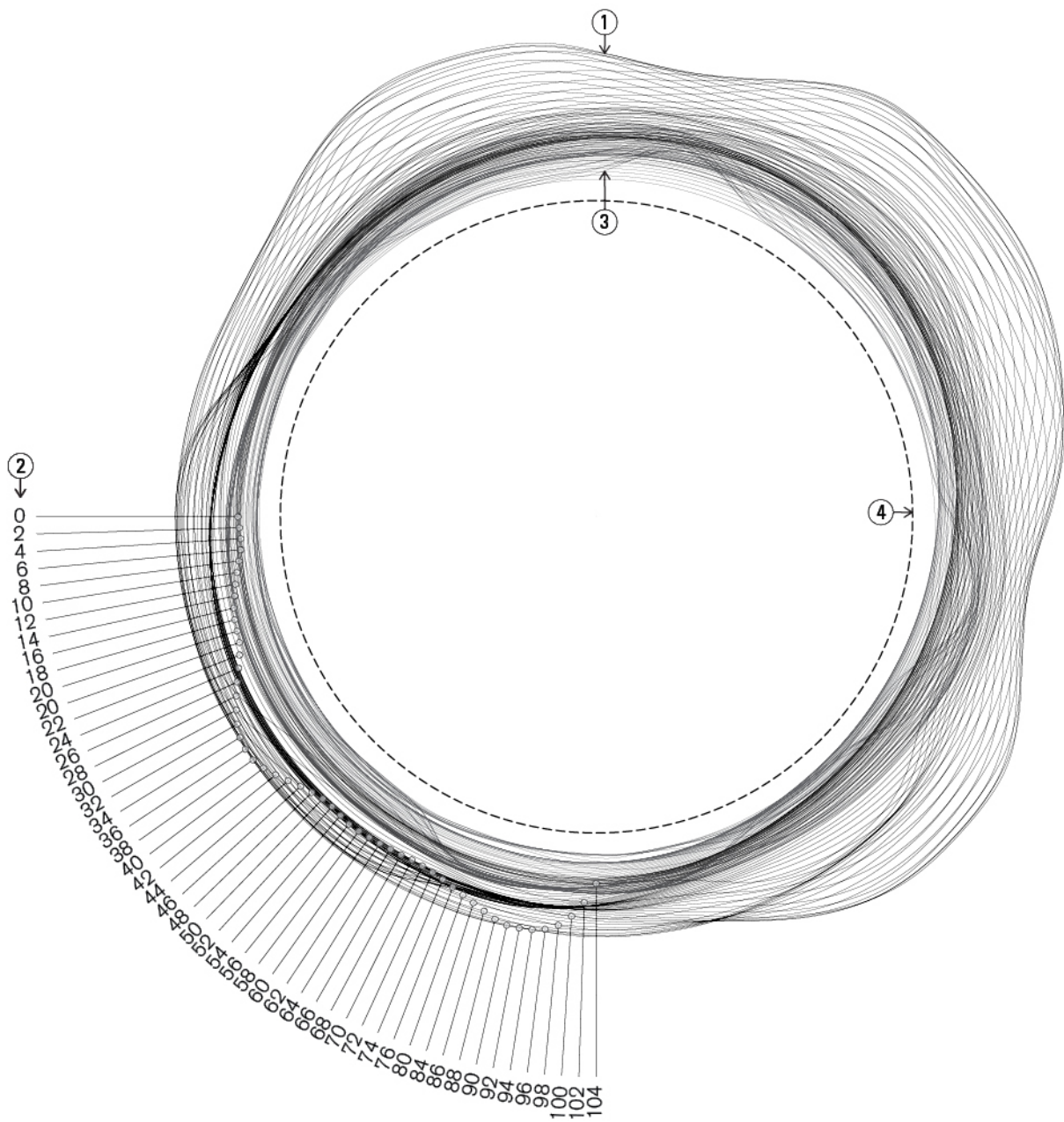
15.1

### **Legend**

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- ① Cavern Profile Contours
- ② Contour Depth Marker (m)
- ③ Tank Profile Contours
- ④ Photo Multiplier Tube Frame Boundary

Opposite: Drawing 15.2  
Neutrino Observatory  
Plan: Detector Cavern Topography



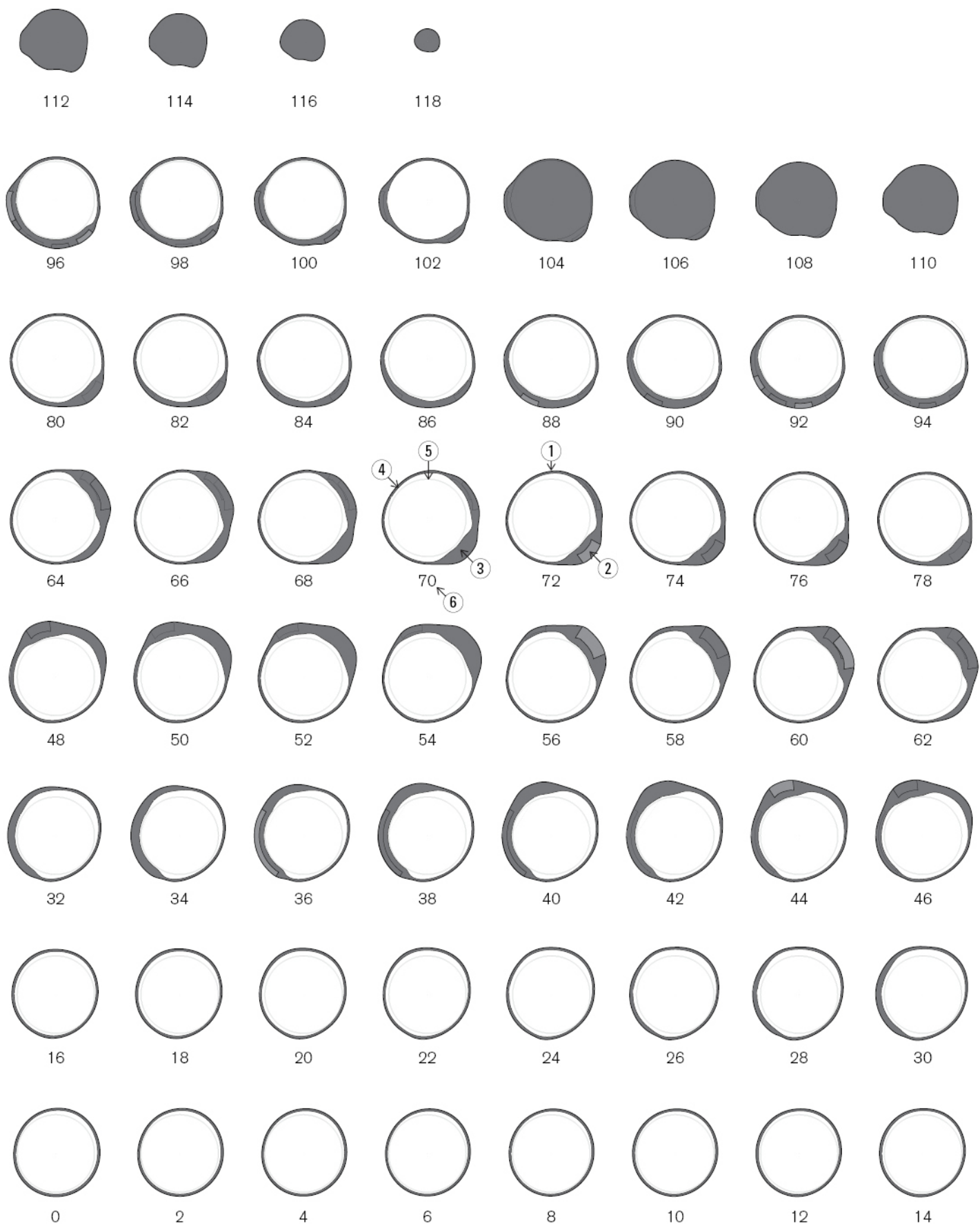


## Legend

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- ① Cavern Profile
- ② Detector Systems Platform
- ③ Helical Airway
- ④ Detector Tanks
- ⑤ Photo Multiplier Tube Frame
- ⑥ Contour Depth

Opposite: Drawing 15.3  
Neutrino Observatory  
Plan: Detector Contours



1:2000

Neutrino Observatory  
Plan : Detector Contours

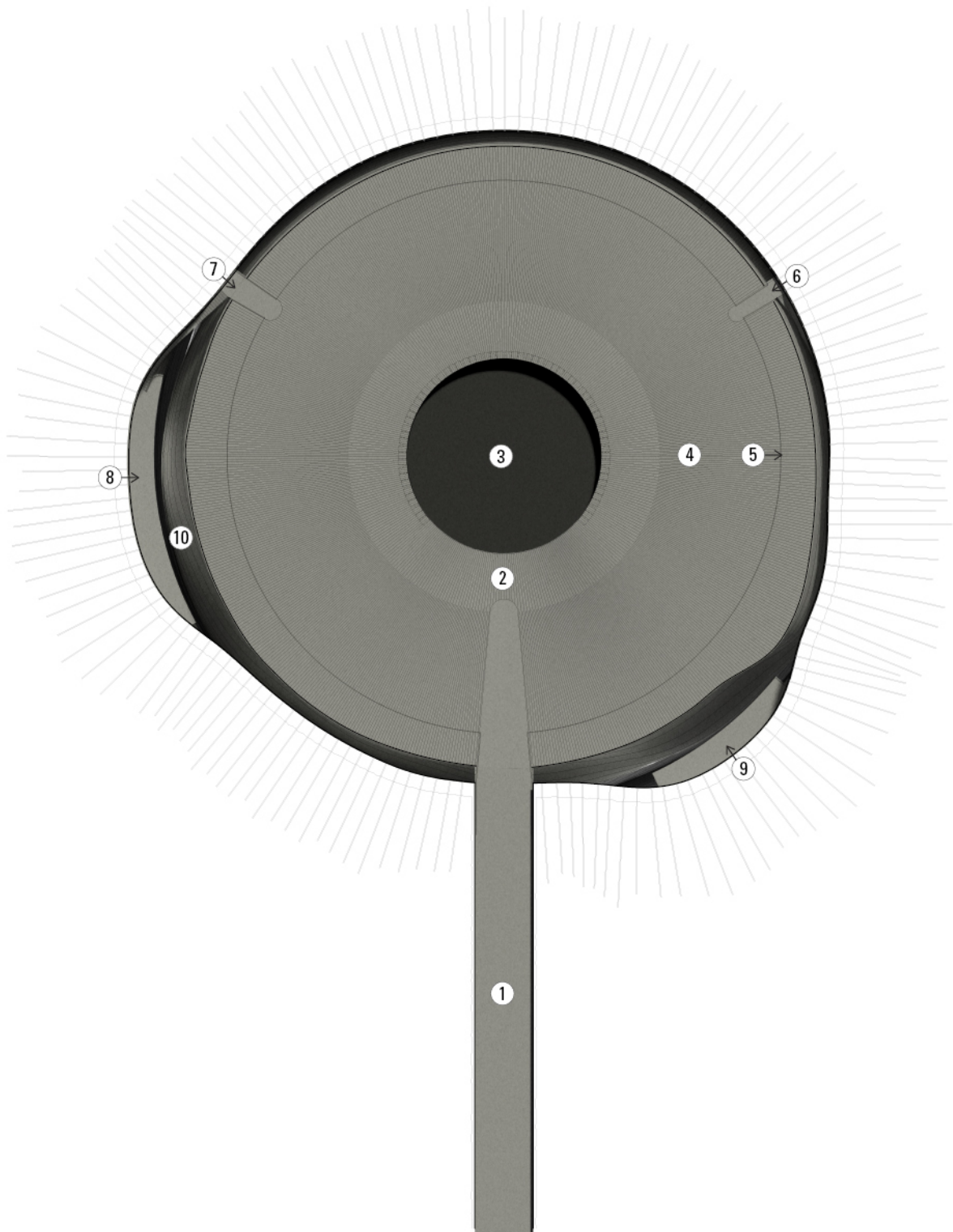
## Legend

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- ① Tunnel from Narthex
- ② Detector Platform (ramping down to data collection area)
- ③ Data Collection Area (top of detector tank)
- ④ Raised Detector Platform
- ⑤ Guard Rail
- ⑥ Staff & Reseracher Stair
- ⑦ Visitor Stair
- ⑧ Control Room Platform Below
- ⑨ Tank Air Purification System Platform

Opposite: Drawing 15.4  
Neutrino Observatory  
Plan: Detector Platform



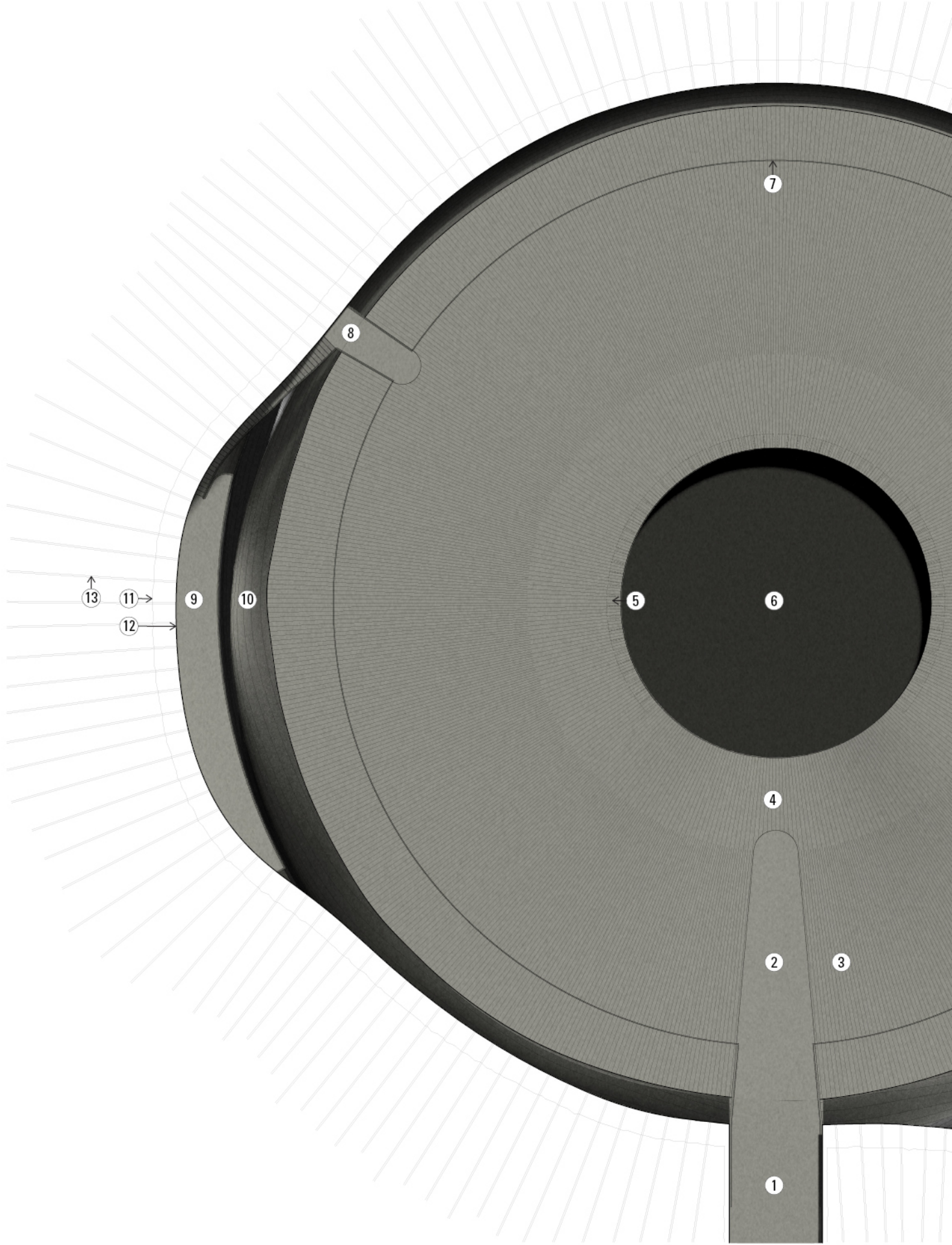


## Legend

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- ① Tunnel from Narthex
- ② Walkway - Lightweight Concrete on Metal Deck
- ③ Raised Platform - Removable Metal Tread Plate (for access to wires below)
- ④ Ramped Platform (sloped down to data collection area)
- ⑤ Data Collection Electronics Racks (edge of raised platform)
- ⑥ Metal Tread Plate Mounted Directly on Top Surface of Stainless Steel Detector Tank
- ⑦ Guard Rail
- ⑧ Top Landing of Visitor Stair (beginning of helical circulation)
- ⑨ Control Room Platform Below
- ⑩ Top of Ventilation Airway
- ⑪ Excavation Profile
- ⑫ Face of Reinforced Shotcrete Lining
- ⑬ Rock Bolt Ground Support

Opposite: Drawing 15.5  
Neutrino Observatory  
Detailed Plan: Detector Platform



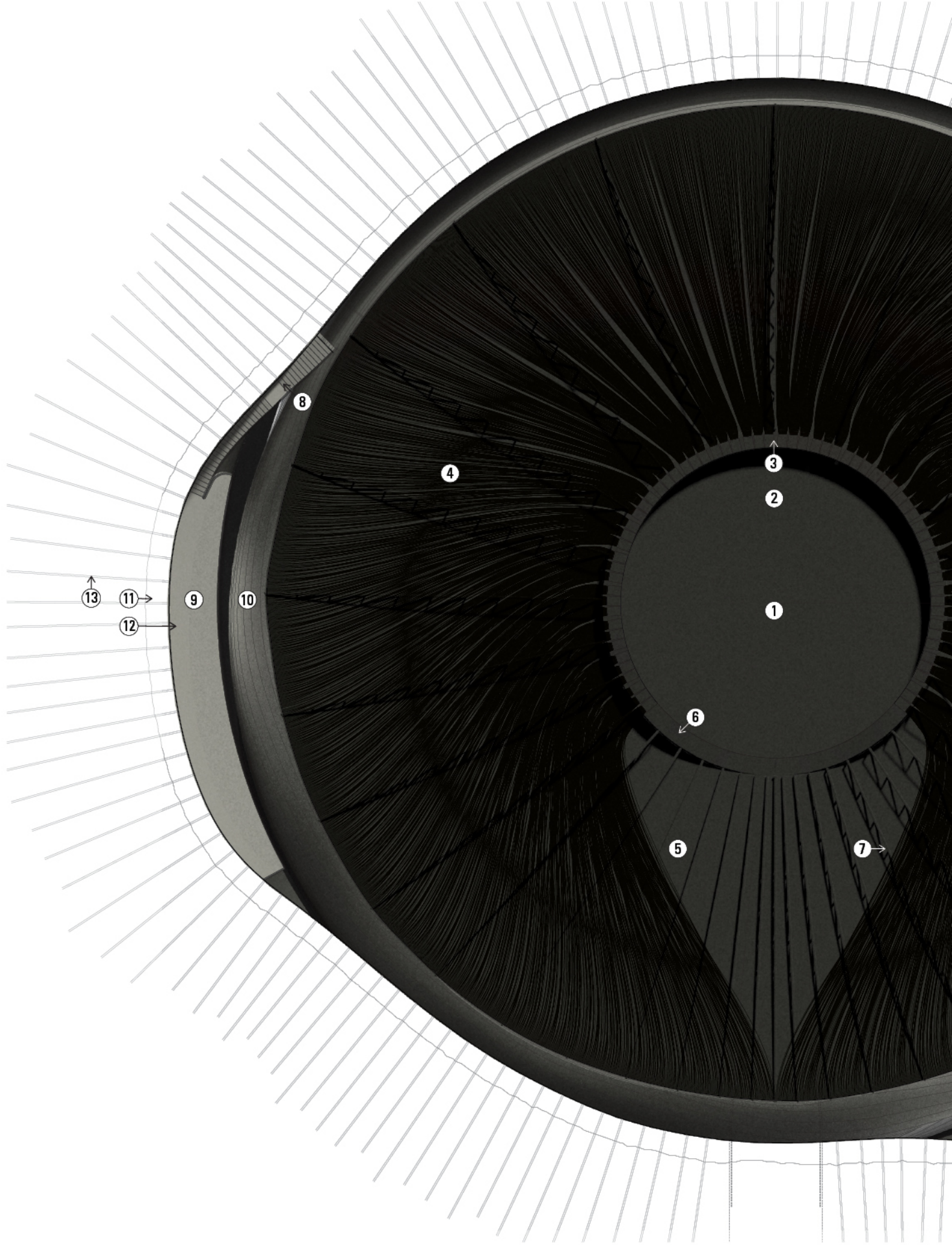
## Legend

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- ① Data Collection Area
- ② Tread Plate Mounted Directly on Surface of Stainless Steel Detector Tank
- ③ Electronics Racks (66 total)
- ④ Cables to Photo Multiplier Tubes (PMTs are linked in groups of 16; 4,224 cables collect light signals from 67,584 PMTs)
- ⑤ Exposed Surface of Stainless Steel Detector Tank
- ⑥ Structural Ring Beam (transfers truss forces)
- ⑦ Steel Trusses (between raised platform and tank)
- ⑧ Visitor Stair (helical circulation)
- ⑨ Control Room Platform Below
- ⑩ Top of Ventilation Airway
- ⑪ Excavation Profile
- ⑫ Face of Reinforced Shotcrete Lining
- ⑬ Rock Bolt Ground Support

Opposite: Drawing 15.6  
Neutrino Observatory  
Detailed Plan: Data Gathering



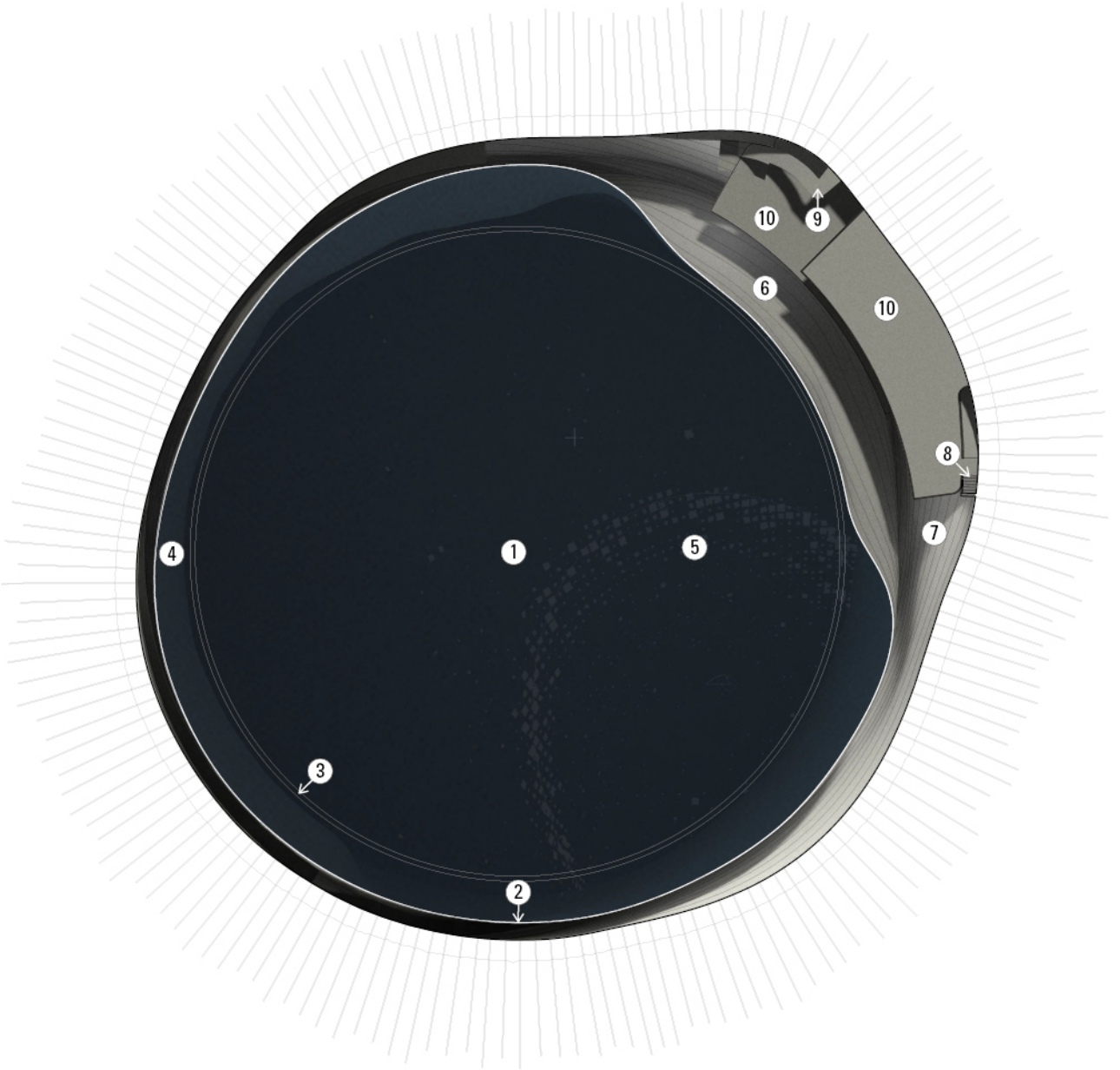


## Legend

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- ① Water Cherenkov Neutrino Detector
- ② Stainless Steel Tank Wall
- ③ Photo Multiplier Tube Frame
- ④ Veto Area (reject non-neutrino background signals)
- ⑤ Signal from Blue Cherenkov Radiation Light Cone (graphic representation)
- ⑥ Detector Tank Below
- ⑦ Cavern Lining Below
- ⑧ Visitor Stair
- ⑨ Staff & Reseracher Stair
- ⑩ Detector Systems Platform

Opposite: Drawing 15.7  
Neutrino Observatory  
Plan: Detector Systems Platforms



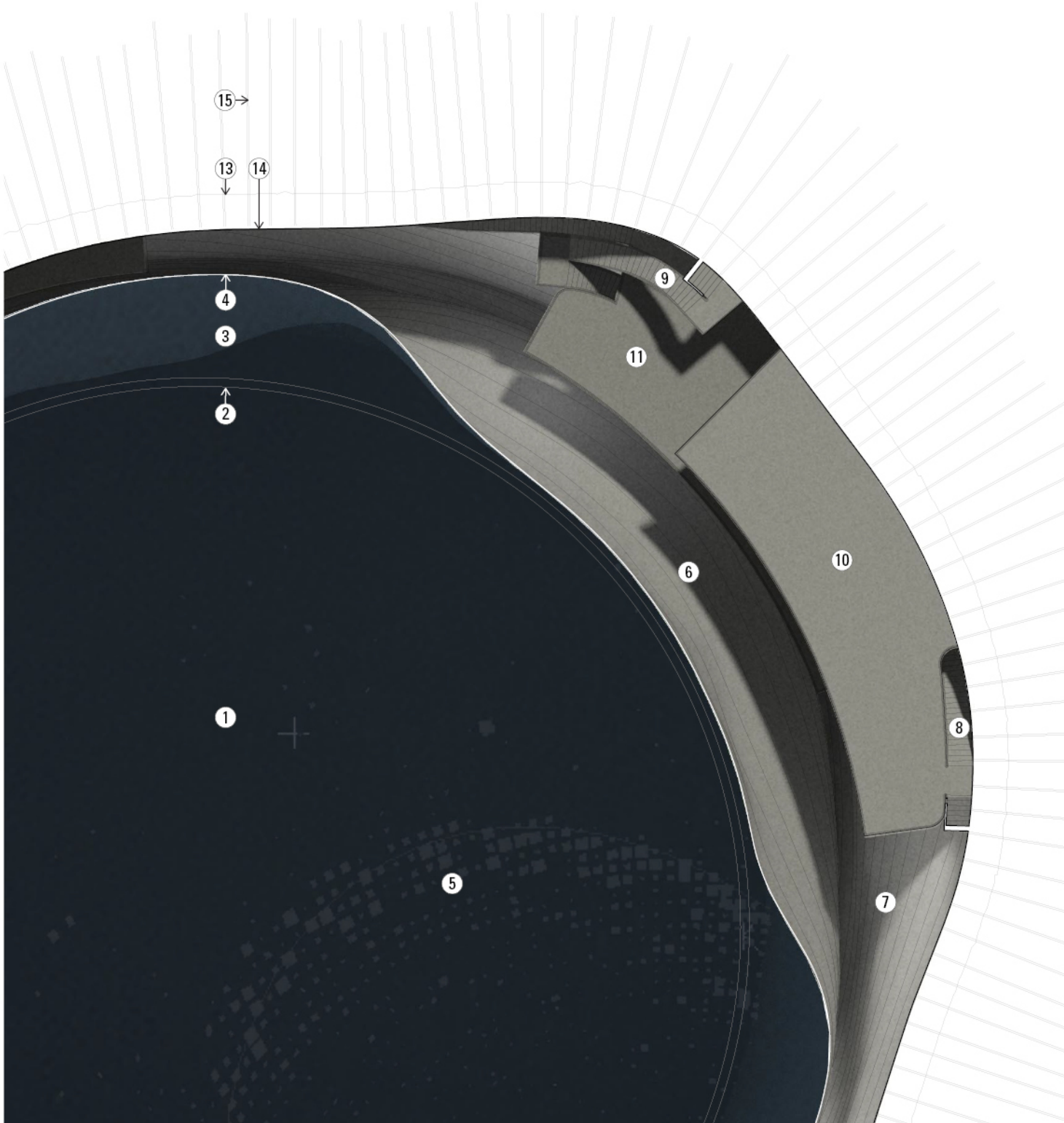
## Legend

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- ① Ultra Pure Water (332 kilotons)
- ② Photo Multiplier Tube Frame
- ③ Veto Area (reject non-neutrino background signals)
- ④ Stainless Steel Tank Wall
- ⑤ Signal from Blue Cherenkov Radiation Light Cone (graphic representation)
- ⑥ Helical Ventilation Airway (detector tank below)
- ⑦ Cavern Lining Below
- ⑧ Visitor Stair
- ⑨ Staff & Reseracher Stair
- ⑩ Water De-ionization Equipment Platform
- ⑪ Water De-gassing Equipment Platform
- ⑫ Top of Ventilation Airway
- ⑬ Excavation Profile
- ⑭ Face of Reinforced Shotcrete Lining
- ⑮ Rock Bolt Ground Support

Opposite: Drawing 15.8  
Neutrino Observatory  
Detailed Plan: Detector Systems Platforms



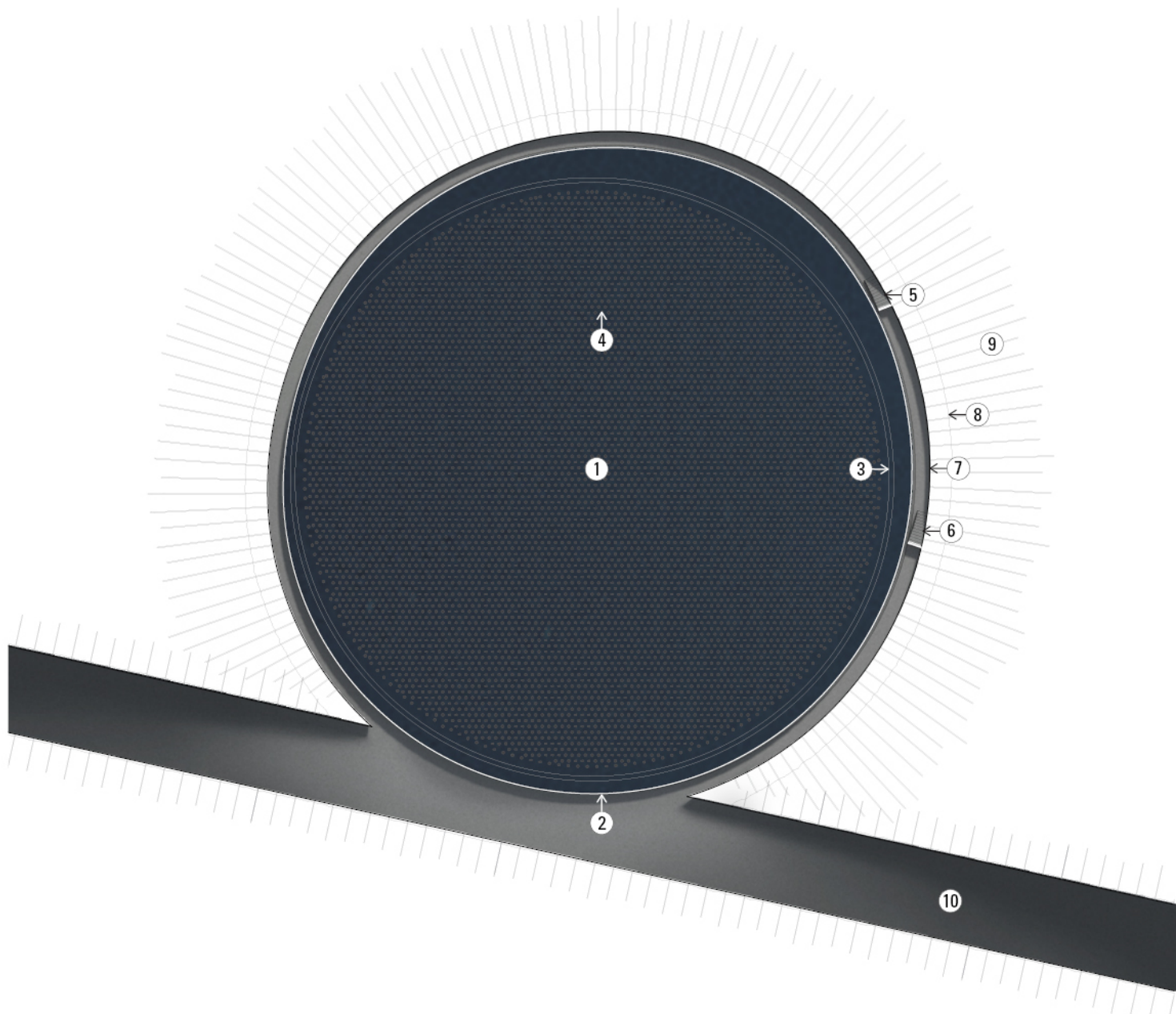


## Legend

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- ① Water Cherenkov Neutrino Detector
- ② Stainless Steel Tank Wall
- ③ Photo Multiplier Tube Frame
- ④ Photo Multiplier Tube Array on Bottom of Detector
- ⑤ Staff & Reseracher Stair
- ⑥ Visitor Stair
- ⑦ Face of Reinforced Shotcrete Lining
- ⑧ Excavation Profile
- ⑨ Rock Bolt Ground Support
- ⑩ Tunnel to Base of Neutrino Detectors and Narthex

Opposite: Drawing 15.9  
Neutrino Observatory  
Plan: Detector Base



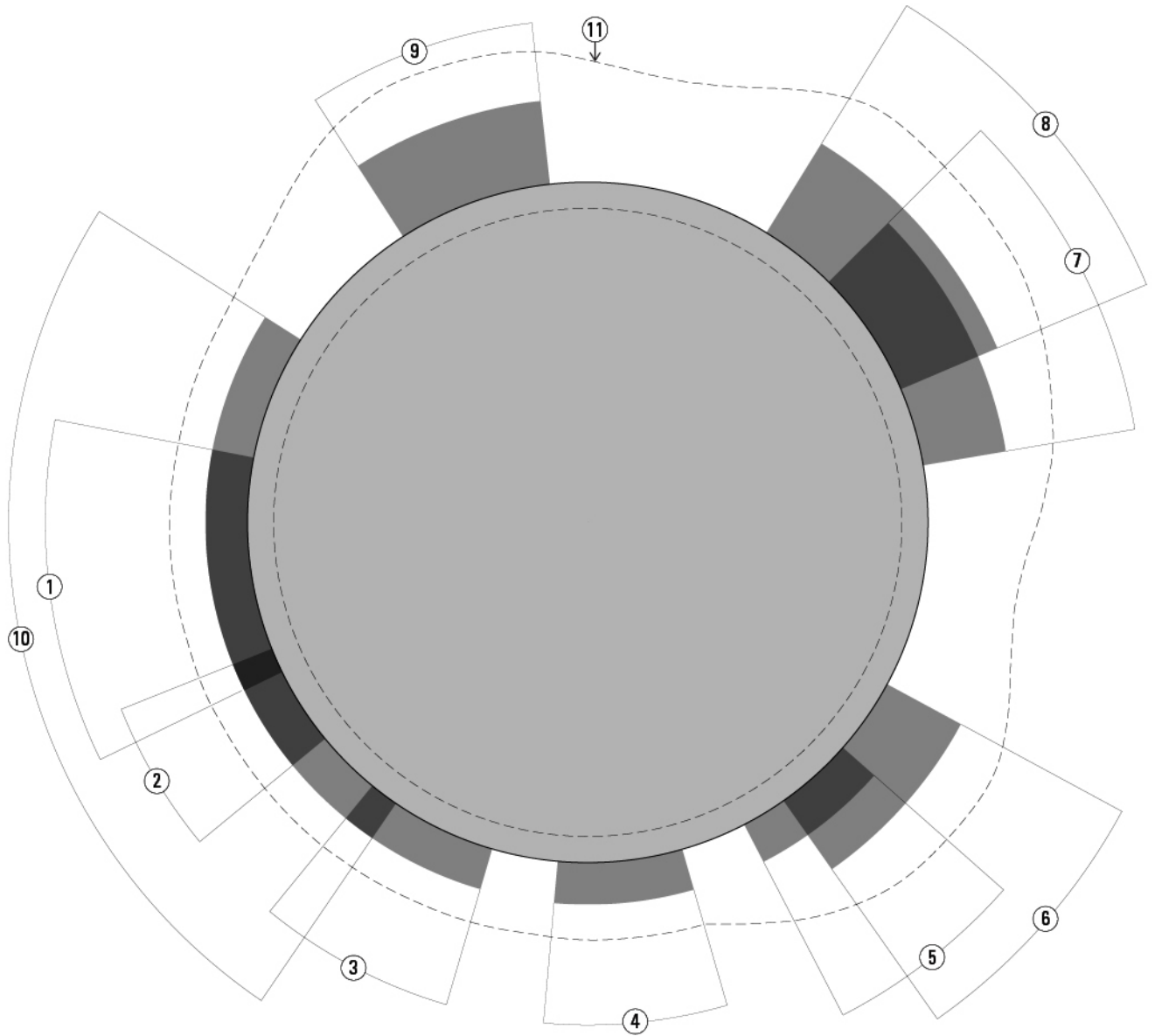
## Legend

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- ① Control Room
- ② Equipment Storage
- ③ Power & Electrical Transformers
- ④ Cooling Equipment
- ⑤ Tank Air Purification
- ⑥ Water UV Treatment
- ⑦ Water De-gassing
- ⑧ Water De-ionization
- ⑨ Water Pumping
- ⑩ Water Ultrafiltration
- ⑪ Cavern Profile

Opposite: Drawing 15.10  
Neutrino Observatory  
Plan: Detector Systems Diagram



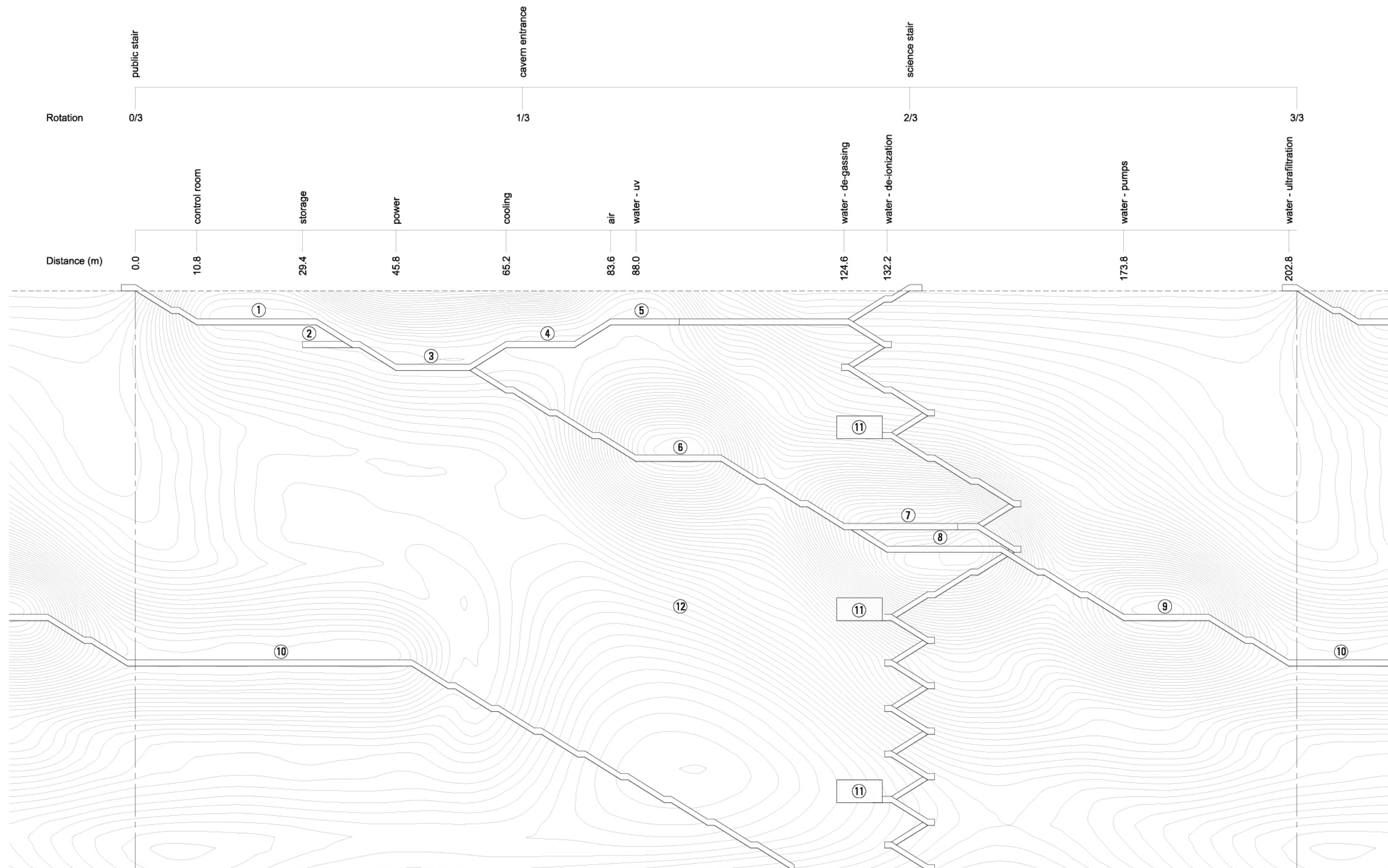


## Legend

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- ① Control Room
- ② Equipment Storage
- ③ Power & Electrical Transformers
- ④ Cooling Equipment
- ⑤ Tank Air Purification
- ⑥ Water UV Treatment
- ⑦ Water De-gassing
- ⑧ Water De-ionization
- ⑨ Water Pumping
- ⑩ Water Ultrafiltration
- ⑪ Refuge Area
- ⑫ Cavern Contours (distance of cavern lining from detector centre line transposed as topographic contour lines)

Opposite: Drawing 15.11  
Neutrino Observatory  
Elevation: Detector Systems



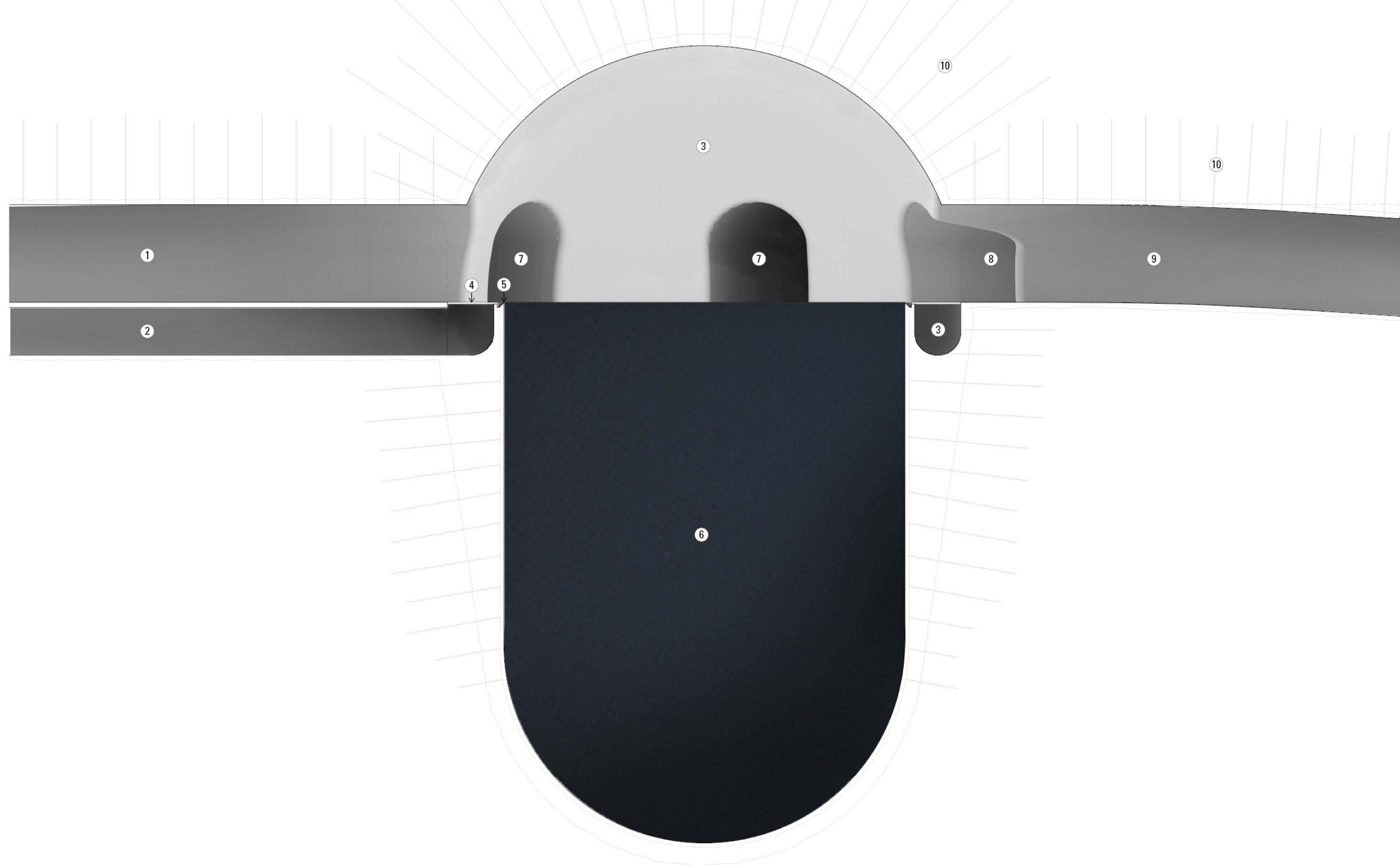
**Legend**

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- ① Observatory Access Tunnel - Fresh Air
- ② Observatory Access Tunnel - Exhaust Air Plenum
- ③ Narthex Dome (trowelled reinforced shotcrete with smooth rubbed parging)
- ④ Perimeter Walkway (removeable perforated metal grating)
- ⑤ Back-sloped Vanishing Pool Edge & Diffuse Dome Lighting Cove
- ⑥ Cooling Water Reservoir
- ⑦ Tunnel to Water Cherenkov Neutrino Detector
- ⑧ Tunnel to Liquid Scintillator Neutrino Detector
- ⑨ Tunnel to Base of Neutrino Detectors
- ⑩ Rock Bolt Ground Support

Opposite: Drawing 16.0  
Neutrino Observatory  
Entrance Hall Section



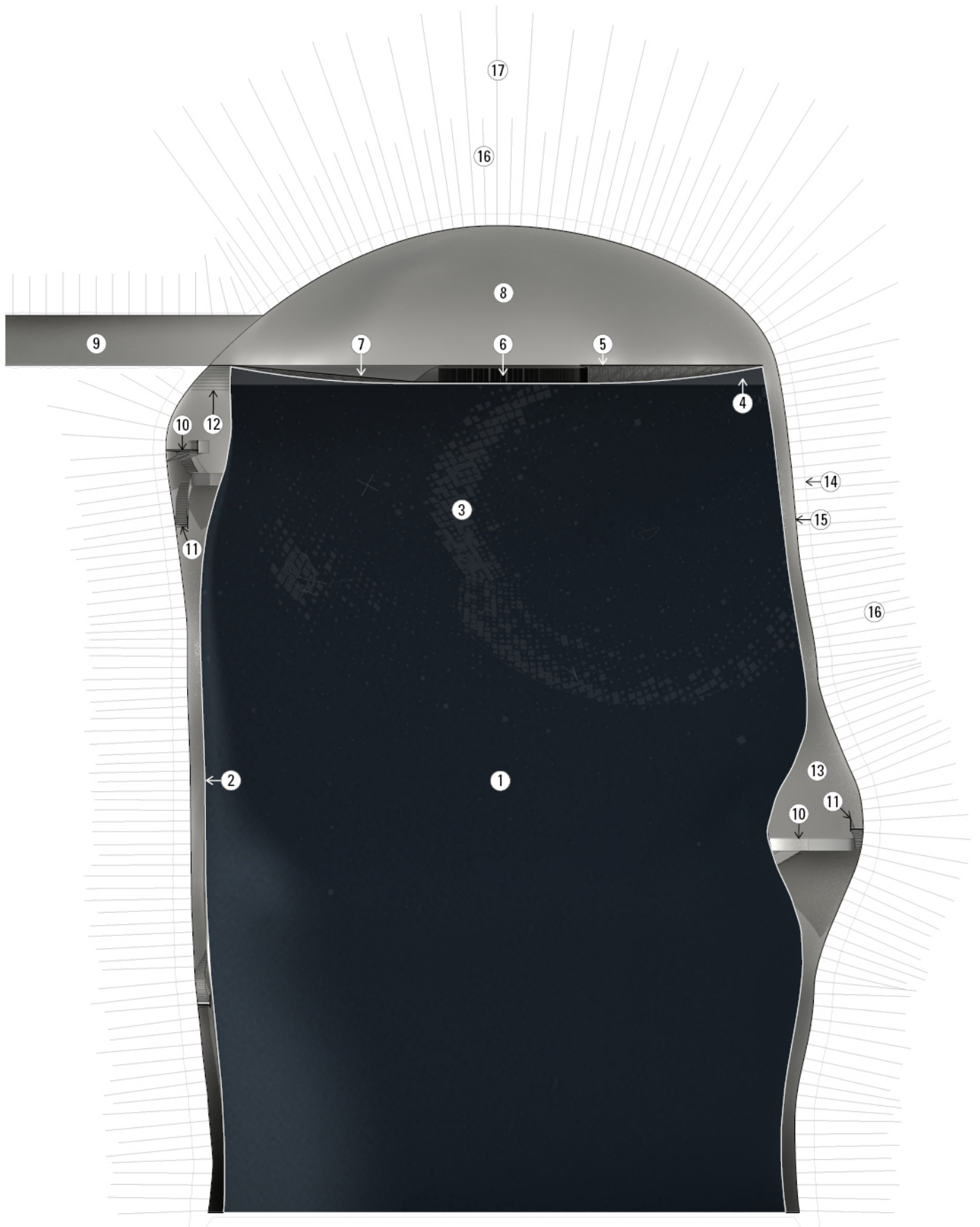


#### Legend

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- ① Ultra Pure Water (332 kilotons)
- ② Stainless Steel Tank Wall
- ③ Signal from Blue Cherenkov Radiation Light Cone (graphic representation)
- ④ Air Space (purification of air needed to remove build-up of trace radioactivity)
- ⑤ Raised Platform
- ⑥ Data Collection Electronics Racks
- ⑦ Dip in Raised Platform - Ramp Down to Data Collection Area
- ⑧ Cavern Dome (diffuse perimeter lighting)
- ⑨ Tunnel to Narthex
- ⑩ Service Equipment Platform
- ⑪ Visitor Stair
- ⑫ Cooling Coils (draw heat from air rising through helical ventilation airway)
- ⑬ Helical Ventilation Airway
- ⑭ Excavation Profile
- ⑮ Surface of Reinforced Shotcrete Lining (1.5m - 2.3m thick)
- ⑯ Rock Bolt Ground Support (12m)
- ⑰ Rock Bolt Ground Support (25m)

Opposite: Drawing 16.1  
Neutrino Observatory  
Neutrino Detector Section



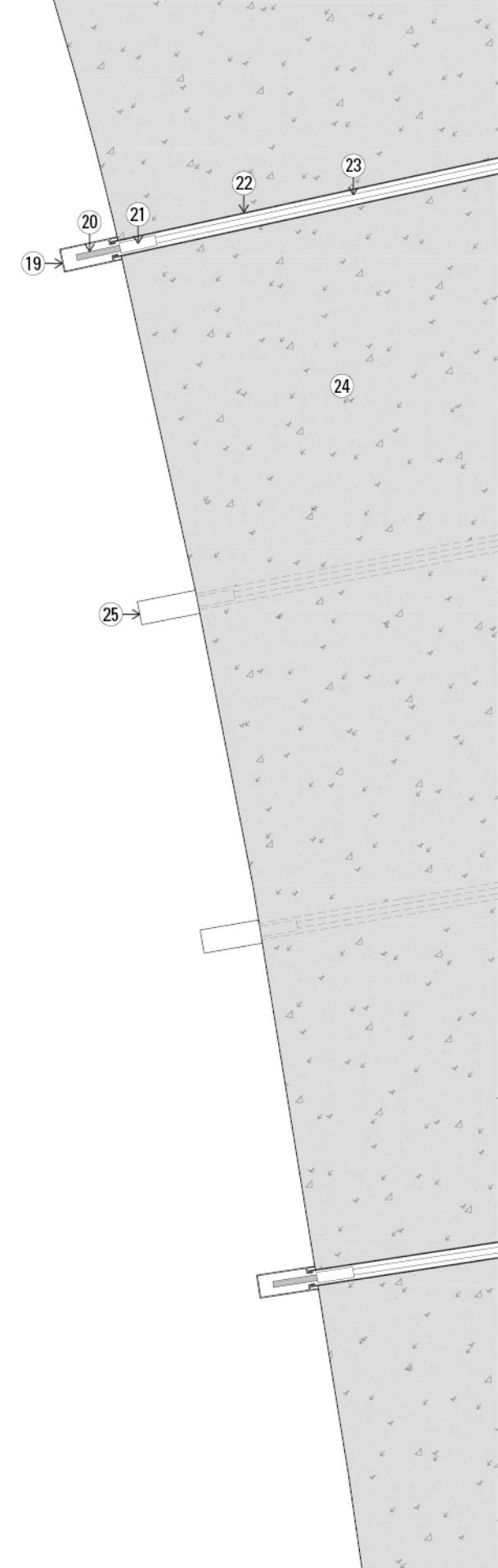
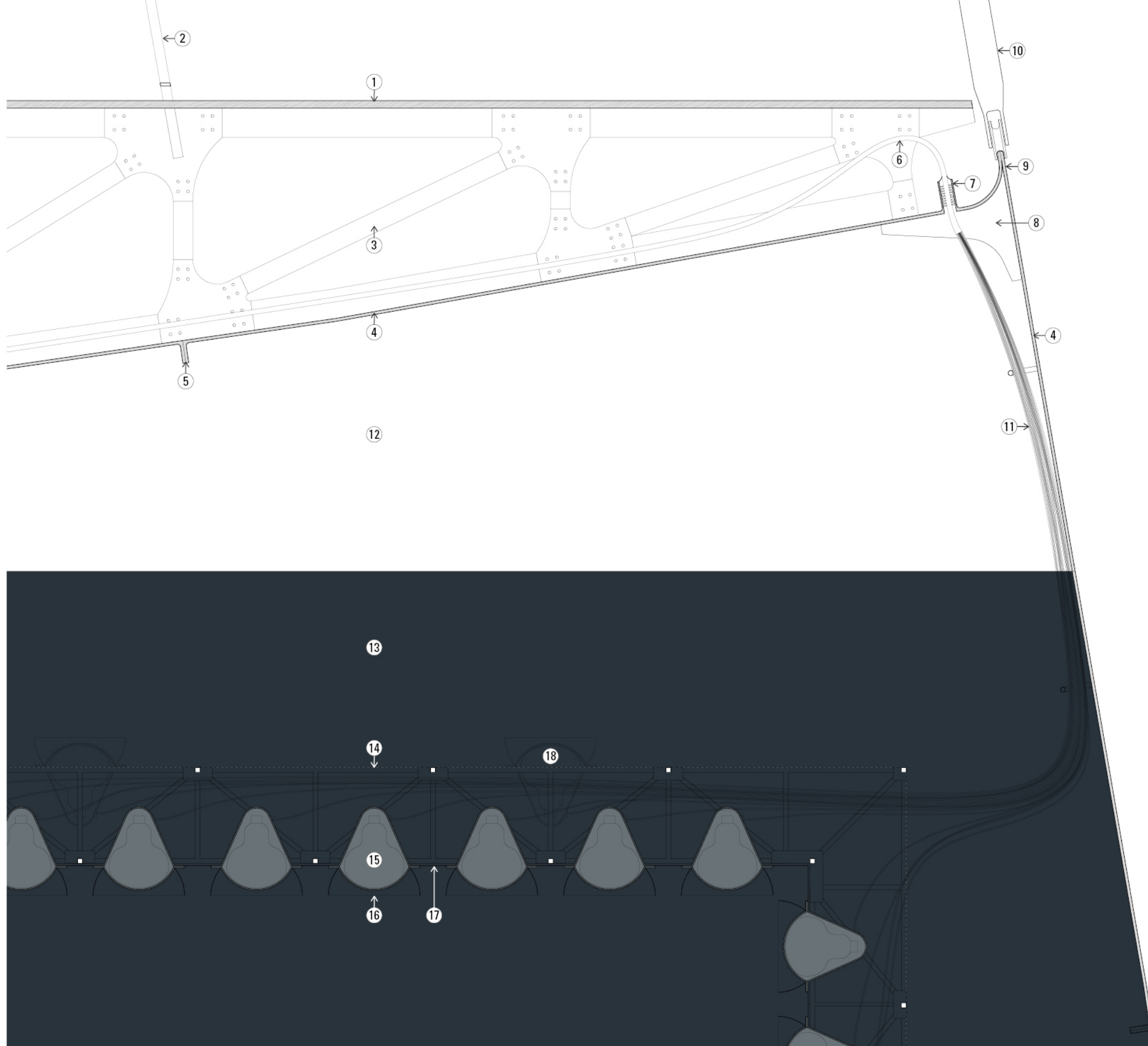
## Legend

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- ① Raised Platform
- ② Guard Rail
- ③ Steel Truss
- ④ Stainless Steel Tank Top
- ⑤ Welded Seam Between Tank Panels  
(panellized for transport and site assembly)
- ⑥ Bundle of Photo Multiplier Tube (PMT) Cables
- ⑦ Gasketed Light and Air-Tight Poke-Through
- ⑧ Stainless Steel Plate Edge Gusset
- ⑨ Rolled and Thicked Edge to Receive Gantry Roller
- ⑩ Gantry Crane
- ⑪ PMT Cables
- ⑫ Air Space
- ⑬ Ultra Pure Water (detection medium)
- ⑭ Stainless Steel Space Frame to Support PMT Array
- ⑮ Photo Multiplier Tube (67584 total)
- ⑯ Reflector (concentrates light to improve sensitivity)
- ⑰ Black Poly Ethylene Light Shield
- ⑱ Veto Region Photo Multiplier Tube
- ⑲ Protective Cap for Anchor
- ⑳ Threaded Rod Anchor (support point for maintenance or future equipment)
- ㉑ Splice Connector
- ㉒ Sheath
- ㉓ Rock Bolt Extension (steel rod)
- ㉔ Trowelled Shotcrete Lining (1.5m - 2.3m thick)
- ㉕ Anchor Cap Beyond

Opposite: Drawing 17.0  
Neutrino Observatory  
Detector Platform, Tank & Cavern



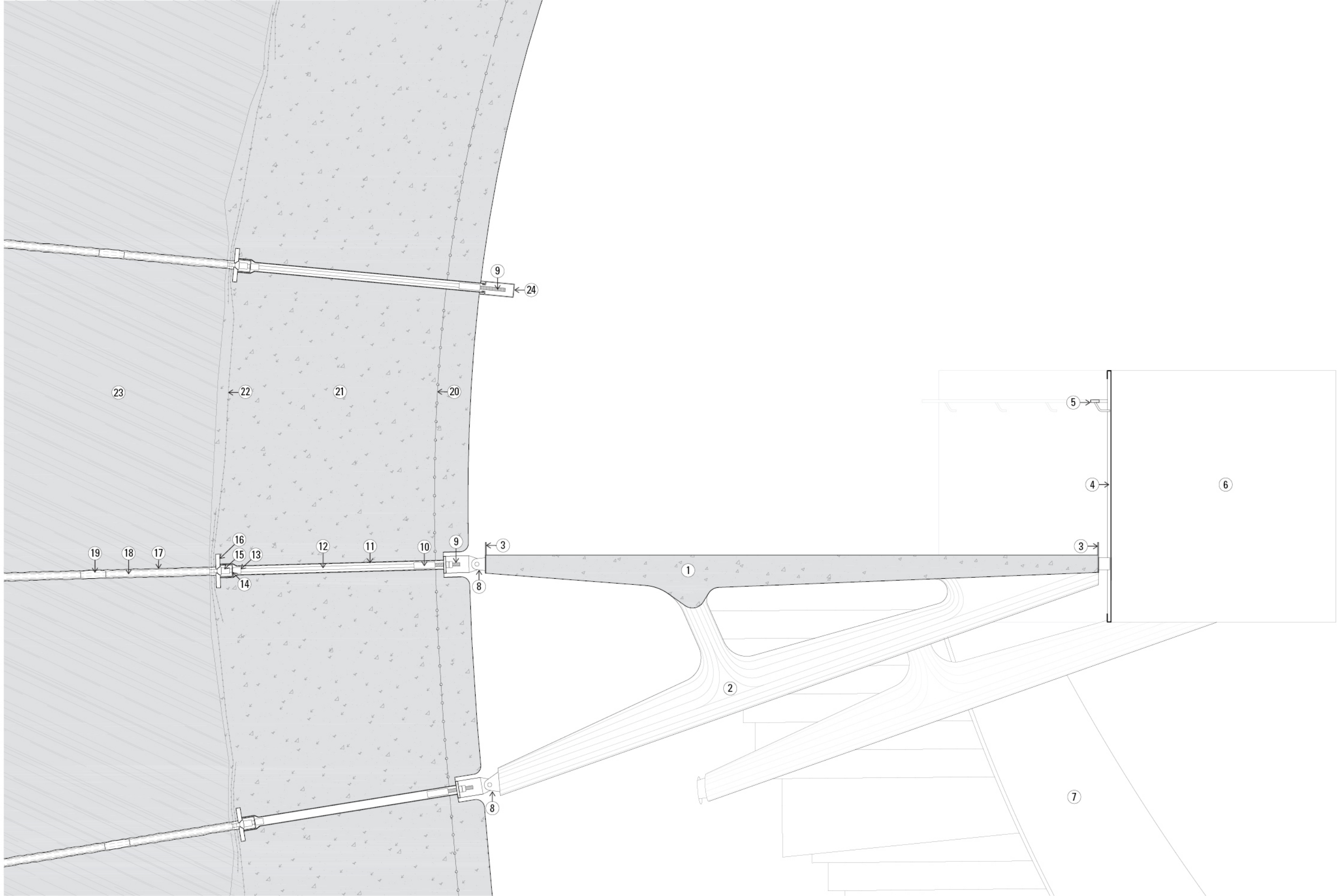


### Legend

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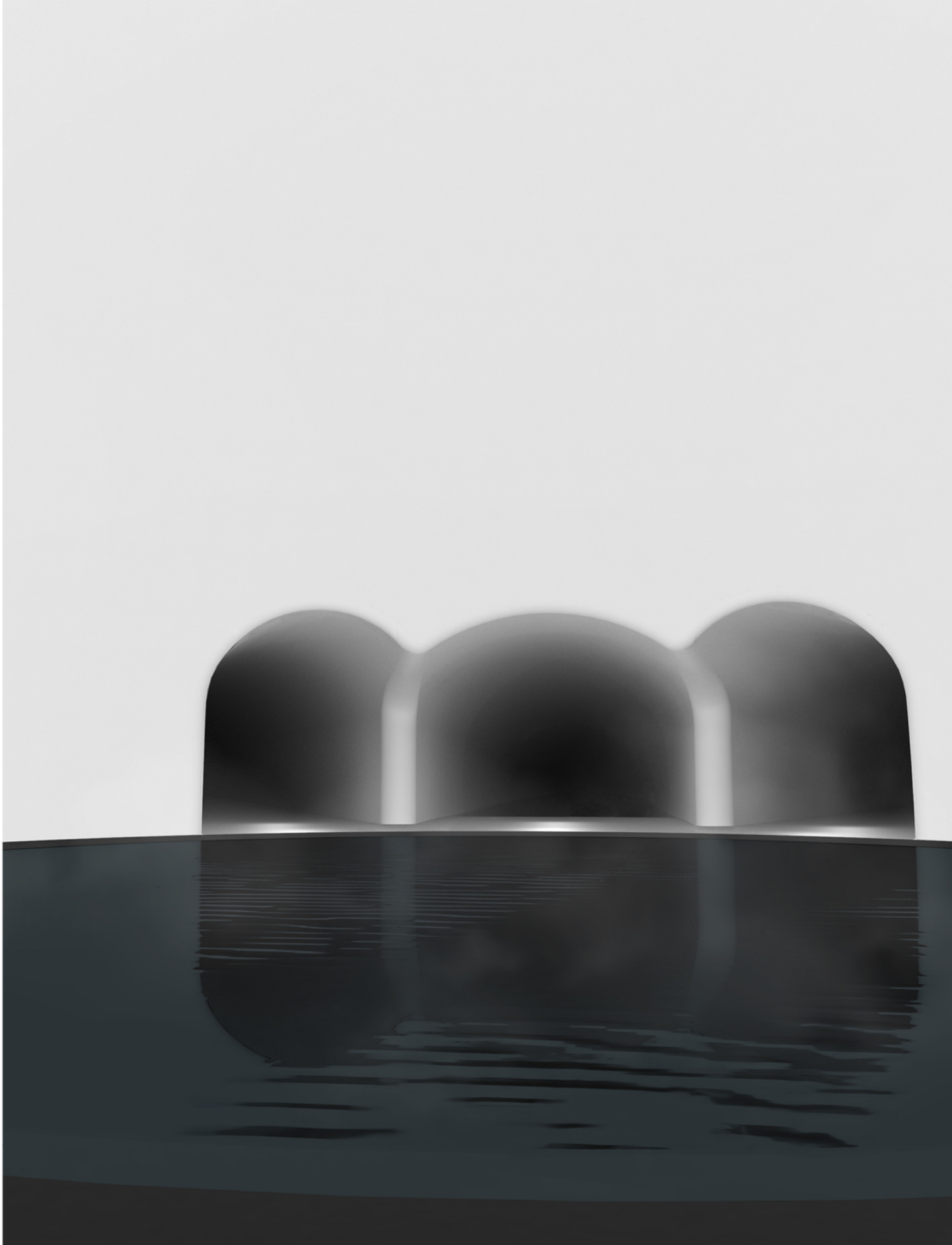
- ① Precast Concrete Detector Systems Platform
- ② Precast Concrete Beam
- ③ Steel Plate Raised Deck Edge
- ④ Painted Bent Steel Plate Guard
- ⑤ Painted Steel Hand Rail
- ⑥ Guard Beyond
- ⑦ Visitor Stair Beyond
- ⑧ Hinged Connection
- ⑨ Threaded Rod Anchor Point
- ⑩ Splice Connector
- ⑪ Plastic Sheath
- ⑫ Steel Rod Rock Bolt Extension
- ⑬ High Strength Plastic Nut
- ⑭ Water Proof Cap
- ⑮ Domed Nut (adjustable concave seat in pressure plate)
- ⑯ Steel Pressure Plate
- ⑰ Bore Diameter
- ⑱ Grouted Rock Bolt
- ⑲ Spacer (ensure even grouting)
- ⑳ Steel Reinforcing
- ㉑ Concrete Cavern Lining (1.5m - 2.3m thick)
- ㉒ Expanded Metal Mesh (temporary ground support)
- ㉓ Unexcavated Rock
- ㉔ Anchor Point Cap

Opposite: Drawing 17.1  
Neutrino Observatory  
Systems Equipment Platforms

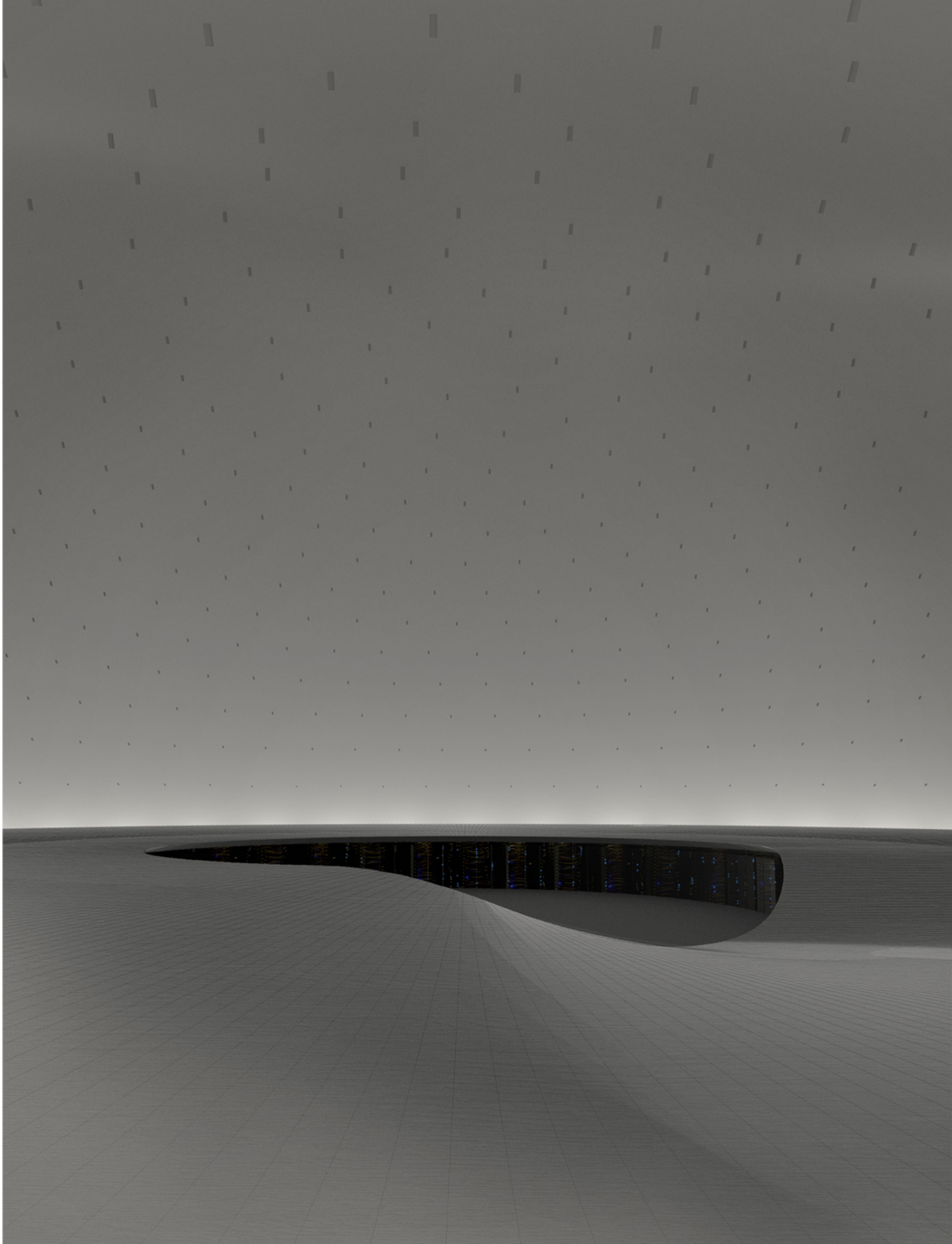


Opposite: Drawing 18.0  
Neutrino Observatory  
View from the Access Tunnel Into the  
Entrance Hall



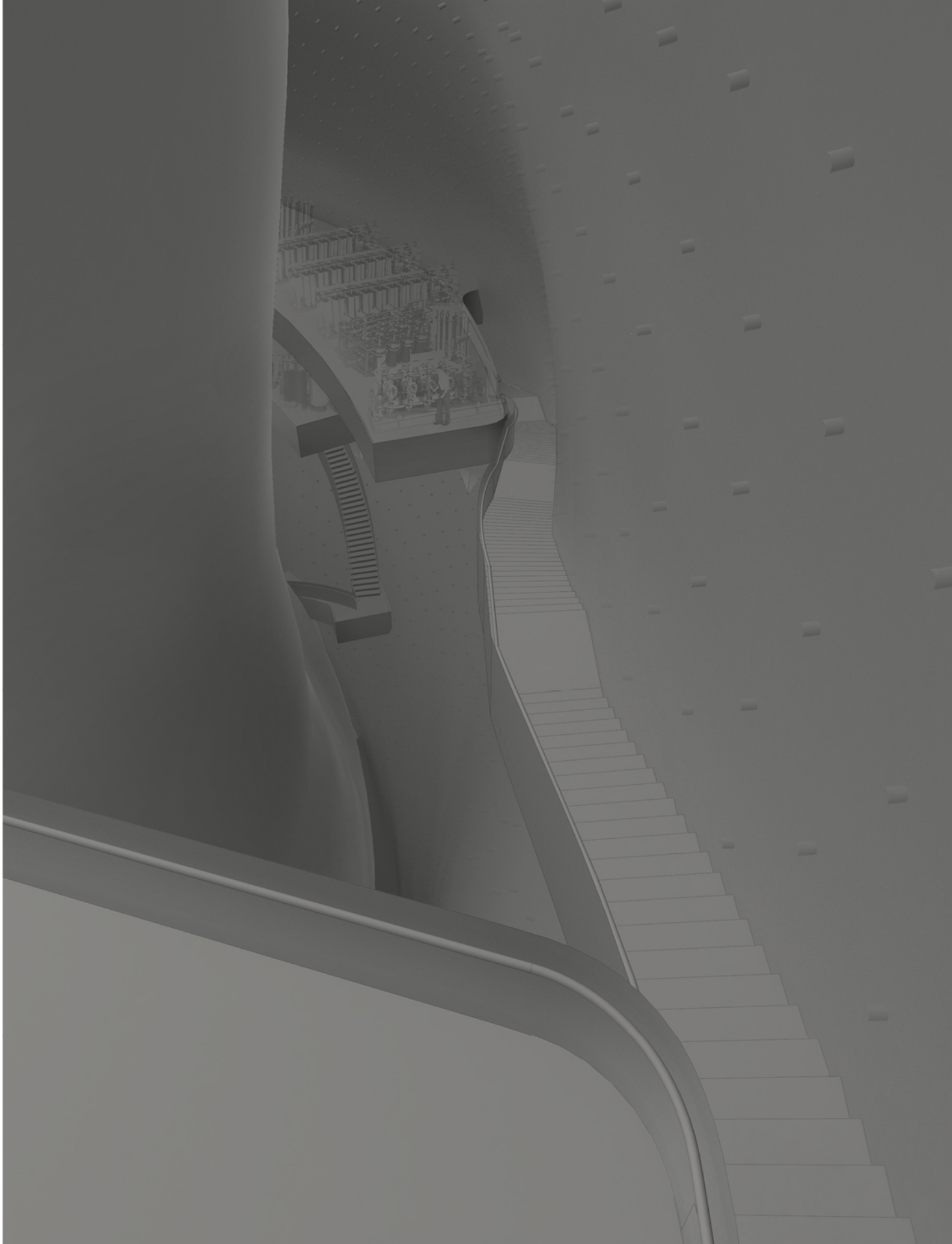


Opposite: Drawing 18.1  
Neutrino Observatory  
View from the Top of the Neutrino  
Detector

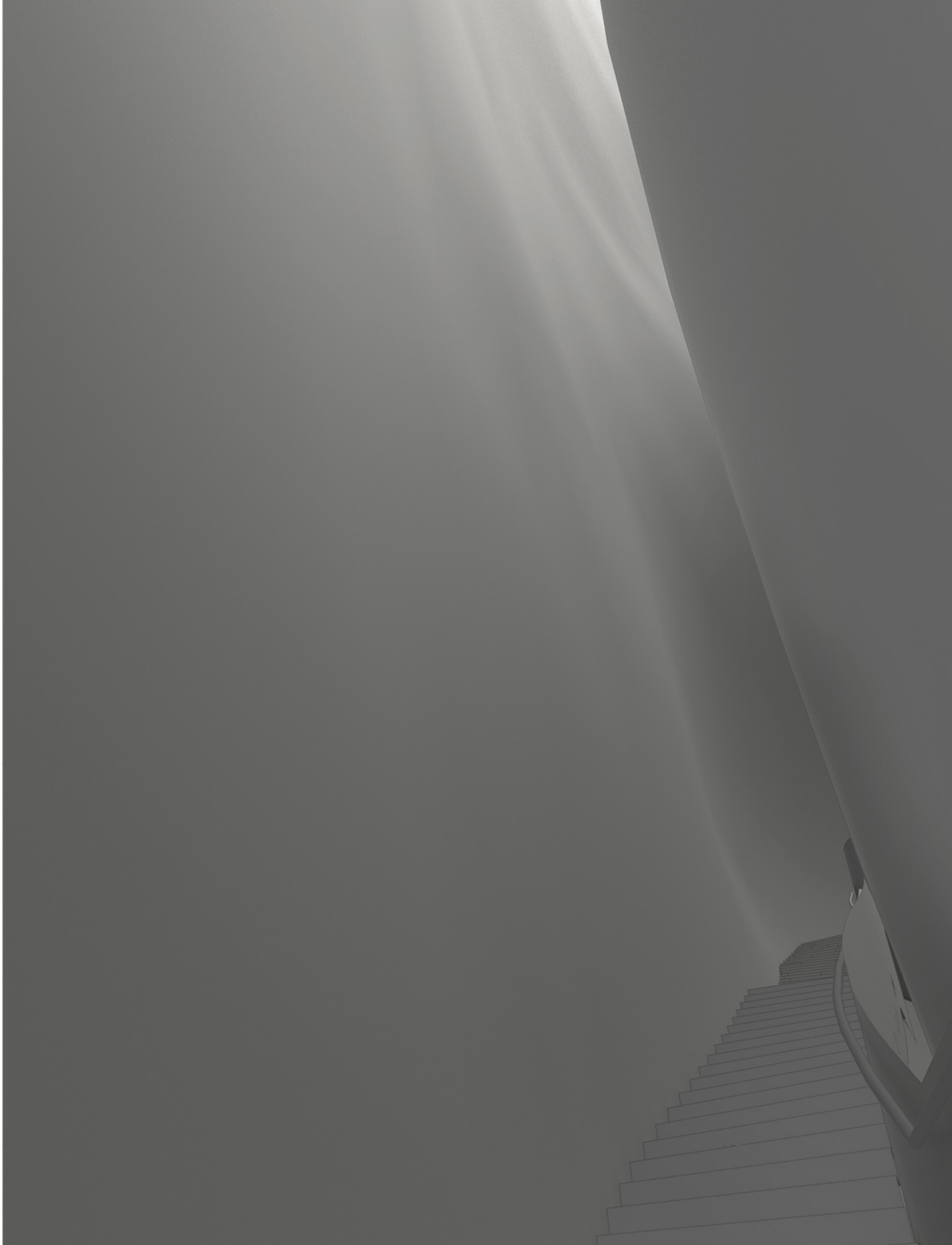


Opposite: Drawing 18.2  
Neutrino Observatory  
View Along the Visitor Stair, Midway  
Down the Detector





Opposite: Drawing 18.3  
Neutrino Observatory  
View Looking Up From the Base of the  
Detector







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