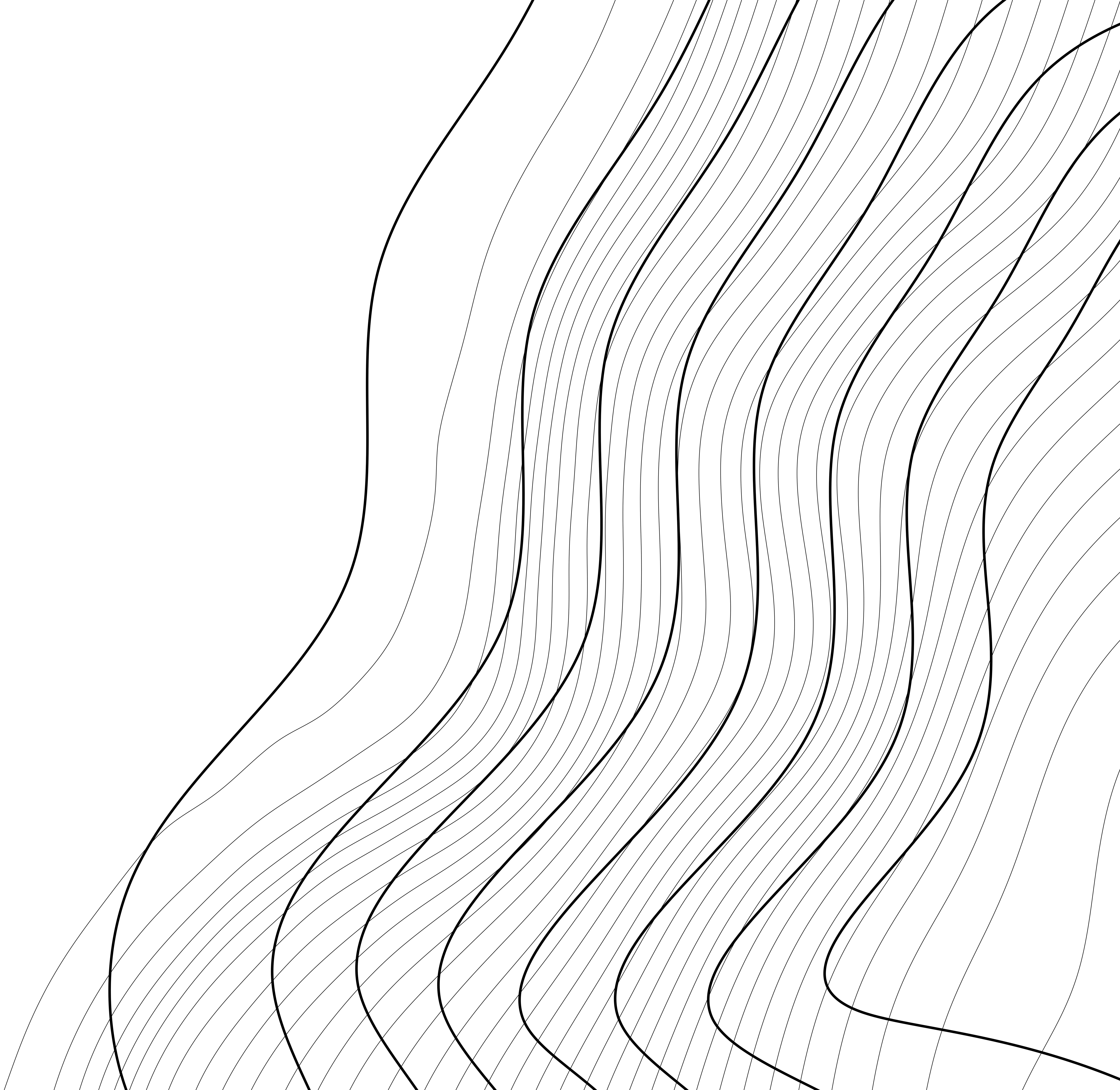
the Ripple



The Bartlett School of Architecture
MEng Engineering & Architectural Design
BARC0163 Design Practice 3
Isaac Wang

Abstract

Driven by the energy often squandered on skyscraper decorations and a commitment to carbon reduction, this project delves into the creation of a green, multifunctional structure in Harlech, Gwynedd, Wales. It envisions a beacon of the fourth industrial revolution, standing as a testament to the future of sustainable technology, all while respecting Harlech's rich history and stunning landscapes. The proposed facility addresses the need for high-end amenities, such as luxury hotels, restaurants, cafes, and sports facilities, aiming to boost the local economy and preserve the region's exceptional natural beauty.

Harlech, celebrated for its historic castle and breathtaking natural environment, is a coastal town with vast growth potential. Nonetheless, the area falls short in terms of luxury hotels, upscale restaurants, and cafés, and also lacks an R&D centre and educational facility. Despite Harlech's stunning views, historical significance, accessible beach, national reserve, and golf club positioning it as a prime holiday retreat and leisure spot, the scarcity of hospitality services hinders its appeal. To address this, the project endeavours to establish a multifunctional facility offering hospitality services and encompassing a leisure centre, training centre, educational hub, R&D centre, and conference centre.

The chosen site for this endeavour is the former location of St. David's Hotel, now a vacant plot in the town's south, adjacent to the golf club, next to the main road and approximately 30 metres above sea level. Its unobstructed sea views and easy accessibility make it an ideal location for this ambitious project.

The envisioned multifunctional facility will incorporate a diverse array of functions to cater to the needs of the local community and tourists. It will host a luxury hotel, high-end restaurants and cafes, a public observation deck, an R&D centre specialising in air and water purification technologies, and an educational centre that delivers workshops on sustainable living. In addition, the venue will include a conference centre, swimming pool, spa, gym, and sauna, thus accommodating an array of leisure and business requirements.

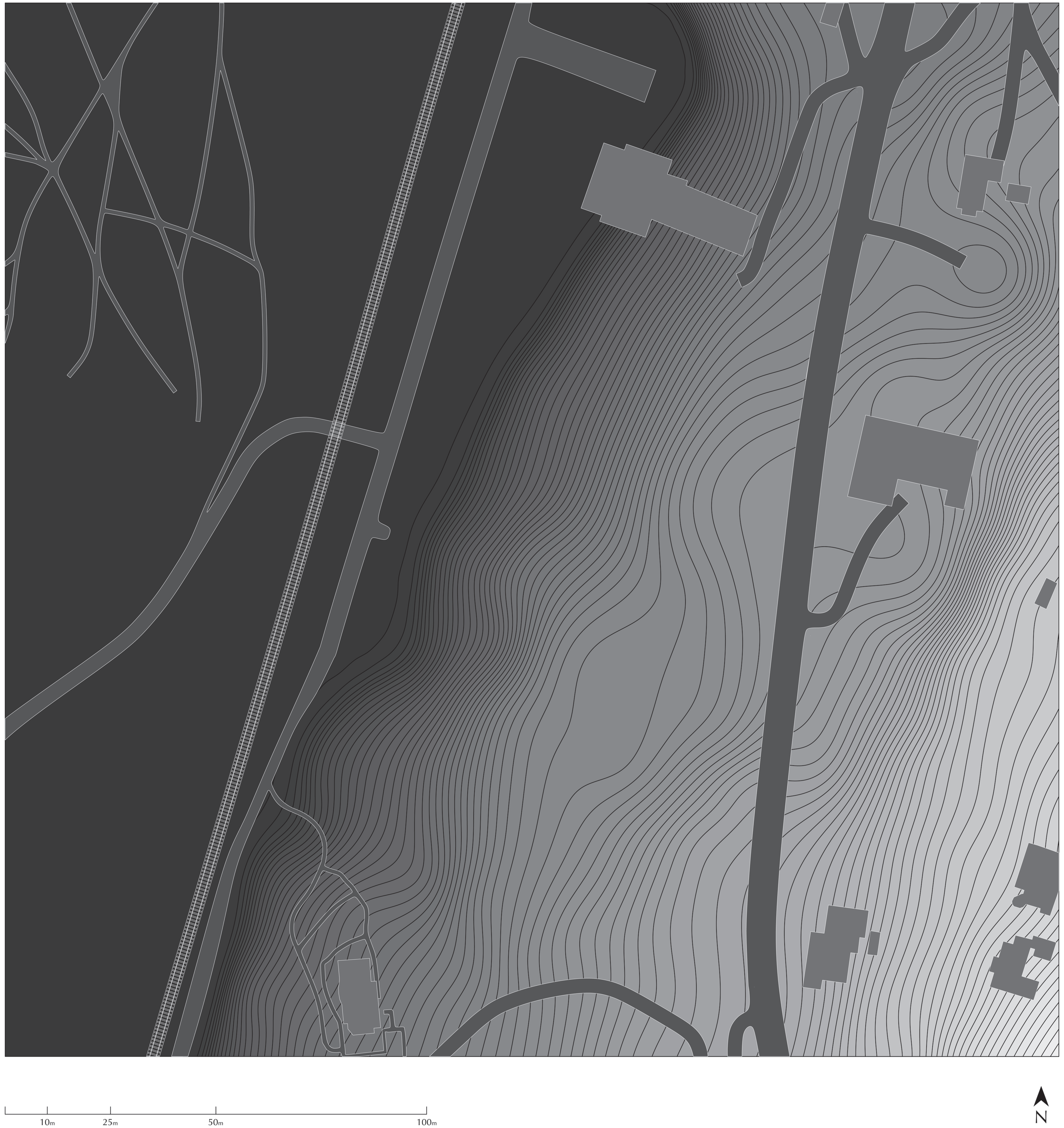
In keeping with the project's sustainable principles, the building will be powered by a 10MW nuclear battery, enabling CO2 capture and seawater purification. The primary products of these processes will be O_2 release, clean water, and liquid methane. Secondary benefits include a fully controlled indoor environment and a heated pool. The novel approach of integrating these elements not only bolsters the building's sustainability but also yields significant environmental benefits.

The design concept prioritises harmony with the surrounding natural environment, and capitalises on the site's potential by building from the terrain. By blending cutting-edge sustainable technologies with a wide range of functions, this project aspires to set a precedent for environmentally conscious development in Harlech and beyond. The multifunctional facility will stand as a symbol of the town's commitment to sustainable growth, providing improved amenities for residents, attracting more tourists, creating job opportunities, and invigorating the local economy.

Greater Site Plan

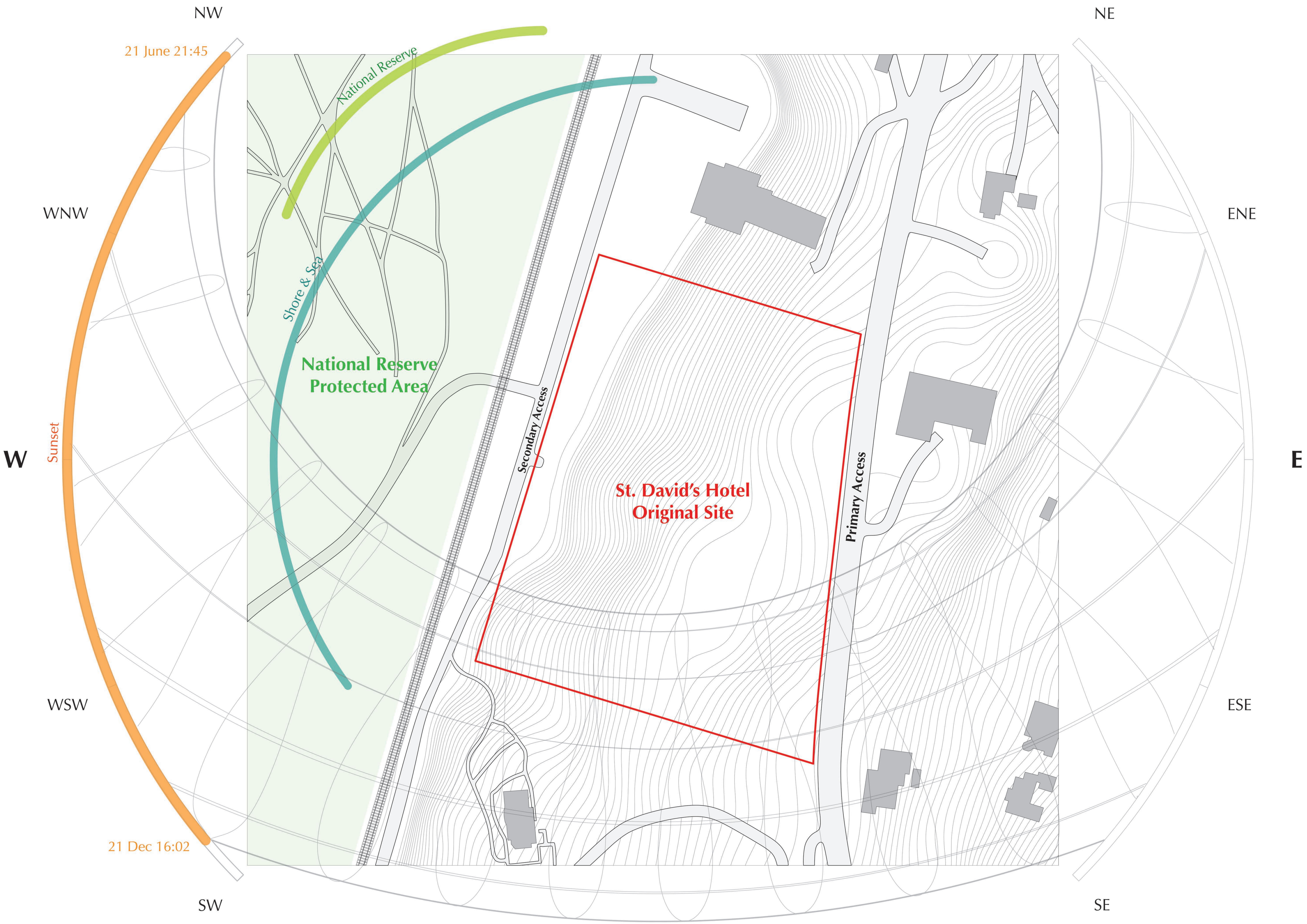
Greater Site Plan

Site Plan



Environmental Analysis

Site Context & Orientation



Environmental Analysis

Climate & Wind

The site where St. David's Hotel once stood, a significant landmark before its demolition in 2021, offers a unique canvas for redevelopment. Its geographical character is inherently captivating, with its hill-like topography that boasts notable altitude differences and a peak facing westward.

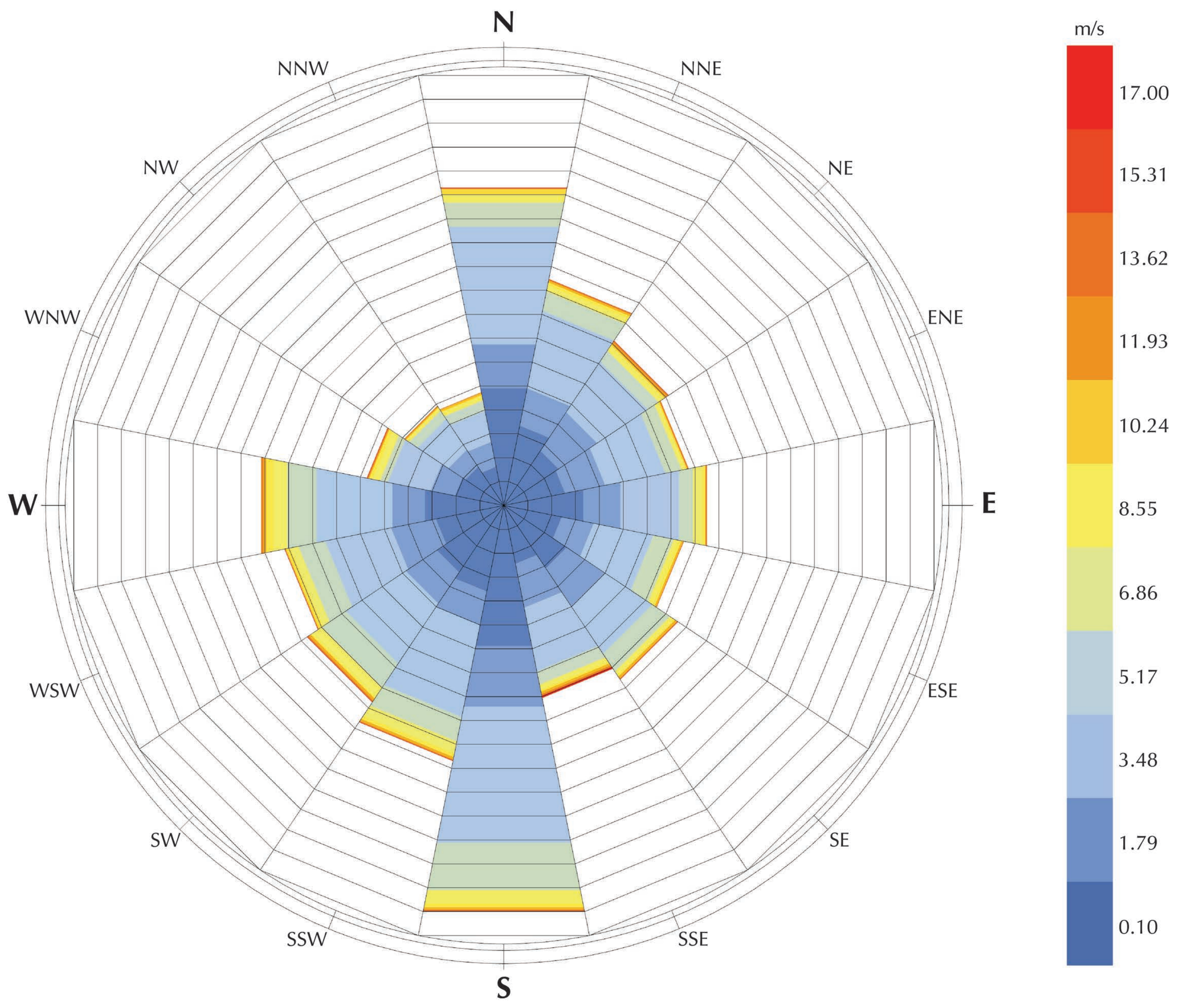
Two primary access avenues serve this distinctive location. The main upper route establishes a direct connection to the town centre, presenting a vital entrance from the hilltop. In contrast, a secondary access, located at the hill's base adjacent to the railway tracks, establishes connectivity from the shoreline and the golf club. Though both are vehicular-friendly, the latter is a one-way street. Currently, the main plot, resting on the flat land segment, is exclusively accessible via the primary entrance. My design vision is to coalesce these entry points, thereby not only enhancing the site's functionality but also fostering better connectivity for the local populace.

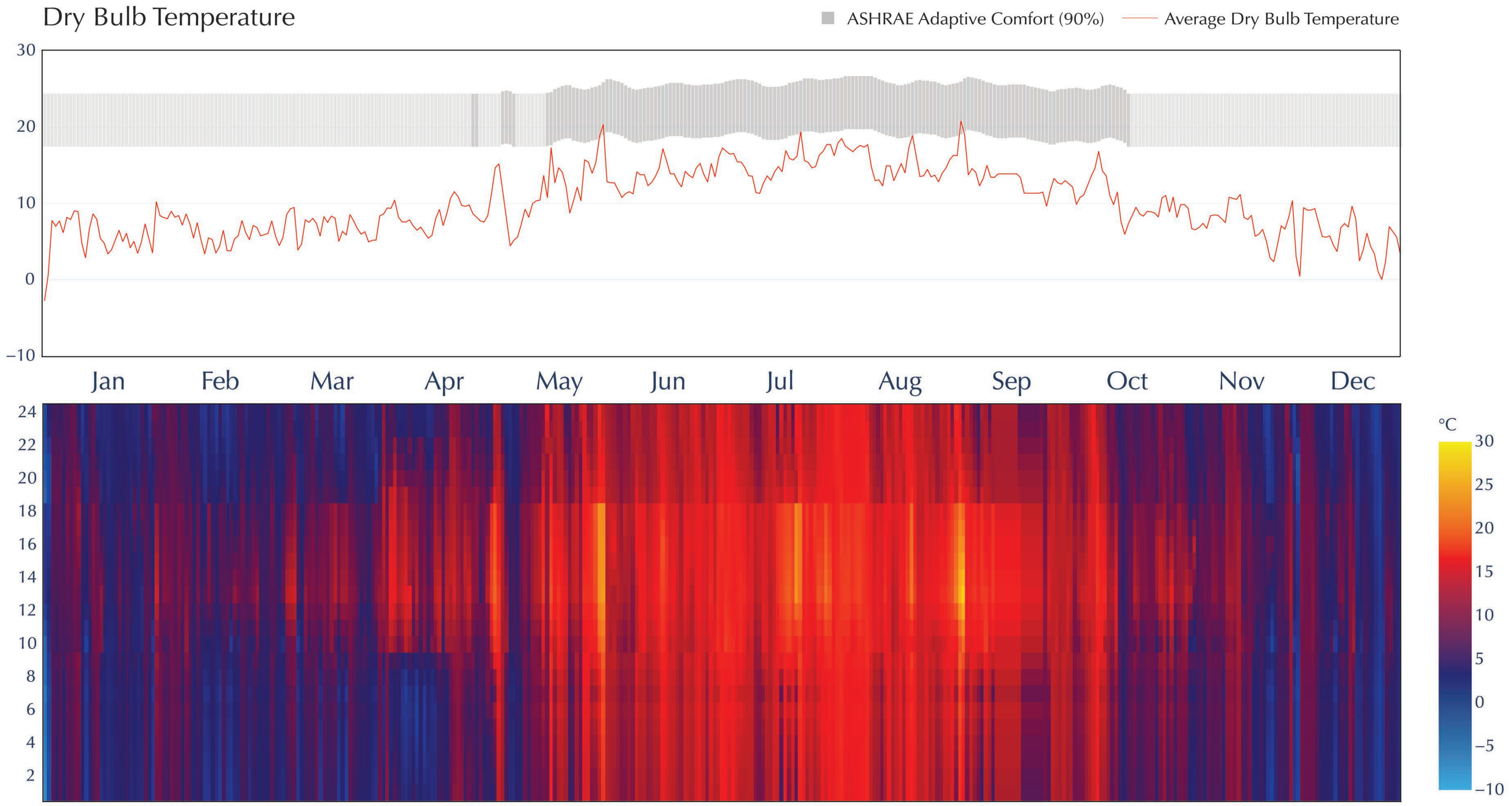
Wind conditions, as illustrated by the wind rose, are dominated by N, NNE, S, and SSW breezes. Yet, winds from the WNW, NW, and NNW are more subdued. The sun path diagram further accentuates the value of a structure oriented primarily west-northwest on this hill. This direction ensures optimal daylight reception, shields the structure from robust wind currents, and aligns the edifice towards the weakest wind directions. Additionally, every floor promises panoramic views: the northwest offers glimpses of the national reserve, while views of the shoreline and sea span from NW to WSW. Moreover, the structure enjoys an uninterrupted spectacle of sunsets throughout the year, ranging from SW to NW.

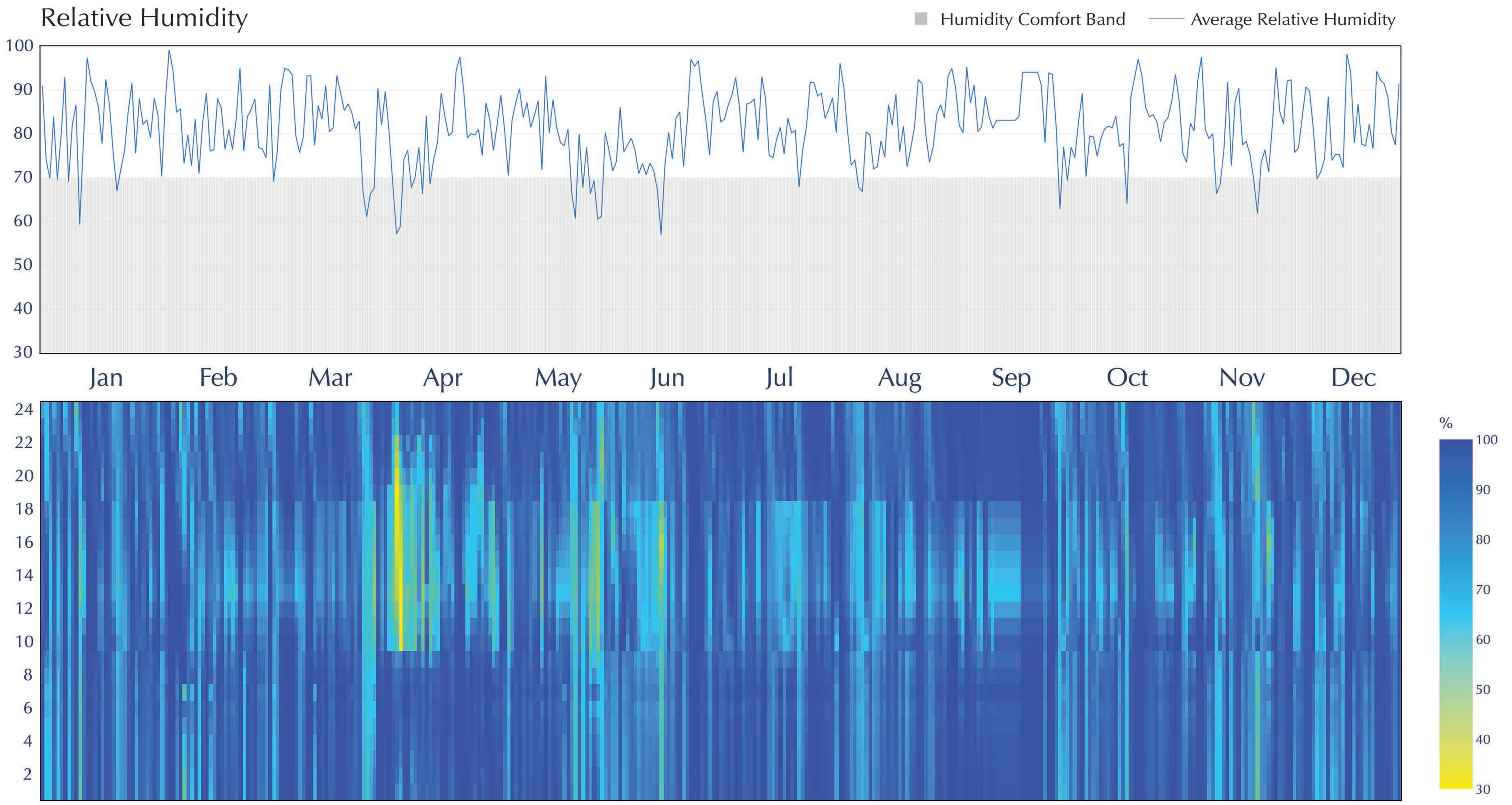
To the site's west, beyond the railway tracks, lies the protected expanse of the national reserve. This protected status prohibits any infrastructural sprawl in that direction, ensuring the natural beauty remains undisturbed.

The area's climatic conditions, characterized by a modest annual average of 10.4 degrees, consistently fall outside the comfort zone. This coolness necessitates a robust HVAC system to counterbalance. The prevalent high humidity, which surpasses comfort levels for a significant part of the year, further necessitates an HVAC system equipped with a humidifier to maintain desirable indoor moisture levels.

Considering the luxury hotel and training centre's intrinsic requirements, especially the inclusion of a pool, external and pool heating is indispensable. Mirroring the Blue Lagoon model, where surplus heat from a power plant is channelled for pool warmth, this design will similarly harness the nuclear battery's abundant thermal output, crafting an experience reminiscent of the Blue Lagoon's opulence.







Research

Turning CO_2 into Opportunity

Controlling Indoor CO_2 Levels for Enhanced Human Performance

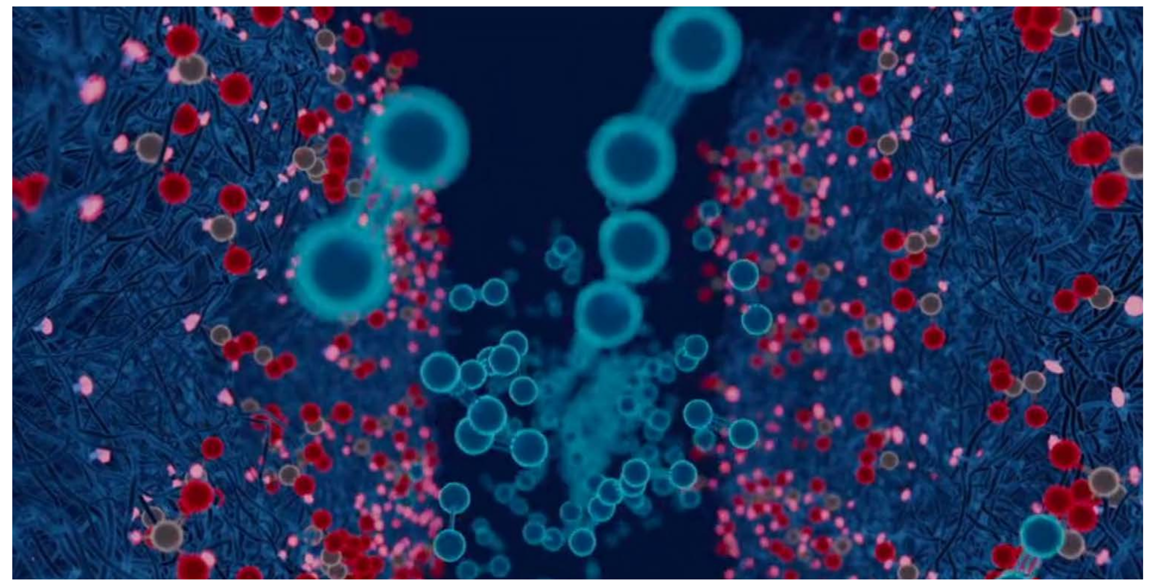
Indoor air quality significantly affects human health and cognitive function, with carbon dioxide (CO_2) concentration playing a pivotal role. Elevated levels of indoor CO_2 have been linked to headaches, restlessness, difficulty in concentrating, and impaired decision-making skills. Studies illustrate that an increase in CO_2 levels from 1,000 to 2,500 parts per million (ppm) can lead to a 50% decrease in cognitive scores. Furthermore, CO_2 concentration higher than 1,000 ppm is known to cause discomfort and may lead to health concerns over prolonged exposure. However, despite the notable impact on human health and cognitive function, currently no hotel worldwide offers adjustable indoor CO_2 concentration levels as a standard feature.

"Is CO_2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance"

Environmental Health Perspectives (2012)

MIT's Revolutionary Carbon Capture Technology

Engineers from MIT have made a groundbreaking contribution with a novel technology that captures CO_2 directly from the air. The method, known as Electroswing Adsorption, utilises a Metal-Organic Framework (MOF) that selectively captures CO_2 molecules based on their size and shape. The system relies on a guanidinium compound in the MOF, which has a high affinity for CO_2, enabling it to selectively attract these molecules while ignoring other molecules in the air.



MIT's carbon capture technology not only offers a means to reduce atmospheric CO_2 levels, but it also presents an opportunity to repurpose this greenhouse gas. Its affordability, scalability, and efficiency offer a tantalising solution for addressing the urgent problem of rising atmospheric CO_2 levels. Furthermore, it provides a valuable mechanism for converting captured CO_2 into beneficial resources such as methane, helping to turn a problematic waste product into a viable energy source.

In conclusion, adopting an innovative approach to convert CO_2 into methane is a significant stride in the global transition towards sustainable energy. By employing cutting-edge technologies like MIT's carbon capture system, it is possible to create healthier indoor environments and contribute to the overarching goal of carbon neutrality. It is my vision to embed these principles into the future of building design, aligning with the global ambition of sustainable development and a carbon-neutral society.

"MIT engineers develop new way to remove carbon dioxide from air"

MIT News (2019)

Liquid Methane and Its Applications

Liquid methane, also known as Liquefied Natural Gas (LNG), holds immense potential as an energy source in this critical transitional phase. According to National Grid, LNG offers a cleaner, more efficient energy solution compared to other fossil fuels. It produces up to 50% less CO_2 when combusted compared to coal and 20-30% less than oil. LNG's energy content is approximately 2.4 times that of the same volume of gasoline, highlighting its high energy efficiency. Its potential applications span across industries – it can be used as fuel for vehicles, in energy storage systems, for refrigeration purposes, and even as rocket fuel, demonstrating its versatility and adaptability to various energy demands.

"What is Liquefied Natural Gas (LNG)"

National Grid (2019)

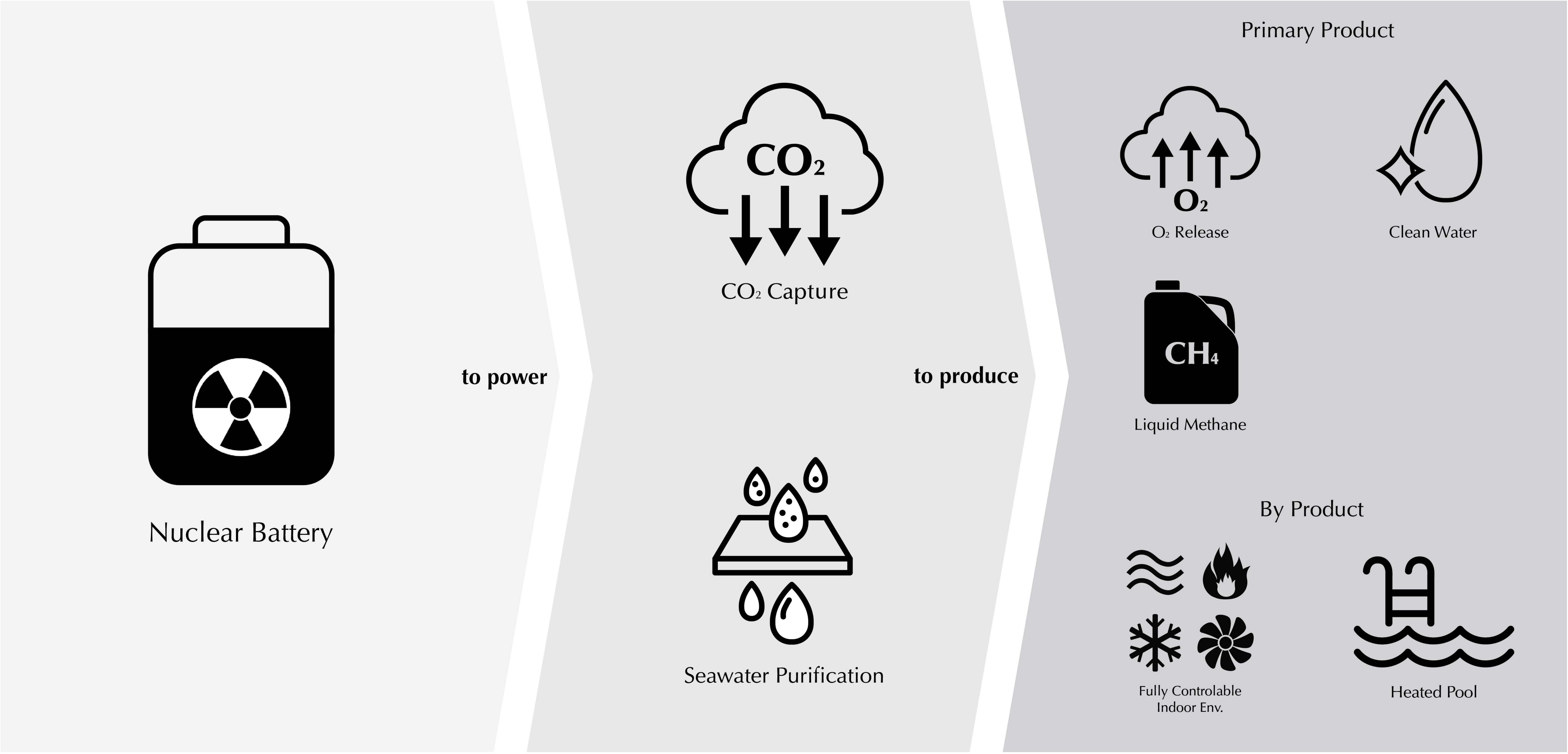
Tackling the Global CO_2 Challenge Through Innovative Solutions

Atmospheric CO_2 emissions continue to accelerate global climate change, leading to extreme weather conditions, rising sea levels, and loss of biodiversity. As the world strives to achieve carbon neutrality, innovative transitional solutions that can mitigate CO_2 emissions are needed more than ever. One such promising solution is the conversion of CO_2 into methane, a potent energy source. Methane, a hydrocarbon, offers energy stability during the transition period, allowing for continued energy utilisation while reducing our carbon footprint.

"Turning Carbon into a Valuable Asset"

U.S. Department of Energy (2019)

Design Concept



Reaction Chain

Conversion Path

Intake Seawater (H_2O) → $4H_2O \rightarrow 4H_2 + 2O_2$

657,000,000 moles (11,826,000 kg) of H_2O

Water Electrolysis

8,128,560 W input from Nuclear Battery

Annually converting intaken seawater into
657,000,000 moles (1,314,000 kg) of H_2 &
328,500,000 moles (10,512,000 kg) O_2

1,016,070 W heat provided to the building

O_2 →

O_2 Released

Generating the same yearly volume of O_2 as 657,000 English oak trees carbon positive

producing 10,512,000 kg of O_2 that is equivalent to

× 52560

Average Human O_2 Annual Consumption

H_2 →

Intake Outside Air → **APD Seperates CO_2**

Air Purification Device (APD) uses an Electroswing Adsorption System to selectively capture CO_2 from air using charged electrodes.
164,250,000 moles (7,227,000 kg) of CO_2 is estimated to be captured annually.

CO_2 → $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Sabatier Reaction

385,487 W input from Nuclear Battery

CO_2 and H_2 are mixed at 300-400° under 3 MPa
With Nickel as catalyst, annually converting
collected CO_2 and reacted H_2 into
164,250,000 moles (2,628,000 kg) of CH_4 &
328,500,000 moles (5,913,000 kg) H_2O

645 W heat provided to the building

CH_4 →

Methane (CH_4) Conversion into Liquid Methane (LCH_4)

164,250,000 moles of Methane gas is compressed annually at 25° under 25 MPa
Compressed Methane gas is then cooled to liquefy at -162° under 3.5 MPa
Liquid Methane stored in double-walled, vacuum-insulated tanks at - 161.5° under 3.5 MPa

producing 2,628,000 kg of LCH_4 that could supply fuel for

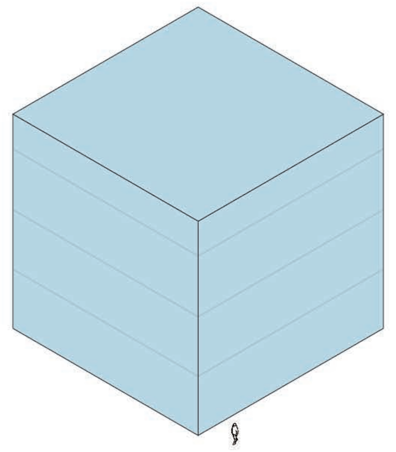
× 2.6

SpaceX Starship Super Heavy Launch

H_2O →

Clean Water (H_2O)

Seperated through condensation
For the use of drinking water and to counteract evaporation



producing 5,913,000 kg of H_2O that is equivalent to an

18.1m

water cube

Purified Air ↓

Controller

Purified Air ↓

Adjusting the volume of purified air blended into the HVAC system based on user preferences to regulate the indoor CO2 concentration level effectively.

Intake Outside Air (constant) → HVAC System → **Fully Controlable Indoor Environment**

Reaction Chain

Energy Calculation

Nuclear Battery			
Power (W)	Annual Energy Output Available (J)	Annual Energy Usage (J)	Annual Heat Usage (J)
10000000	3.1536E+14	2.73738E+14	-3.20631E+13

CO2 Capture						
Floor Area (m^2)	Avg Floor Height (m)	ACH	Efficiency	APD Avg Air Mixture Ratio	APD Avg Time on	APD CO2 Capture (m^3)
10000	3.5	3	0.4	0.1	0.1	3679200

Ideal Gas Molar Volume (m^3/mol)
0.022414

Sabatier Reaction E	CO2 + 4H2 -> CH4 + 2H2O					
CO2 (m^3/mole)	CO2 (mole)	H2 (mole)	Enthalpy Change (kJ/mole)	Efficiency	Q (J)	
0.0224	164250000	657000000	-165	0.75	-20325937500	-644.53125
					-5646.09375	kWh
Initial Temperature (°C)	CO2 Specific HC (J/mol°)	H2 Specific HC (J/mol°)	Sabatier Temp (°)	ΔT (°)	Efficiency	Energy Input for Heating (J)
25	37	29	350	325	0.75	1.08898E+13
Energy = (moles × specific heat capacity × temperature change) / efficiency						
Initial Pressure (MPa)	CO2 Adiabatic Index γ	H2 Adiabatic Index γ	Sabatier Pressure (MPa)	Ideal Gas Constant (J/molK)	Efficiency	Energy Input for Compression (J)
0.1	1.3	1.4	3	8.314	0.75	1.26696E+12
P1 * V1^γ = P2 * V2^γ						
E = (moles * ideal gas constant * initial temeprature in K * [(Final Pressure/Initial Pressure)^((γ-1)/γ) - 1]) / efficiency						
						Total E input required (J)
						1.21567E+13

Sabatier Reaction Chamber Size				
CO2 (m^3) annually intaken	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for CO2 (m^3)
3681499.5	0.116739583	60	2	14.00875
H2 (m^3) annually intaken	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for H2 (m^3)
14725998	0.466958333	60	2	56.035
CH4 (m^3) annually produced	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for CH4 (m^3)
3681499.5	0.116739583	60	2	14.00875
H2O (m^3) annually produced	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for H2O (m^3)
5918.01948	0.000187659	60	2	0.0225191
k times the volume of the daily MAX containment volume is the		Equipment Volume Factor (k)		Total Chamber Size (m^3)
volume of the equipment for Sabatier Reaction		0.5		126.1125287
				Cubic Chamber Dimension (m)
				5.014789924

Seawater Electrolysis E	4H2O -> 4H2 + 2O2			
Initial Tempreature (°C)	Water Specific HC (J/mol°)	Efficiency	Energy Input for Heating (J)	
12	75.32	0.75	5.80627E+12	
H2O Gibbs free E Δ (kJ/mol)	H2 required (mole)	H2O (mole)	Efficiency	E Input for electrolysis (J)
286	657000000	657000000	0.75	2.50536E+14
E = moles * Gibbs free energy change		328500000		
	Q (J)	O2 Emission (kg)	O2 Emission (tree)	Total E input required (J)
	-3.20428E+13	10512000	657000	2.56342E+14

Seawater Electrolysis Chamber				
H2O (m^3) annually intaken	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for H2O (m^3)
11836.03896	0.000375318	300	2	0.225191
H2 (m^3) annually produced	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for H2O (m^3)
14725998	0.466958333	60	2	56.035
O2 (m^3) annually intaken	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for H2O (m^3)
7362999	0.233479167	60	2	28.0175
k times the volume of the daily MAX containment volume is the		Equipment Volume Factor (k)		Total Chamber Size (m^3)
volume of the equipment for Water Electrolysis		0.5		126.4165365
				Cubic Chamber Dimension (m)
				5.018816254

Methane Compression						
Initial Pressure (MPa)	Final Pressure (MPa)	Ideal Gas Constant (J/molK)	Temperature (°C)	CH4 (mole)	Efficiency	Energy Input for Compression (J)
3	25	8.314	25	164250000	0.75	1.15043E+12
E = moles * ideal gas constant * temp in K * ln(final pressure/initial pressure)/efficiency						
Initial Temperature (°C)	Final Temperature (°C)	CH4 Specific HC (J/mol°)	Efficiency	Energy Input for Cooling (J)		
350	25	35.8	0.75	2.54807E+12		
						Total E input required (J)
						3.6985E+12

Methane Compression & Storage Chamber				
CH4 (m^3) annually intaken	Rate (m^3/s)	Temporary Containment (s)	Safety Factor	Chamber Size for CH4 (m^3) (V)
3681499.5	0.116739583	120	3	42.02625
LCH4 (m^3) annually converted into	Rate (m^3/s)	Long-term Containment (**day**)	Safety Factor	Chamber Size for LCH4 Storage (m^3) (V)
6243.060375	0.000197966	30	3	1539.38475
k times the volume of the daily produced CH4 volume is the		Equipment Volume Ratio (k)		Total Chamber Size (m^3)
volume of the equipment for compression & storage		0.5		1581.411
Chamber designed to contain 30-day amount of LCH4 produced				Spherical Chamber Radius (m) (r)
For safety, it is able to contain 90-day amount of LCH4 produced MAX			V = 3/4*π*r^3	8.755437921

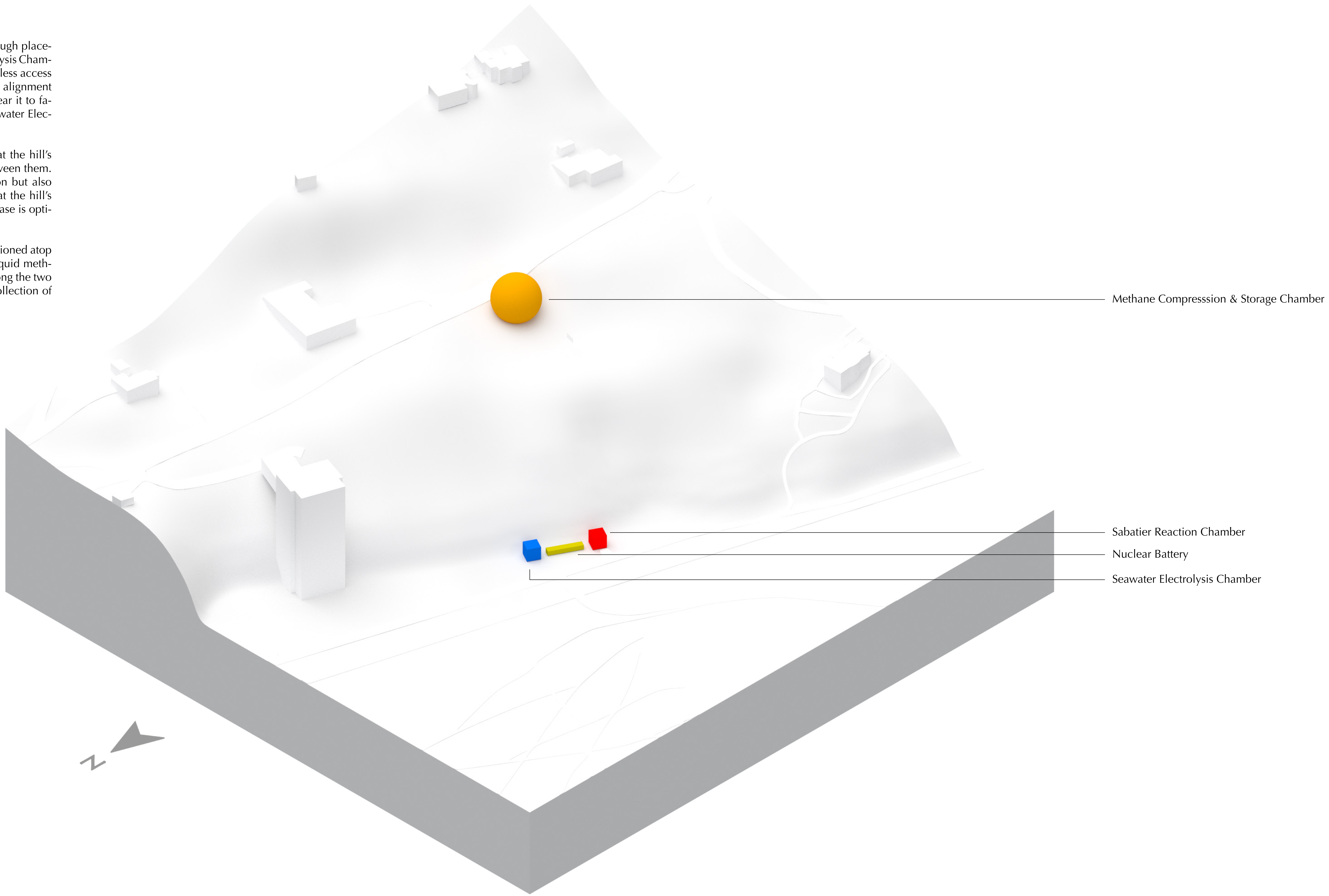
Liquid Methane Storage					
Initial Temperature (°C)	Final Temperature (°C)	CH4 Specific HC (J/mol°)	Efficiency	Energy Input for Cooling (J)	
25	-161.5	35.8	0.75	1.4622E+12	
Container U-Value	Area (m^2)	Inside Temperature (°C)	Outside Temperature (°C)	Efficiency	Energy Input for Storage (J)
0.01	1000	-161.5	24	0.75	77999040000
					Total E input required (J)
					1.5402E+12

Volumetric Study

This page provides an accurate scale representation of the rough placements of the primary reaction chambers. The Seawater Electrolysis Chamber is strategically positioned at the hill's base, ensuring seamless access to the seawater supply due to its proximity to the shore and alignment with sea level. The Sabatier Reaction Chamber is situated near it to facilitate the direct transfer of hydrogen products from the Seawater Electrolysis process.

Given that the two major power-consuming chambers are at the hill's base, it's logical to position the nuclear battery centrally between them. This placement not only ensures efficient energy distribution but also offers visibility from the main concierge, anticipated to be at the hill's base. Furthermore, this central positioning at the building's base is optimal for riser extensions.

Lastly, the Methane Compression & Storage Chamber is envisioned atop the hill. This facilitates the efficient gathering of produced liquid methane. The primary access remains the sole vehicular route among the two available access routes, making it essential for the regular collection of stored liquid methane.



Shape Forming

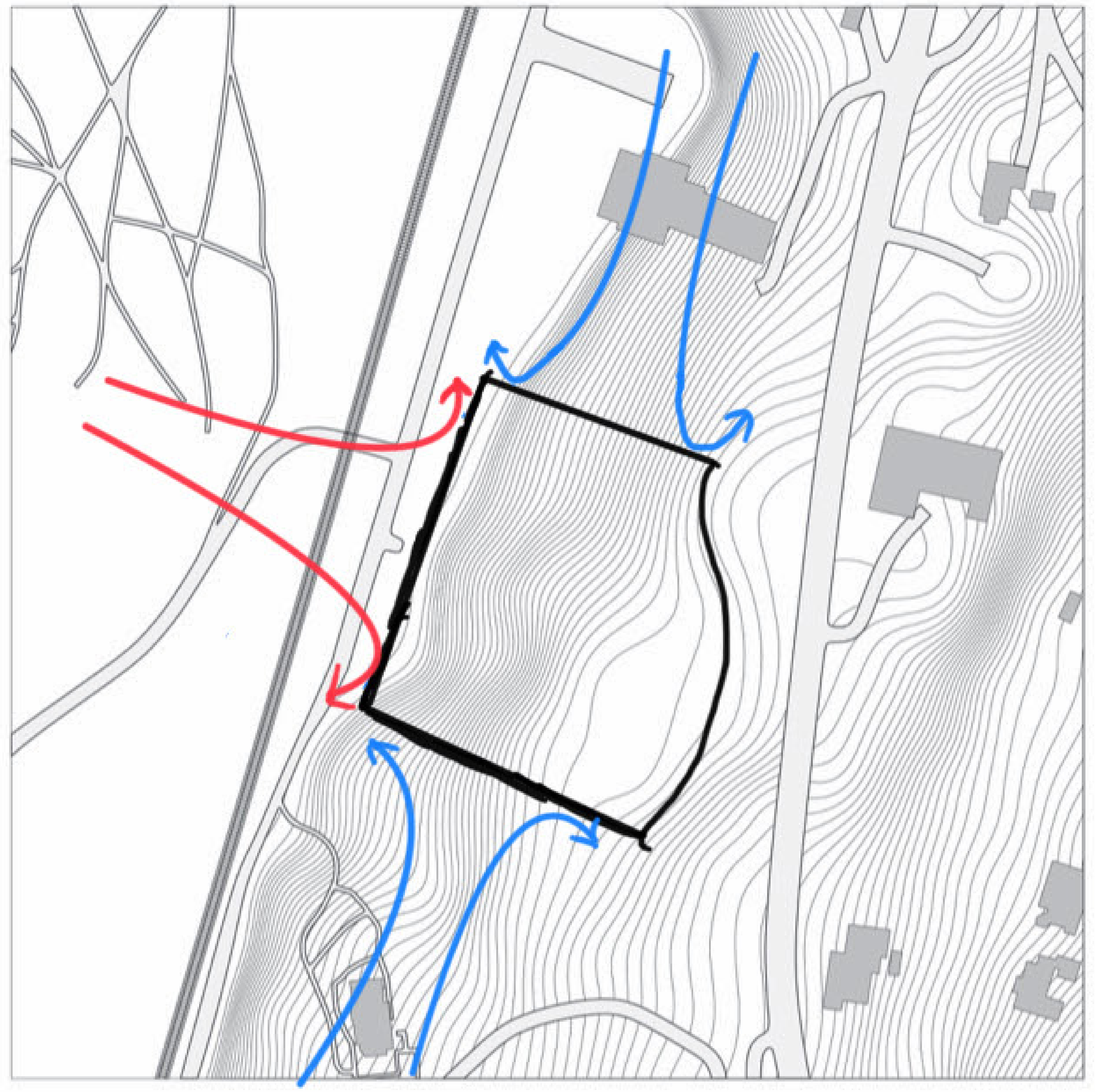
Shape Finding

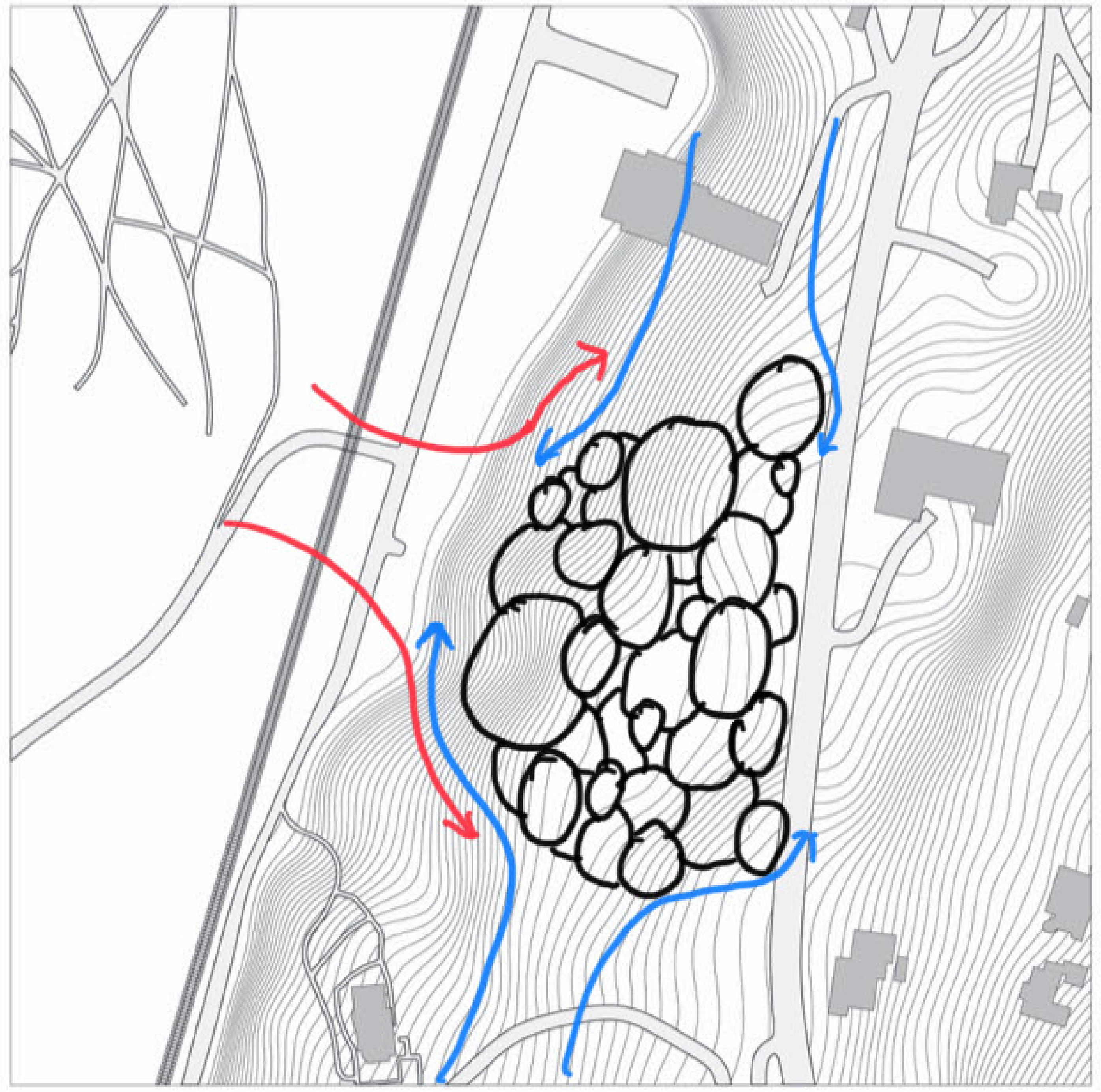
Four distinct architectural shapes were projected onto the site plan, with wind patterns visualised to understand their interaction with each building form. Blue arrows indicate winds from the north and south, whilst red arrows depict winds from the western shoreline. A rectangular configuration tends to rebound wind, leading to substantial wind loads and potentially uncomfortable experiences on balconies.

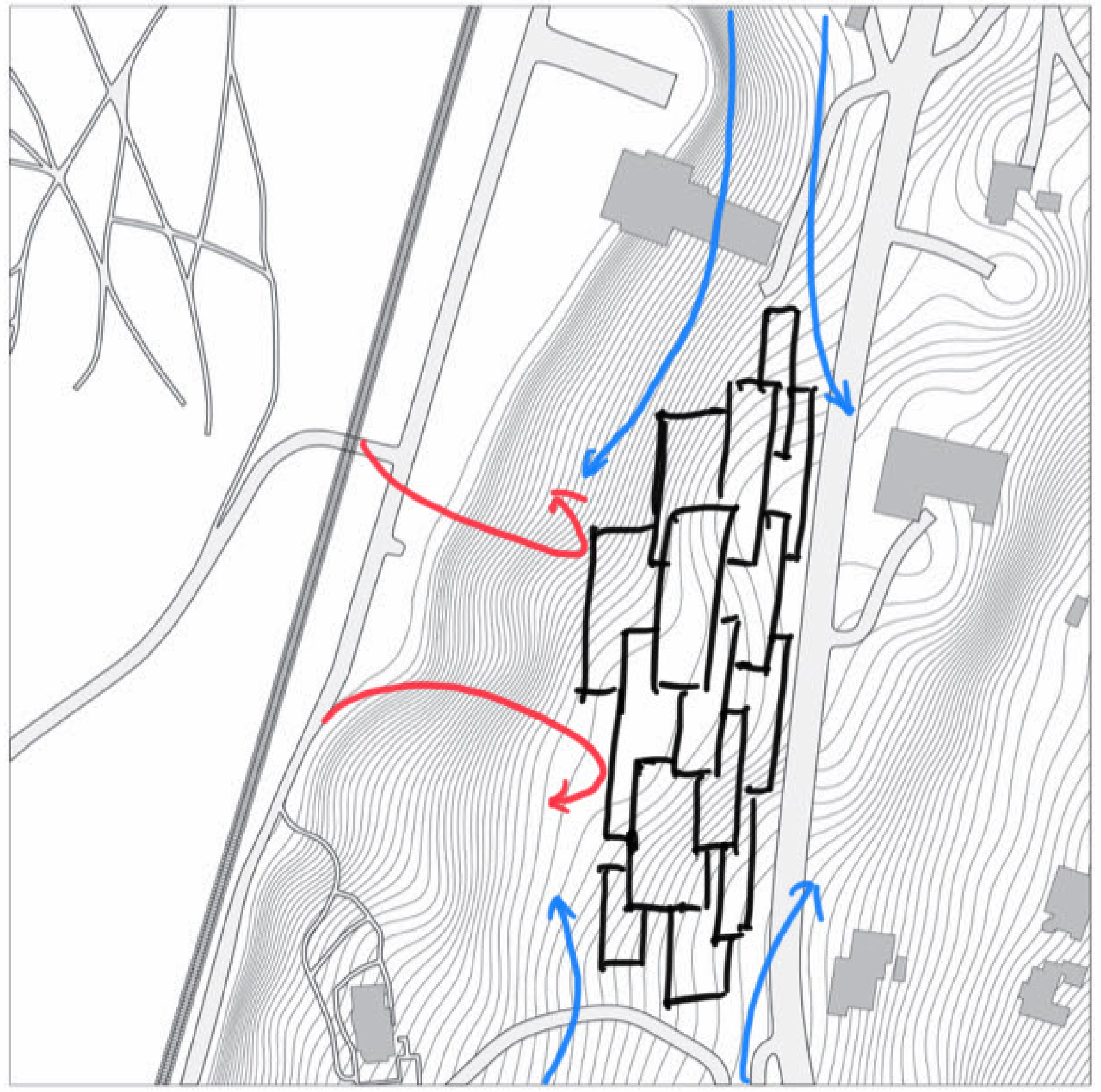
Circular and spherical designs disperse wind from all directions, reducing wind loads. However, there's potential for winds from opposing directions to meet, especially at balcony areas (e.g., northern winds deflected southwest might collide with westerly winds deflected northeast).

A building that's essentially rectangular but segmented into smaller blocks can effectively manage the dominant north and south winds. Nonetheless, its western façade could be subjected to pronounced wind loads due to direct westerly winds.

The most favourable approach is to design in harmony with the site's natural topography. This not only naturally diverts winds from all directions, minimising wind loads on the façade and ensuring balcony comfort, but also blends visually with the environment. Moreover, a design echoing the consistent patterns of the natural landscape ensures a unified aesthetic throughout the building.



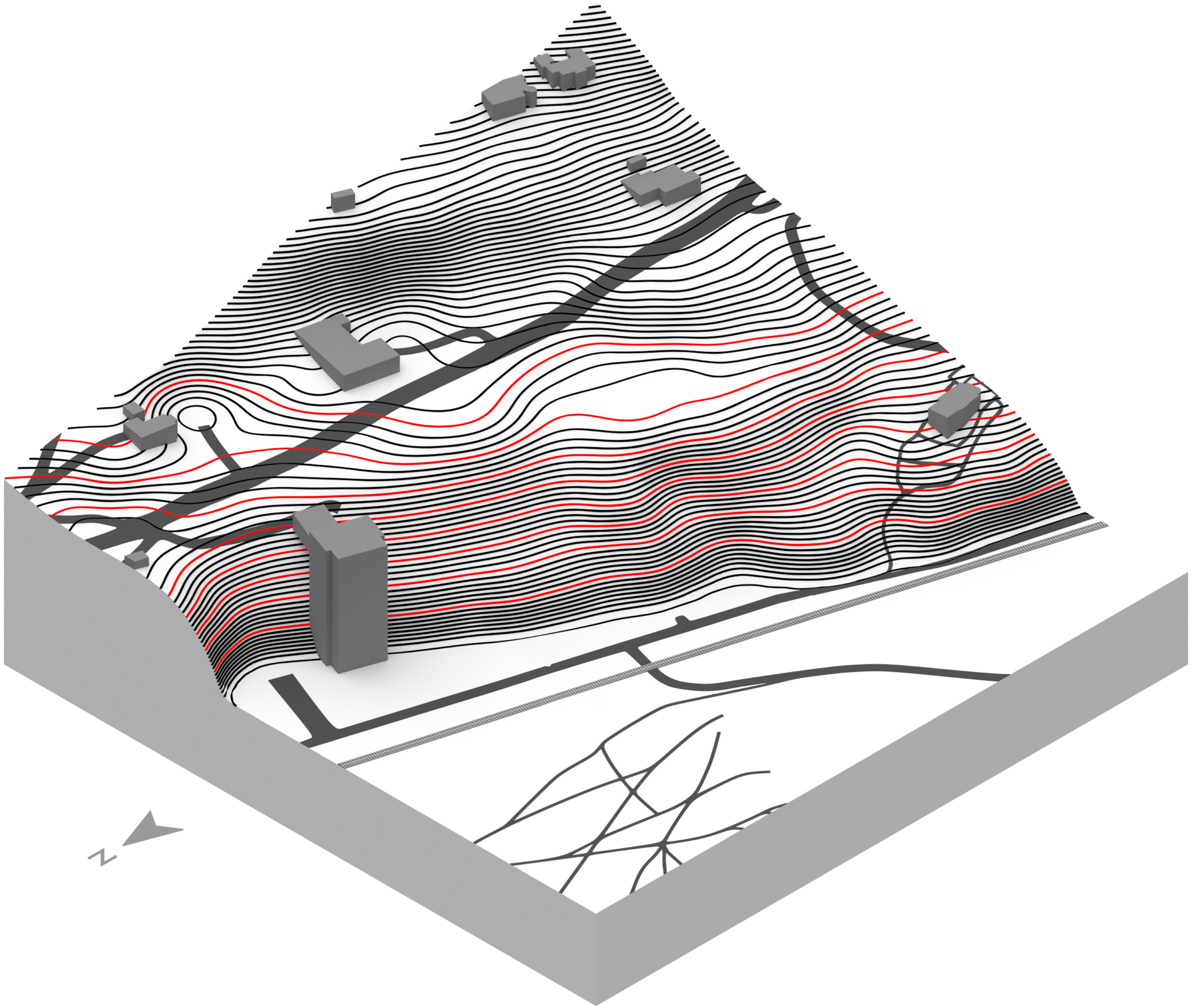




Shape Forming

Selected Contour Lines

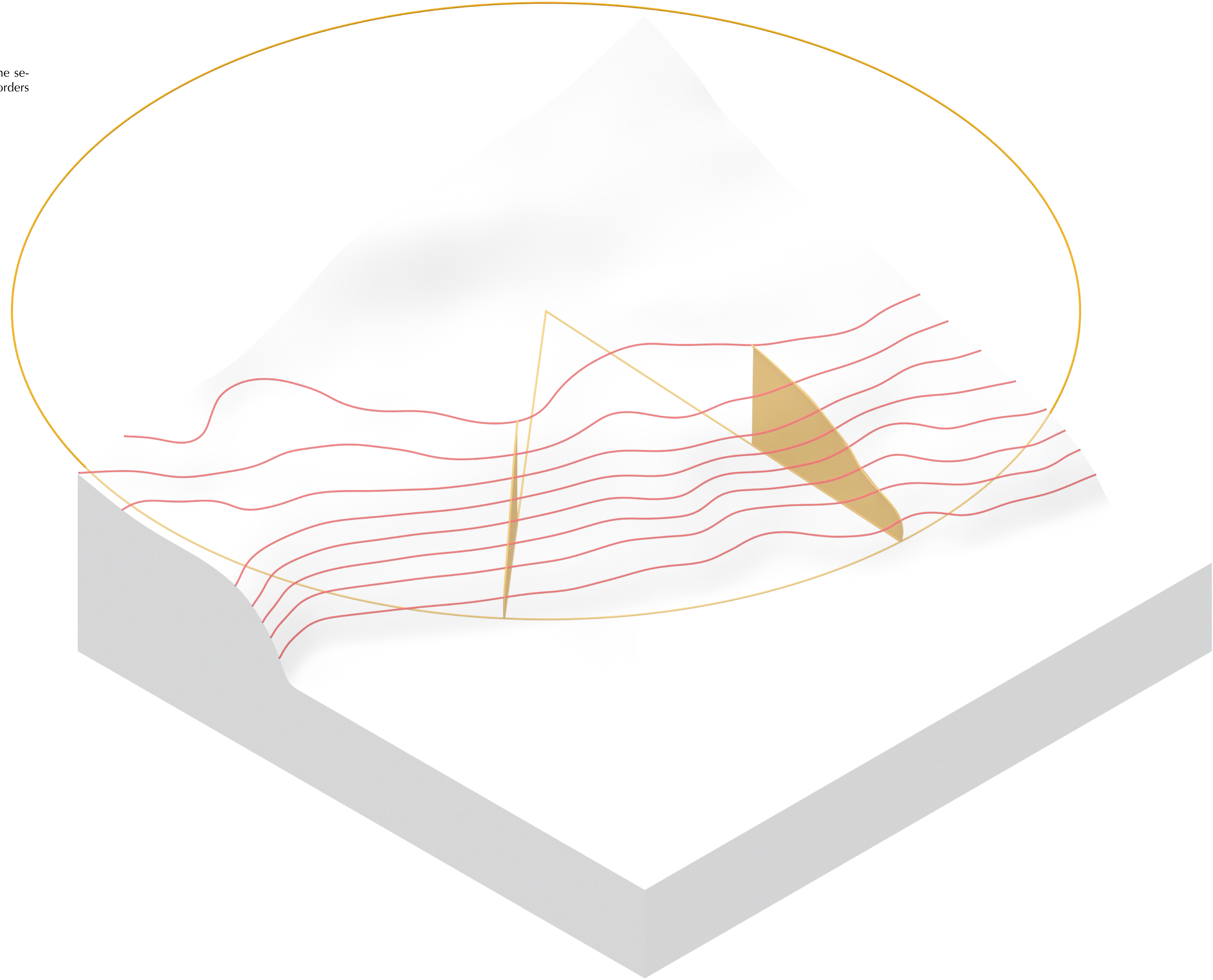
The terrain was selected as the starting point for the design, with contour lines at 4-meter intervals (bar the ground floor) being the cornerstone of the architectural concept.



Shape Forming

Setting Boundary

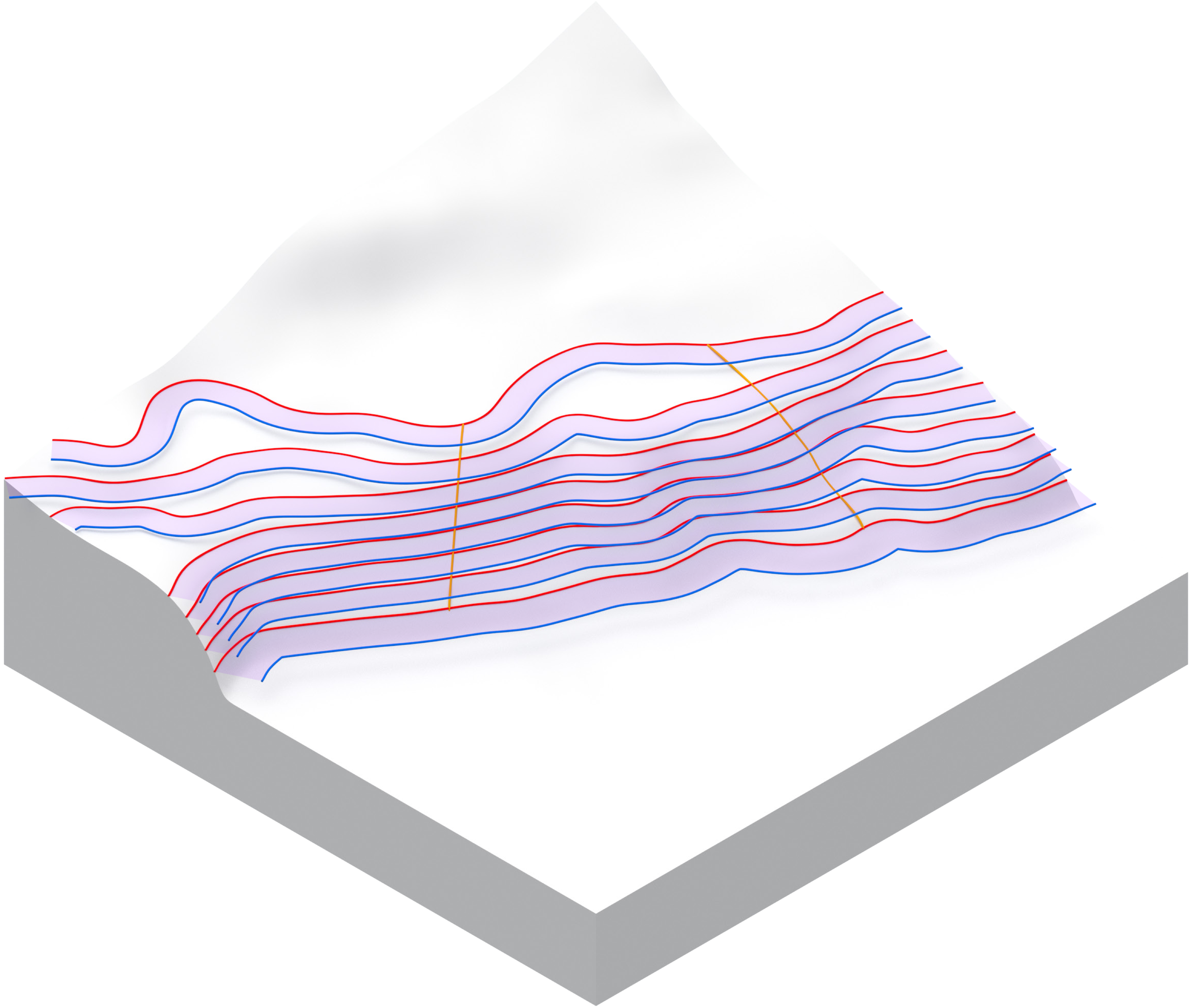
A uniform circle's radii were projected onto the selected contour lines, shaping the building's borders with consistency across all levels.



Shape Forming

Offsetting Contour Lines

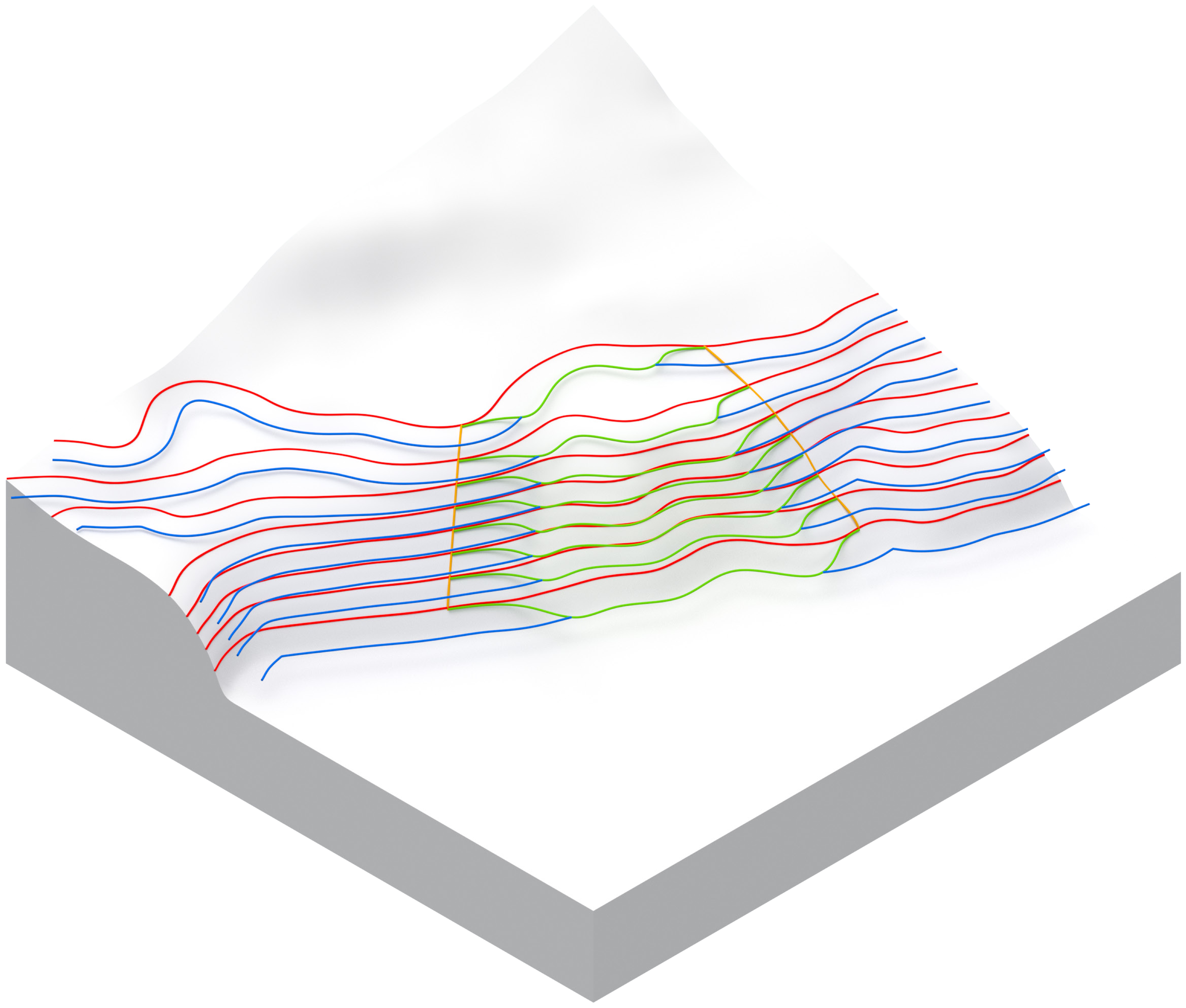
To create floor spans, the selected contour lines were offset by 10 meters, producing additional offset contour lines.



Shape Forming

Joining Contour Lines

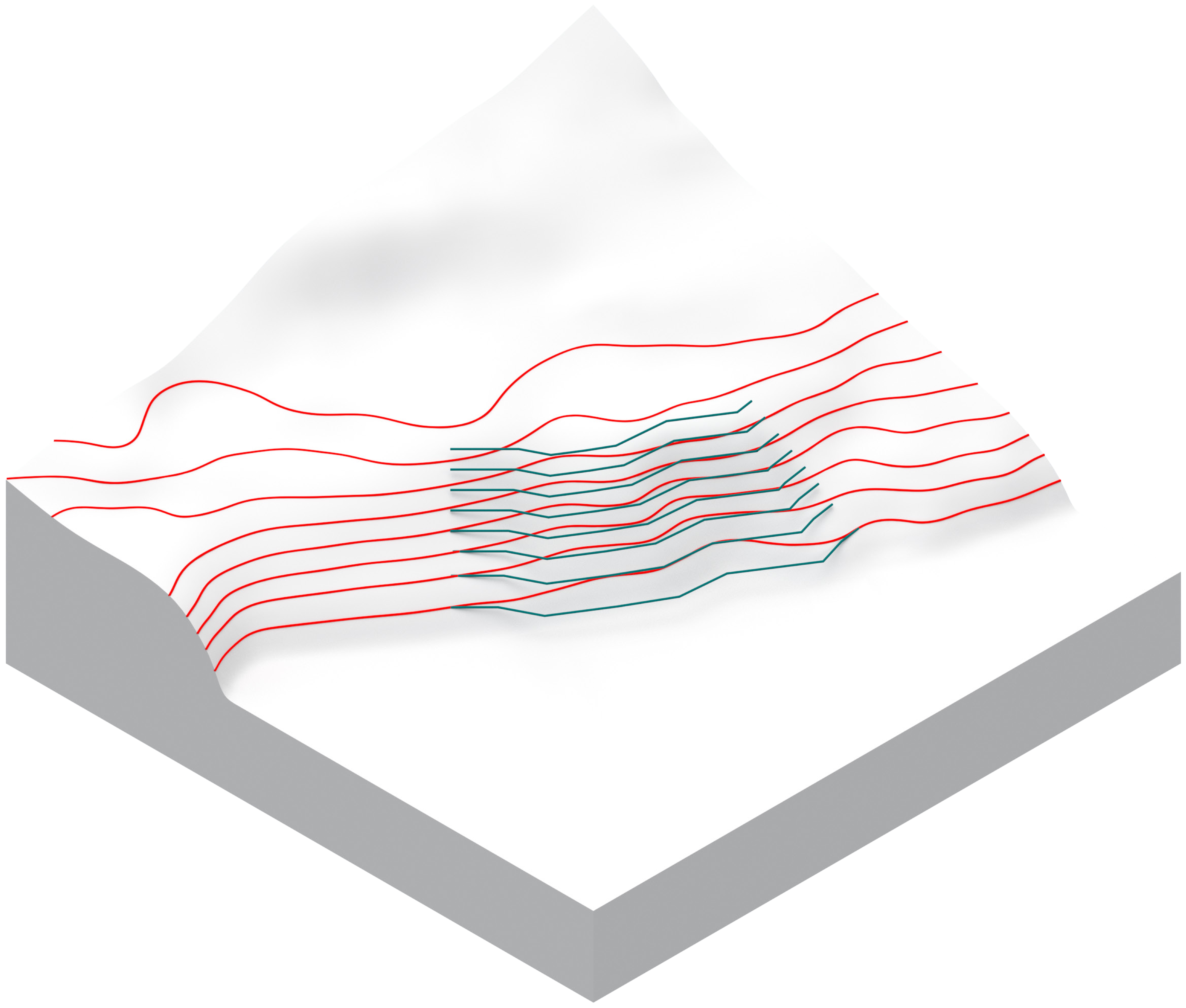
The selected and offset contour lines were then joined according to the predetermined boundaries.



Shape Forming

Common Pattern

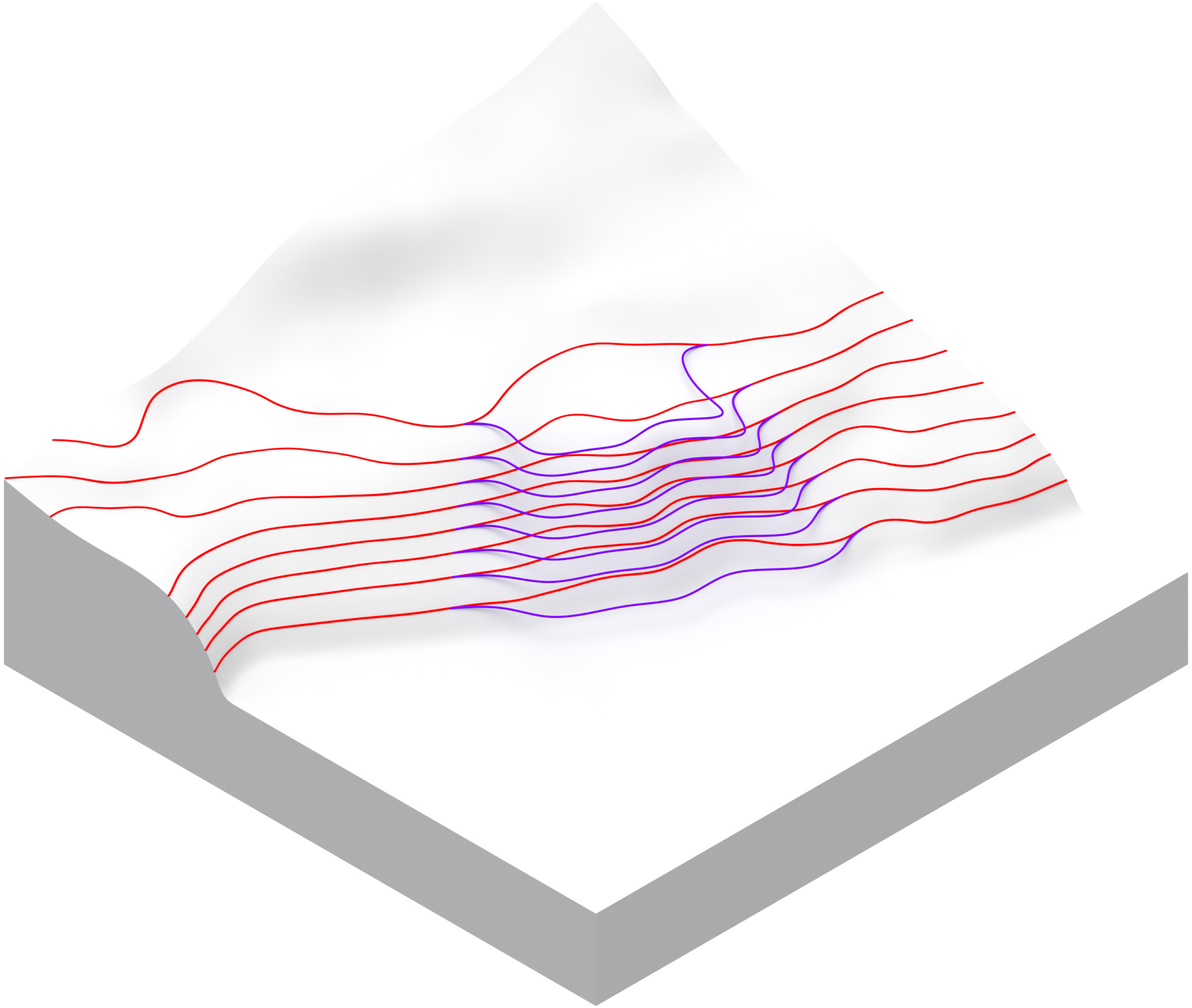
After carefully studying and calculating the average curvature, a shared pattern across all levels was established.



Shape Forming

Rationalisation

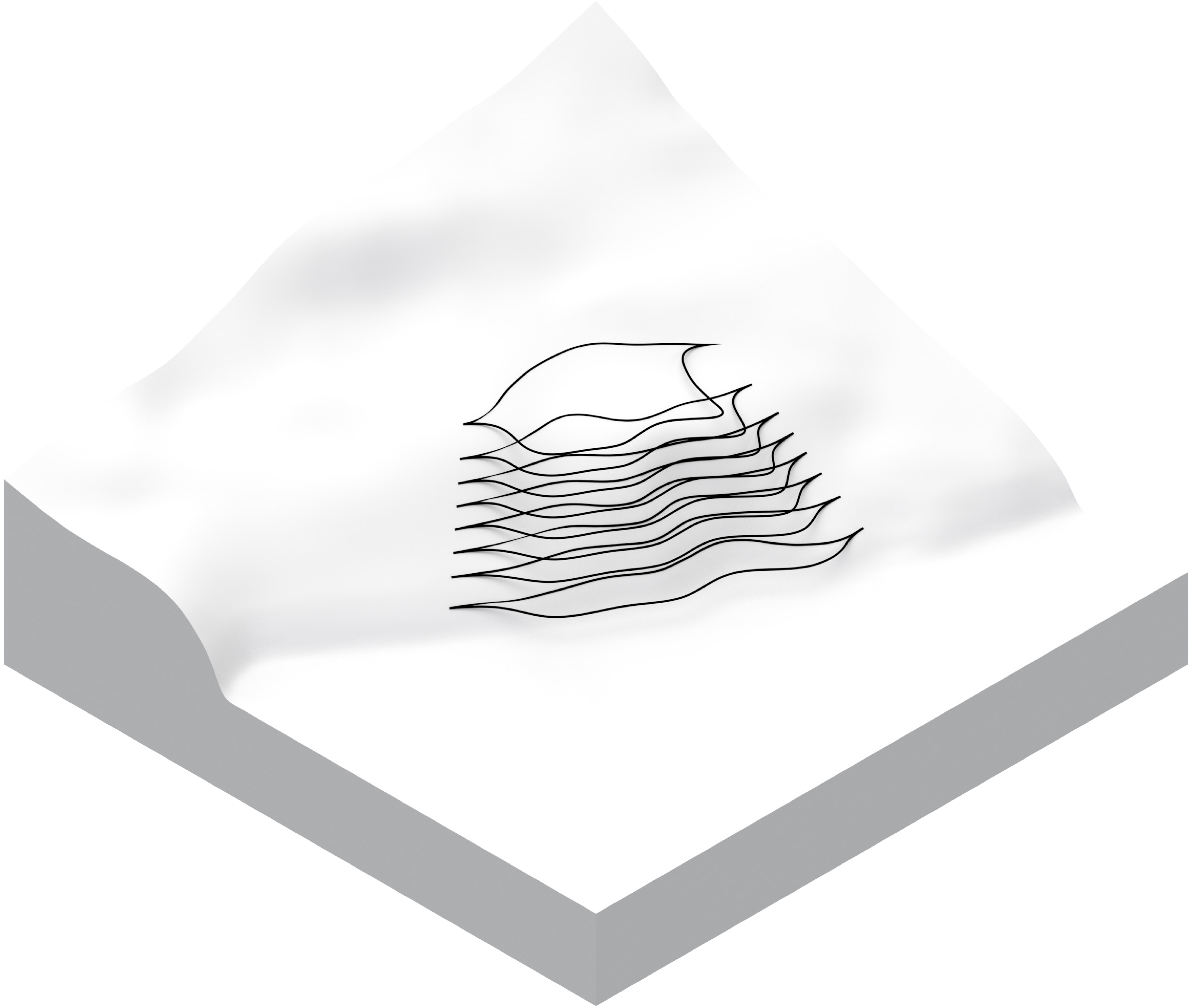
The shared pattern was then used to rationalise the floor spans, promoting consistency whilst preserving the charm of the natural terrain curvature.



Shape Forming

Forming Floor Plan

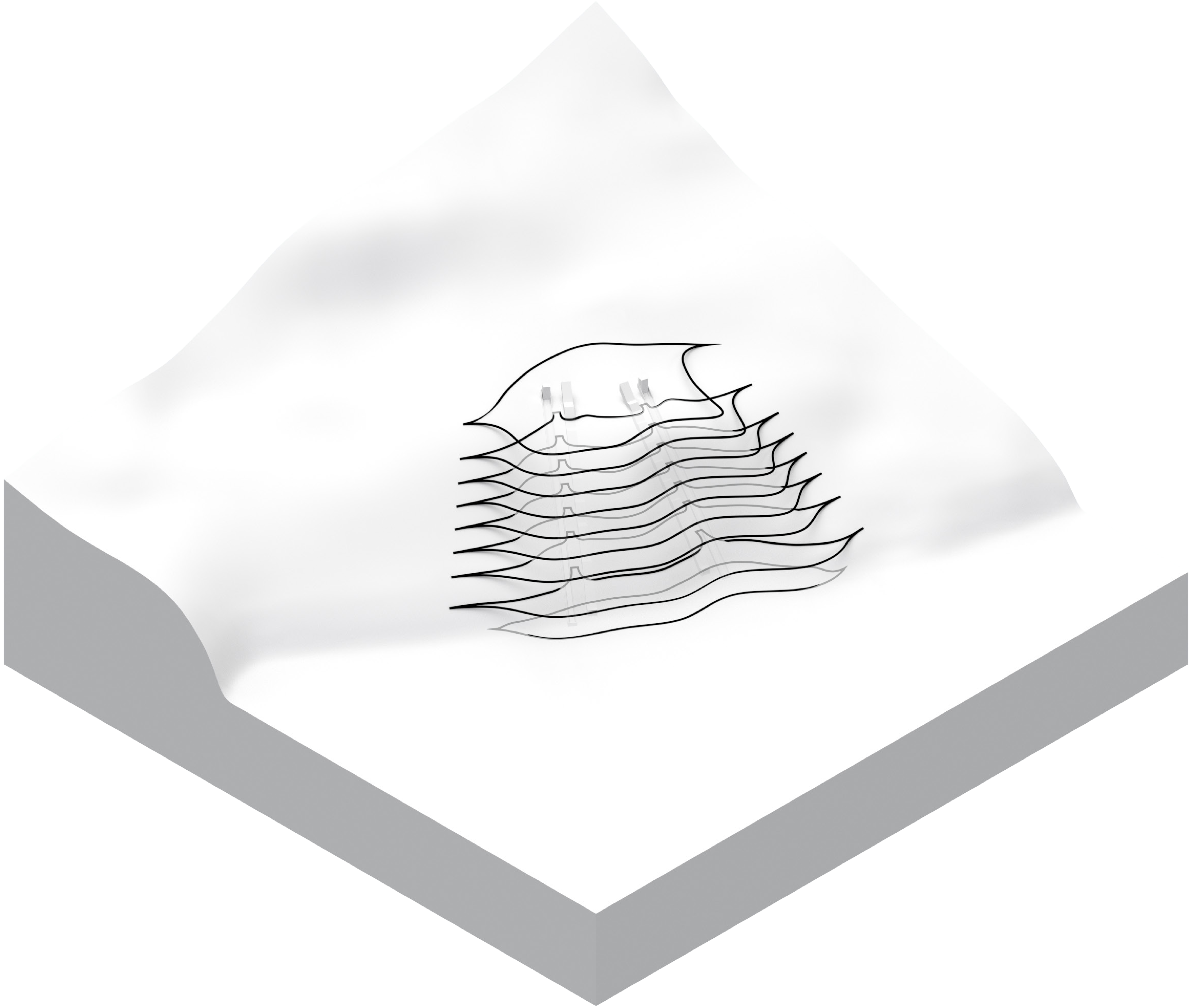
The floor plan was subsequently finalised based on the rationalised pattern and the set boundaries.



Shape Forming

Lift Shaft & Staircases

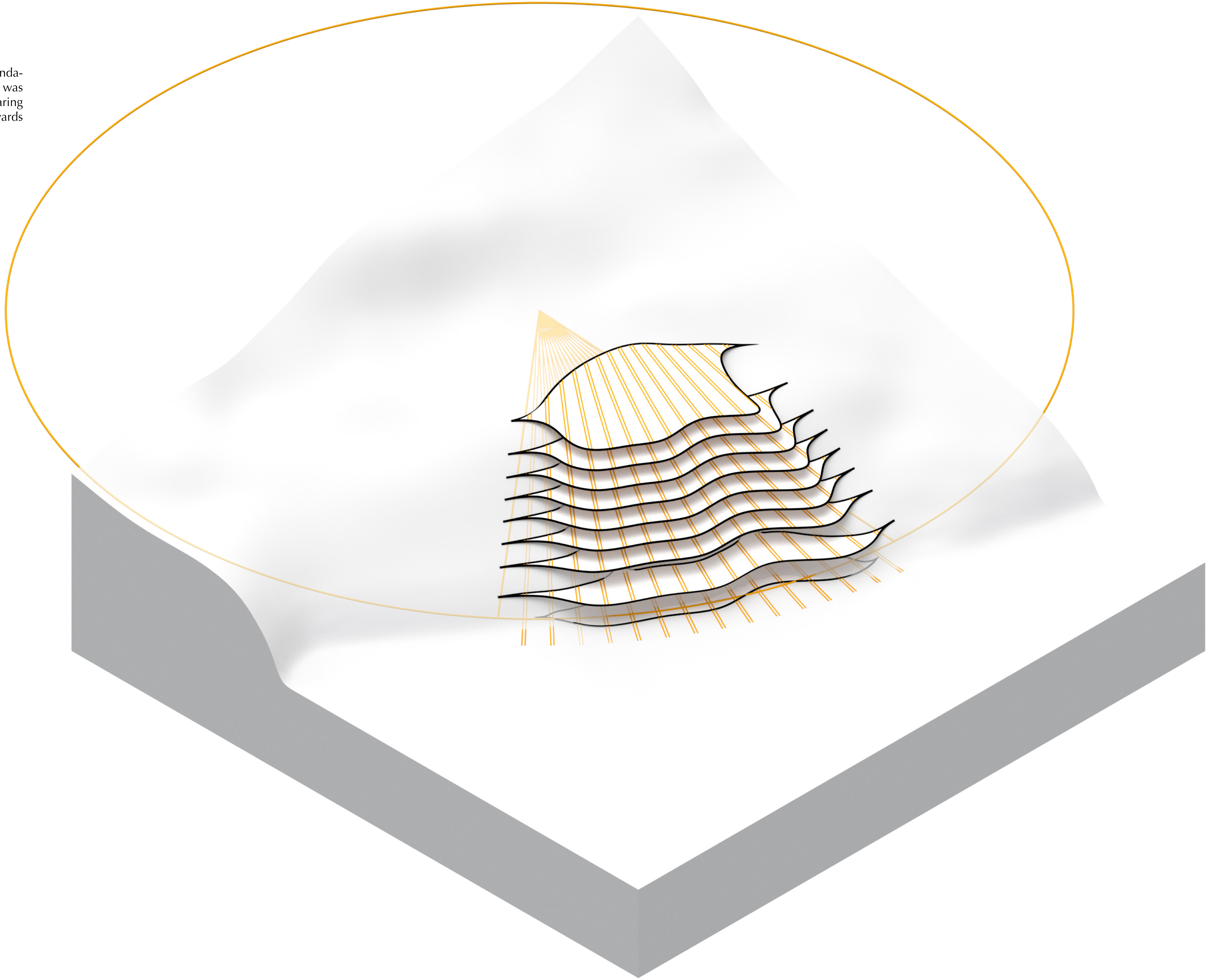
To account for the significant hill slope, and to respect the original design ethos of minimal intrusion into nature, inclined lifts were introduced. Accommodations were made in the floor plan to incorporate the lift shafts and staircases.



Shape Forming

Load-bearing Lines

To achieve optimal load distribution to the foundation, the same circle used to define boundaries was further divided into 13 sectors with 14 load-bearing lines, enabling the load to be directed downwards towards the foundation.



Construction

Foundation

The construction process commenced with the building of retaining walls and foundation, using a MAT foundation where each sector forms a load-bearing MAT.

Construction

Foundation

A comprehensive rebar structure was constructed upon the cover blocks and PCC to provide reinforcement for the MATs, load-bearing walls and columns.

Construction

Foundation

Concrete was subsequently poured into the formwork to complete the foundation construction.

Construction

Carbon Calculation

Construction Method	$kgCO_2e/kg$	Advantages	Disadvantages	Feasibility	Cost	Transportation
In-situ Concrete C40/50	0.138	High strength Versatility in design Suitable for curved structures Reduced transportation costs	Time-consuming curing process Requires formwork	High	Moderate - High	Low (Mixed on-site, little precast element)
Precast Concrete C40/50	0.178	Faster construction Quality control in factory settings Consistent quality	Requires transportation Less flexibility in changes on-site	High	Moderate	High (Large precast element)
Insulated Concrete Formwork (ICF)	0.280	Excellent insulation Energy efficiency Suitable for cold climates Versatile design for curved structures	Specialised labor required Higher initial cost	High	High	Low - Moderate (Lightweight forms, but specialised transport)
Blockwork	0.120	Durable Aethetic appeal Traditional method	Limited to linear Planar structures Heavier construction	Moderate	Moderate	Moderate (Relatively small, but bulky)
Timber Studwork	0.263	Renewable Carbon sequestration Lightweight Quick construction	Pests Regular maintenance Fire-resistance Height limitations	High	Low - Moderate	Moderate (Large precast element, but relatively lightweight)

Data from P. GO and others, 'Table 2.3, 2.2 Inputs', How to calculate Embodied Carbon (Institution of Structural Engineers (ISTRUCTE 2022)

Floor - In-situ Concrete

Prioritising the building's durability, especially in the chilly Harlech climate, concrete was identified as the ideal material for the structure, ensuring long-lasting performance with minimal upkeep. The building's distinctive design, marked by a lack of straight lines on the floor plan, called for a construction approach that offers adaptability. In-situ concrete poured using formwork on-site is perfectly tailored for such intricate, curvilinear designs. This method also provides the flexibility for immediate modifications, accounting for any differences between the actual terrain and computer models. Moreover, given the logistical challenges presented by the site's singular vehicle access route (primary access), the benefits of in-situ concrete became even more pronounced. Its application considerably cuts down on transportation costs and complications, further cementing its choice for floor construction.

Load-bearing Wall - Insulated Concrete Formwork (ICF)

ICF, or Insulated Concrete Formwork, offers outstanding insulation, making it a prime choice for chilly locations like Harlech. The energy efficiency of ICF walls translates to lower heating expenses, presenting long-term operational advantages. Furthermore, ICF is adaptable in its design, facilitating the creation of curved and distinctive structures, in line with the design prerequisites for sinuous walls. The amalgamation of insulation, energy-saving, and design versatility renders ICF a persuasive option for the building's walls. Given that the formwork remains an integral part of the structure, it considerably diminishes the CO2 emissions compared to conventional formwork construction techniques. Consequently, ICF was chosen as the construction method for the load-bearing walls.

Element	Construction Method	$kgCO_2e/kg$	Volume (m^3)	Density (kg/m^3)	Area (m^2)
Floor	In-situ Concrete	0.138	9,021	2,320	15,200
Load-bearing Wall	Insulated Concrete Formwork (ICF)	0.120	939	2,320	/

$$EC = \sum_{i=1}^{n} Q_i(ECF_i)$$

EC = Total Embodied Carbon
Q = Quantity (kg)
ECF = Carbon Factor ($kgCO_2e/kg$)
ECA = Embodied Carbon per Unit Area

$$EC = 0.138 \times 9021 \times 2320 + 0.120 \times 939 \times 2320$$

$$EC = 3149581$$

$$ECA = 3149581/15200$$

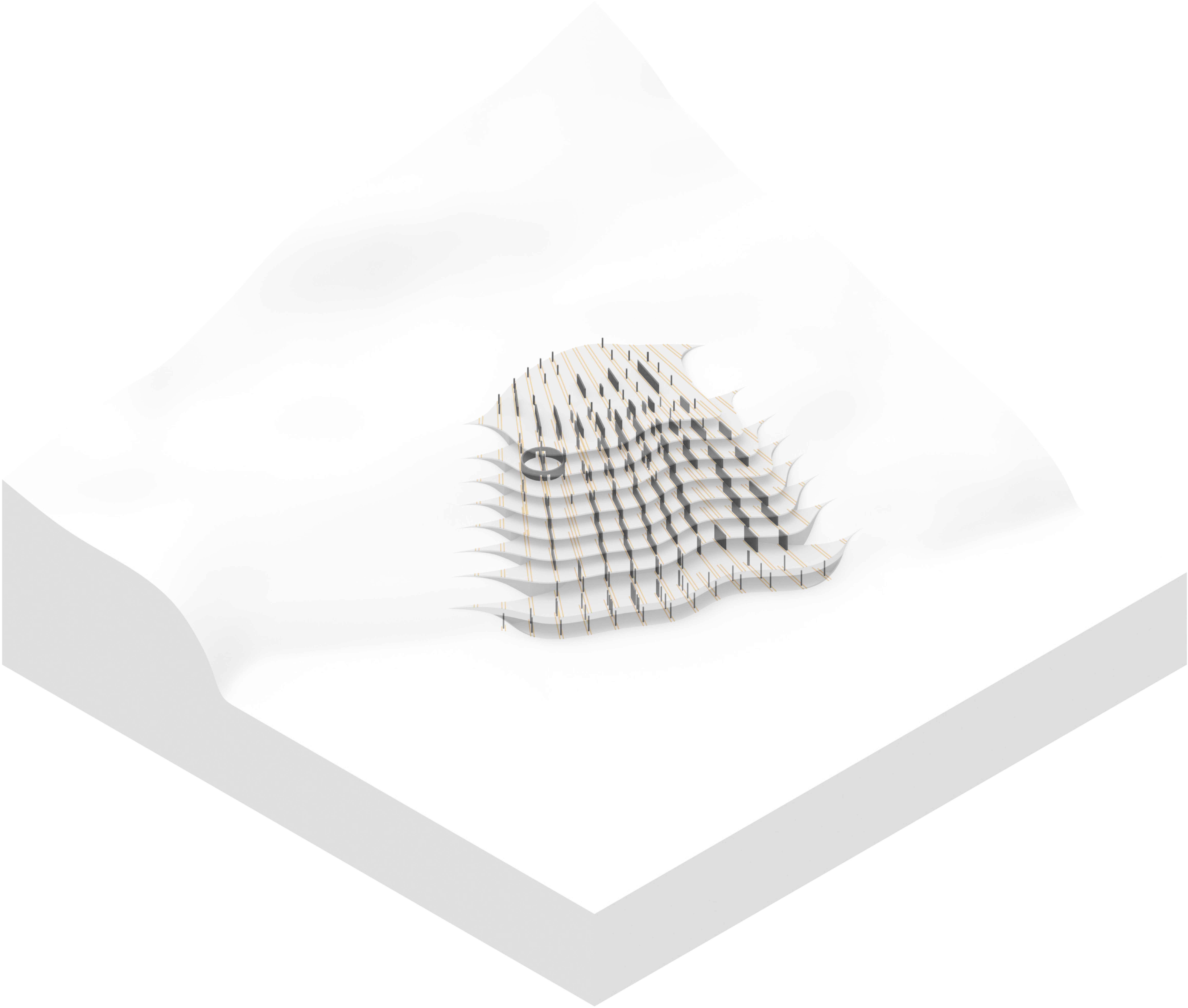
$$ECA = 207.2$$

Embodied Carbon = **207.2 kg/m^2**
(excluding foundation)

Construction

Load-bearing Walls & Columns

Load-bearing walls and columns strictly adhering to the projected load-bearing lines were erected, guaranteeing direct load transfer to the foundation.



Construction

Load-bearing Walls & Columns

To accommodate the curved design's unique challenges, Insulated Concrete Formwork (ICF) was selected for the construction of load-bearing walls. This choice not only facilitates the creation of curvy and irregular shapes but also reduces carbon emissions and simplifies the construction sequence, as the formwork remains and integrates into the wall structure. For the load-bearing columns, recyclable steel formwork was used, negating the need for added insulation, ensuring efficiency in their formation.

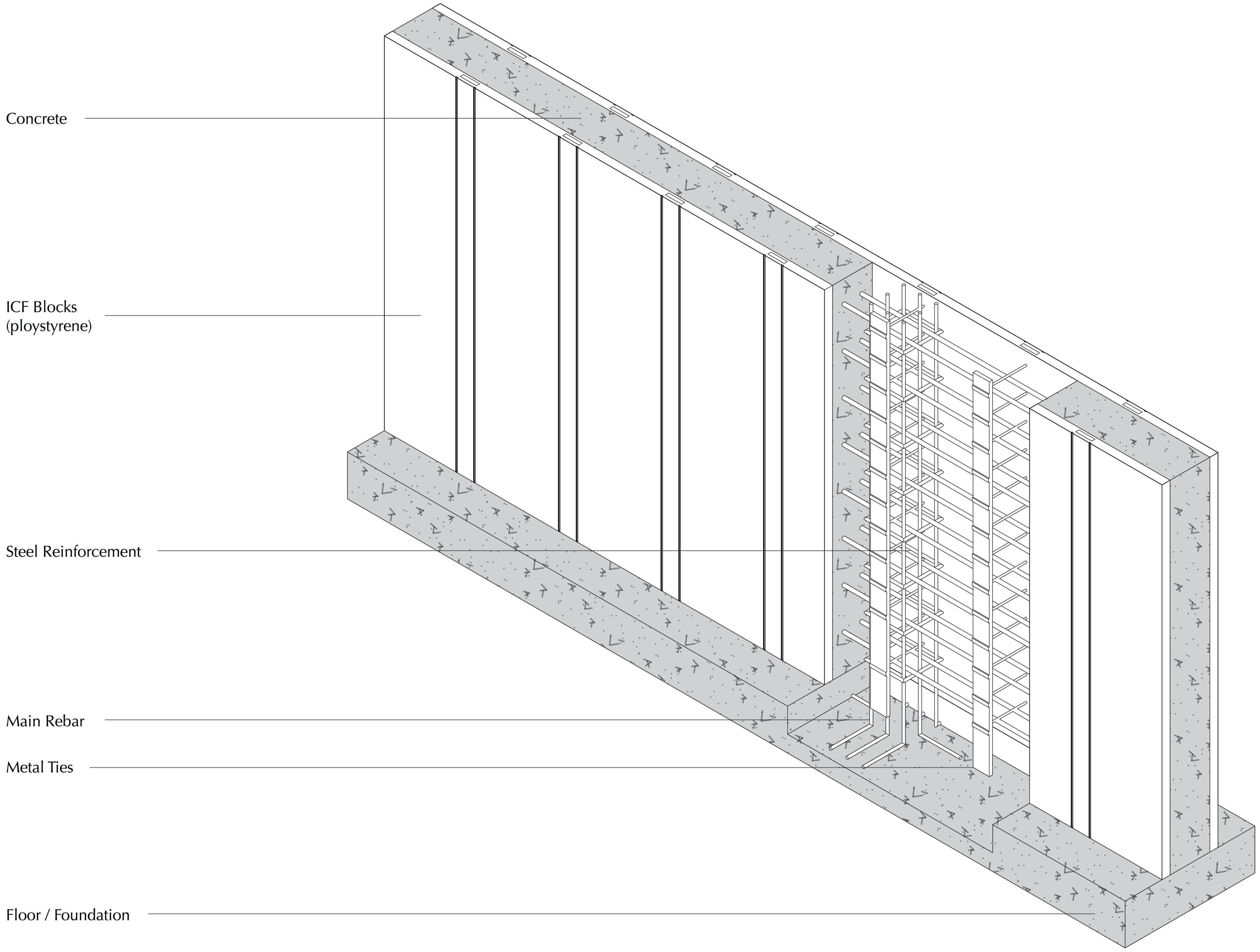
Construction

Load-bearing Walls & Columns

Once formwork was in place, concrete was poured to finalise the construction of the load-bearing walls and columns.

Construction

Load-bearing Wall Details



Construction

Floor & Ceiling

The floor and ceiling were then constructed on top of the load-bearing walls and columns.

Construction

Floor & Ceiling

Rebar mesh reinforcement is arranged on the steel deck, creating a formwork ready for the concrete pour.

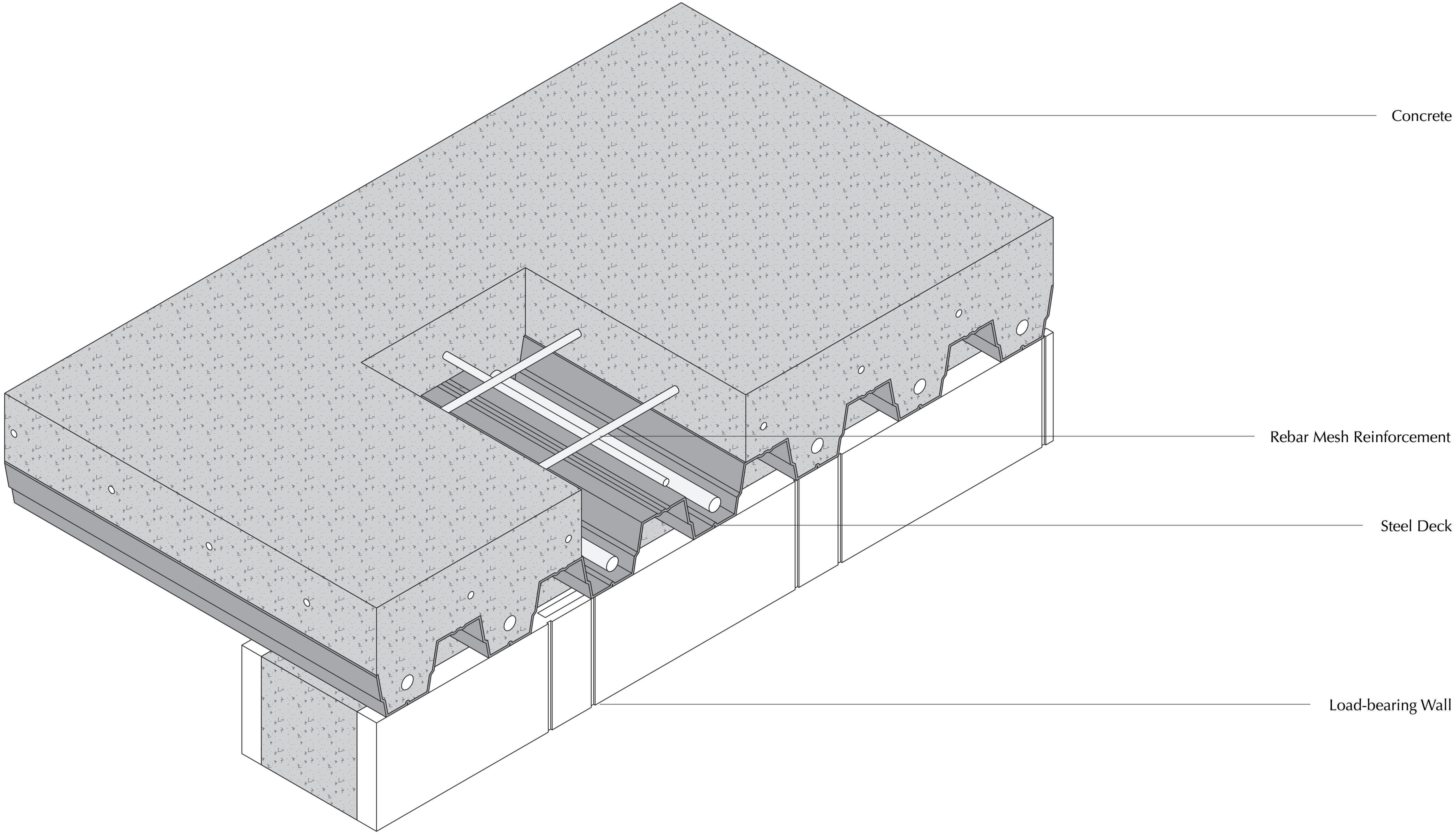
Construction

Floor & Ceiling

Following the setup of the rebar mesh on the steel formwork, concrete is poured to create the ceiling/floor structure.

Construction

Floor Details



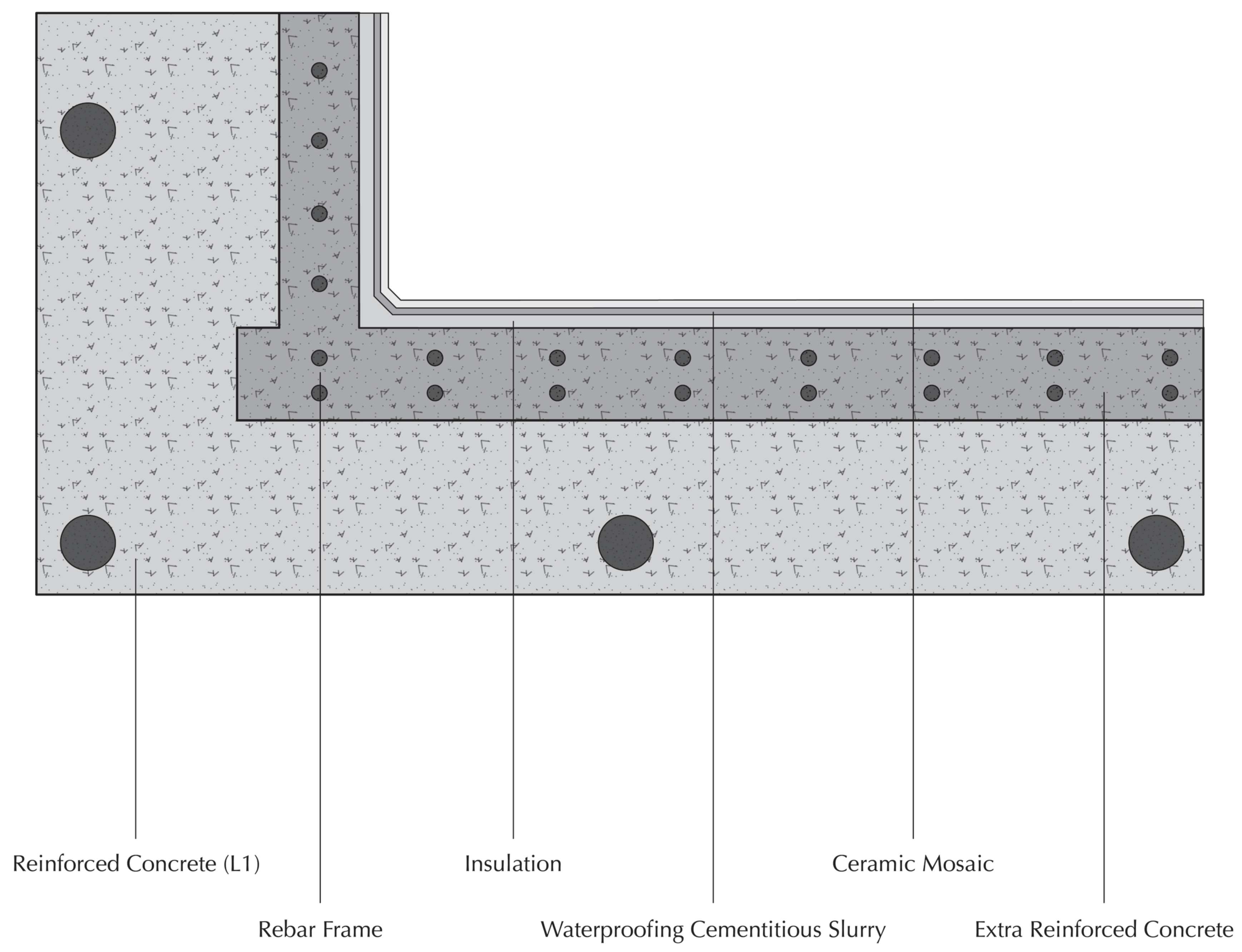
Construction

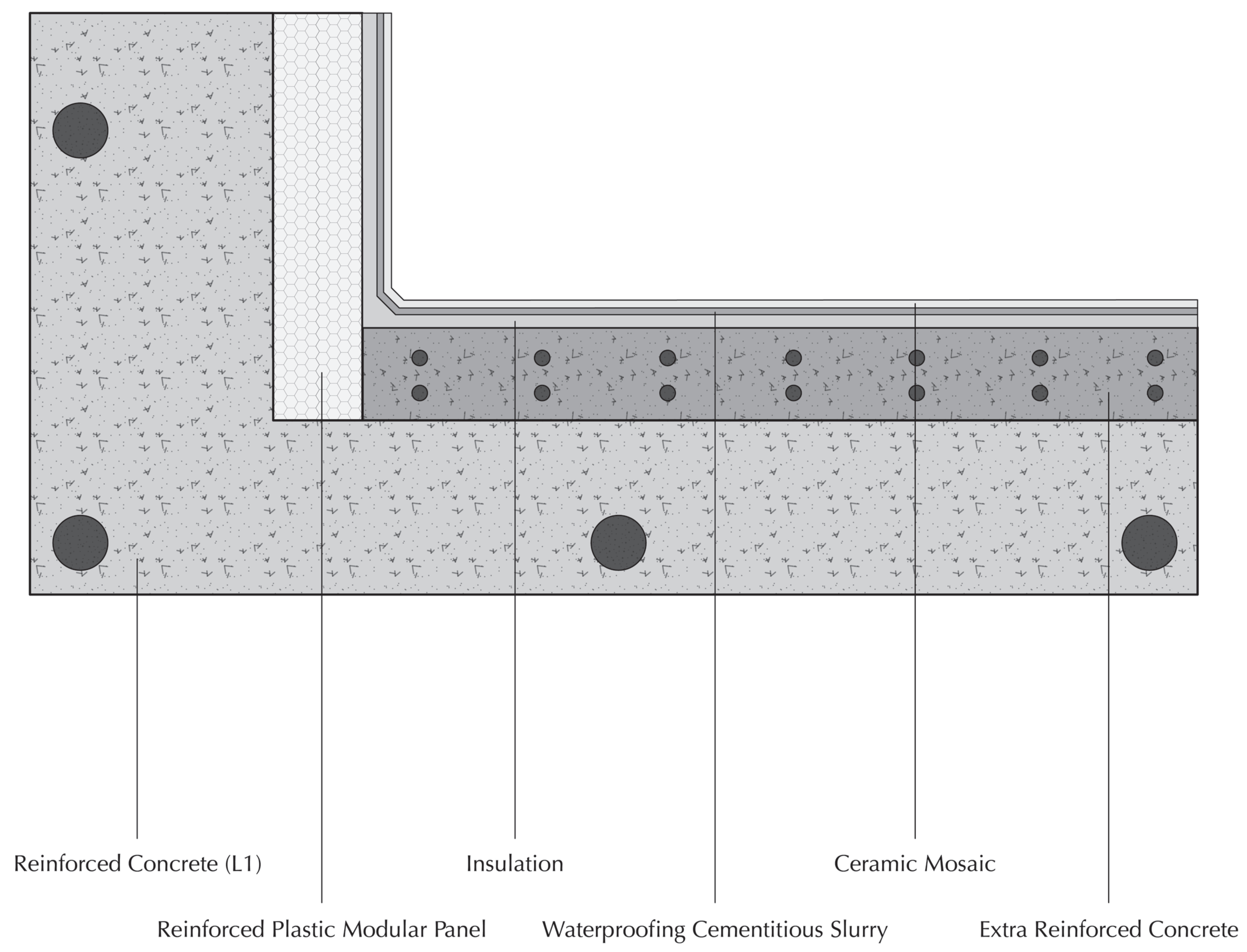
Pool Construction Options

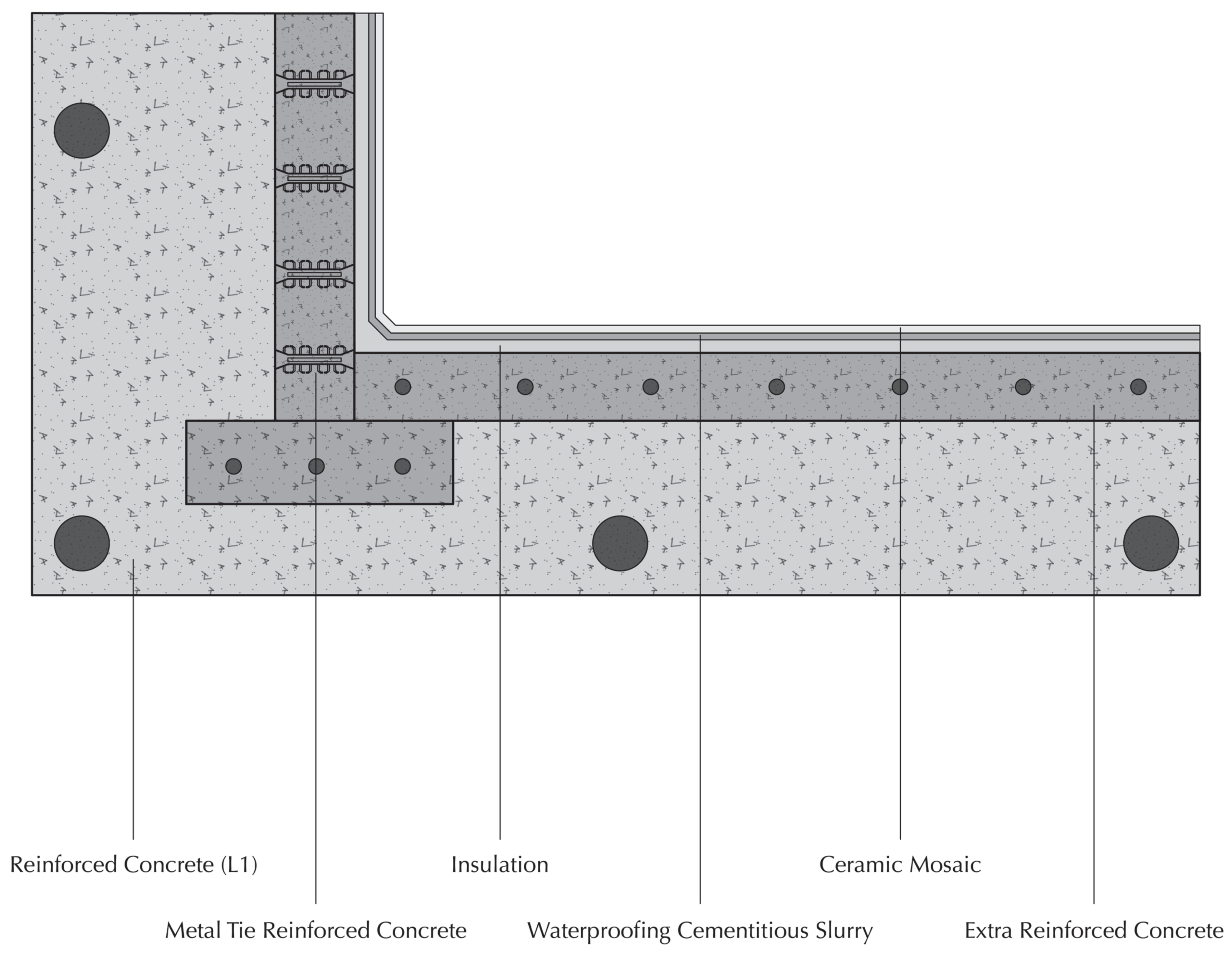
The first approach involves using a single, monolithic reinforced concrete block for the entire structure, fortified with an extra rebar frame. However, the sheer weight of such a one-piece concrete block poses significant challenges, rendering it less viable for implementation.

The second method introduces a novel alteration. While retaining the finishing layers of insulation, waterproofing cementitious slurry, and ceramic mosaic from the first option, it replaces the retaining wall with a reinforced plastic modular panel. These panels, advantageous for their ease of transport and superior insulation, raise concerns about their load-bearing capacity. This becomes particularly pressing given the expected high activity in the adjacent sunbathing area. With the absence of base support inherent to this design, the pool's bottom is supplemented by a reinforced concrete block reinforced further with an extra rebar frame.

The third and preferred option involves employing metal-tie-reinforced concrete for the pool's retaining wall. In addition to this, a reinforced concrete block at the base supports the pool's bottom, which itself is reinforced by yet another similar concrete block. The construction is completed with layers of insulation, waterproofing cementitious slurry, and ceramic mosaics. Upon thorough evaluation of the inherent merits and limitations of each approach, the third method emerges as the most favourable for the construction of the pool.



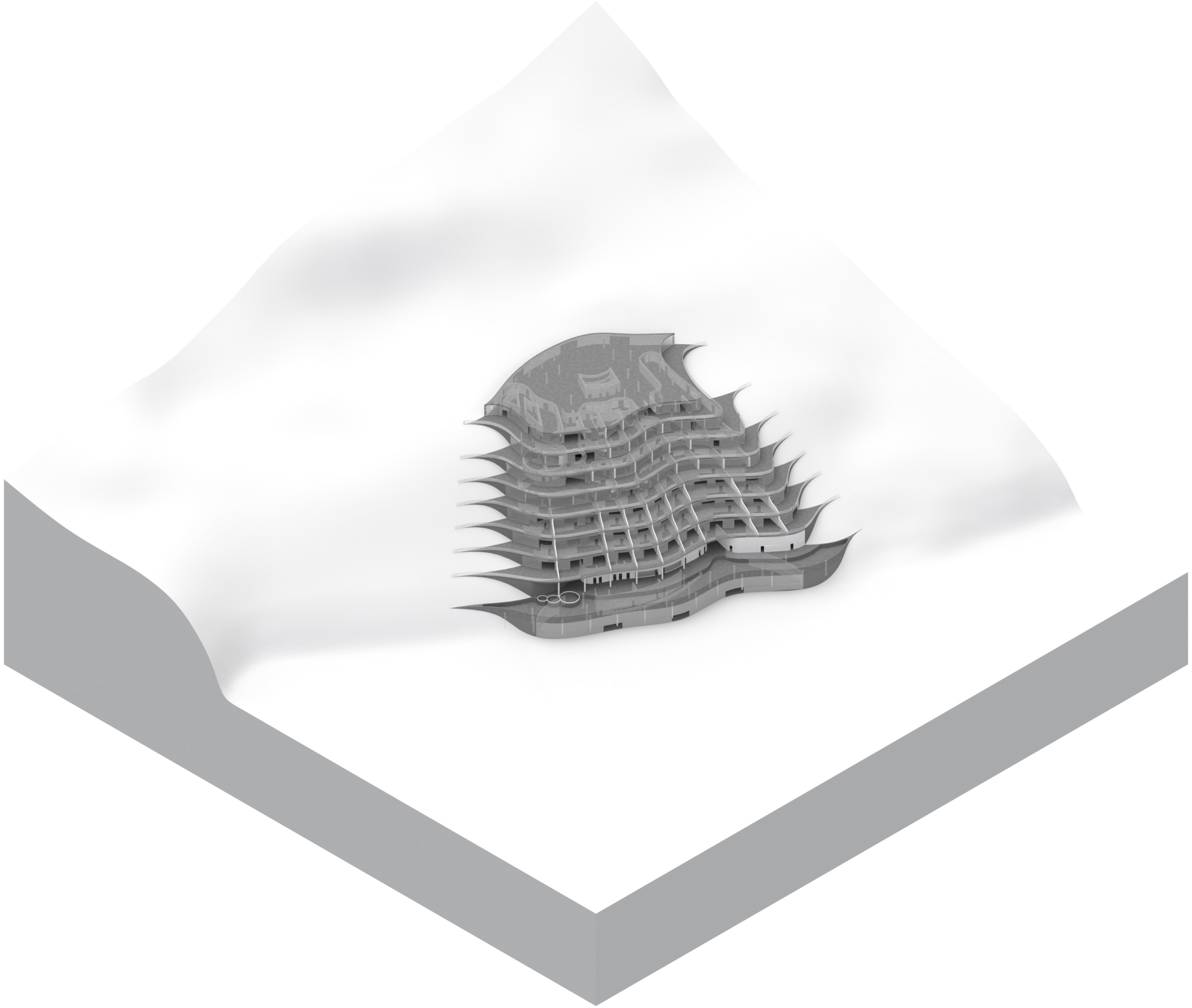




Construction

Internal Design

The internal and partition walls, are designed with unreinforced concrete complemented by insulation, delineate the space according to its various functions.



Energy System

Annual Energy Flow

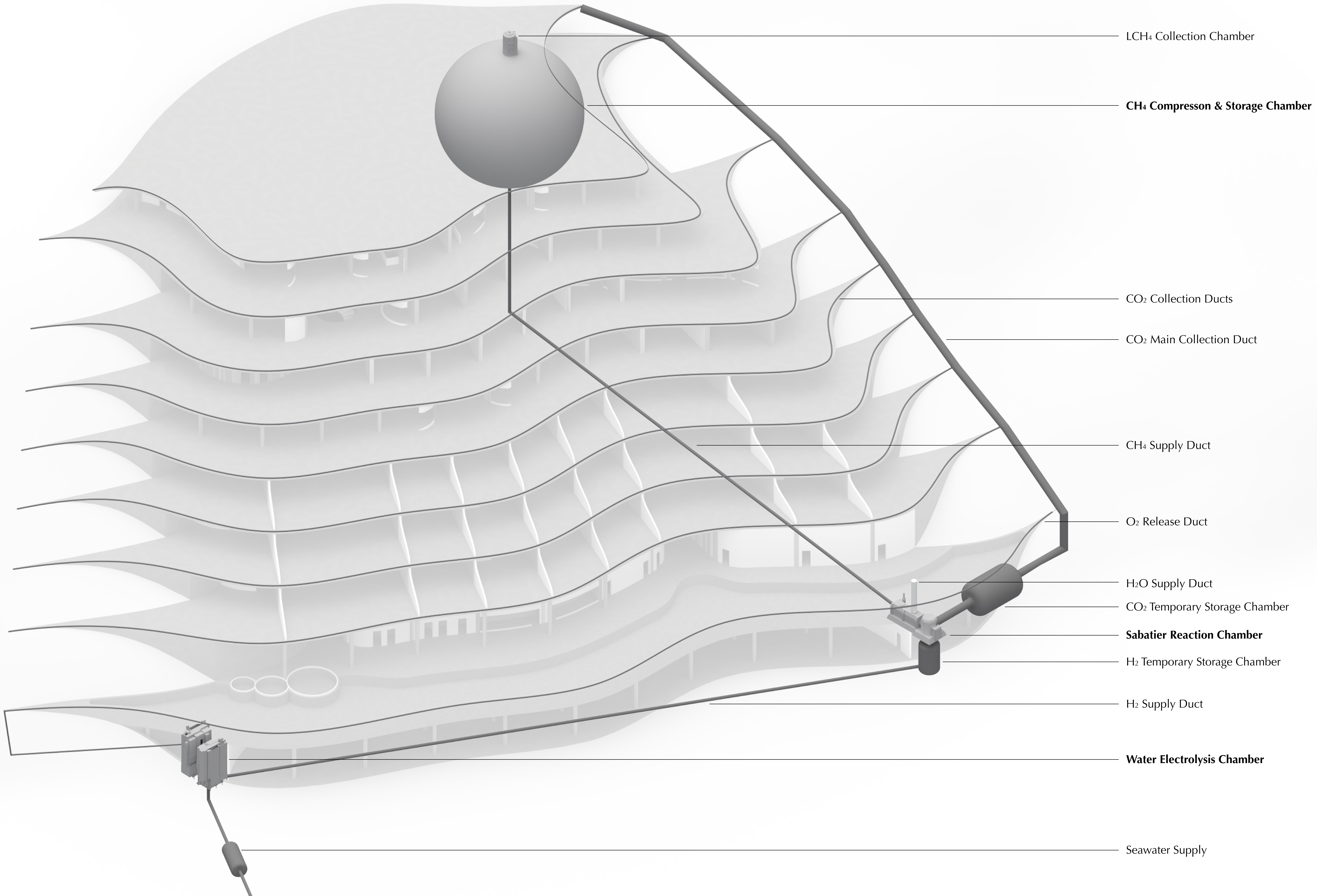
Energy System

System Layout

Located on G are the Water Electrolysis Chamber and Sabatier Reaction Chamber. Meanwhile, the Methane (CH_4) Compression & Storage Chamber is positioned on L8 for convenient retrieval. Seawater is channelled directly from the shore to the Water Electrolysis Chamber, which in turn produces O_2, which is then vented through an integrated release duct in the façade of L1.

H_2 produced in the Water Electrolysis Chamber is transferred to the temporary storage within the Sabatier Reaction Chamber. Concurrently, CO_2 from all levels is consolidated via the CO_2 Collection Ducts that converge into the CO_2 Main Collection Duct, leading to the Sabatier Reaction Chamber's CO_2 temporary storage. This sets in motion the transformation of H_2 and CO_2 into CH_2 and H_2O (clean water). The latter is distributed throughout the building, with a significant portion being directed to the pool. Produced CH_4 is channelled to the CH_4 Compression & Storage chamber, where it's condensed into liquid methane (LCH_4) ready for collection.

While the bulk of the Water Electrolysis Chamber and Sabatier Reaction Chamber is subterranean, essential sections remain accessible on G for maintenance. The entire spherical portion of the CH_4 Compression & Storage Chamber is also submerged, with only the LCH_4 Collection Chamber extending into the L8 lobby. This design choice ensures that the building's overall form and aesthetic are maintained.



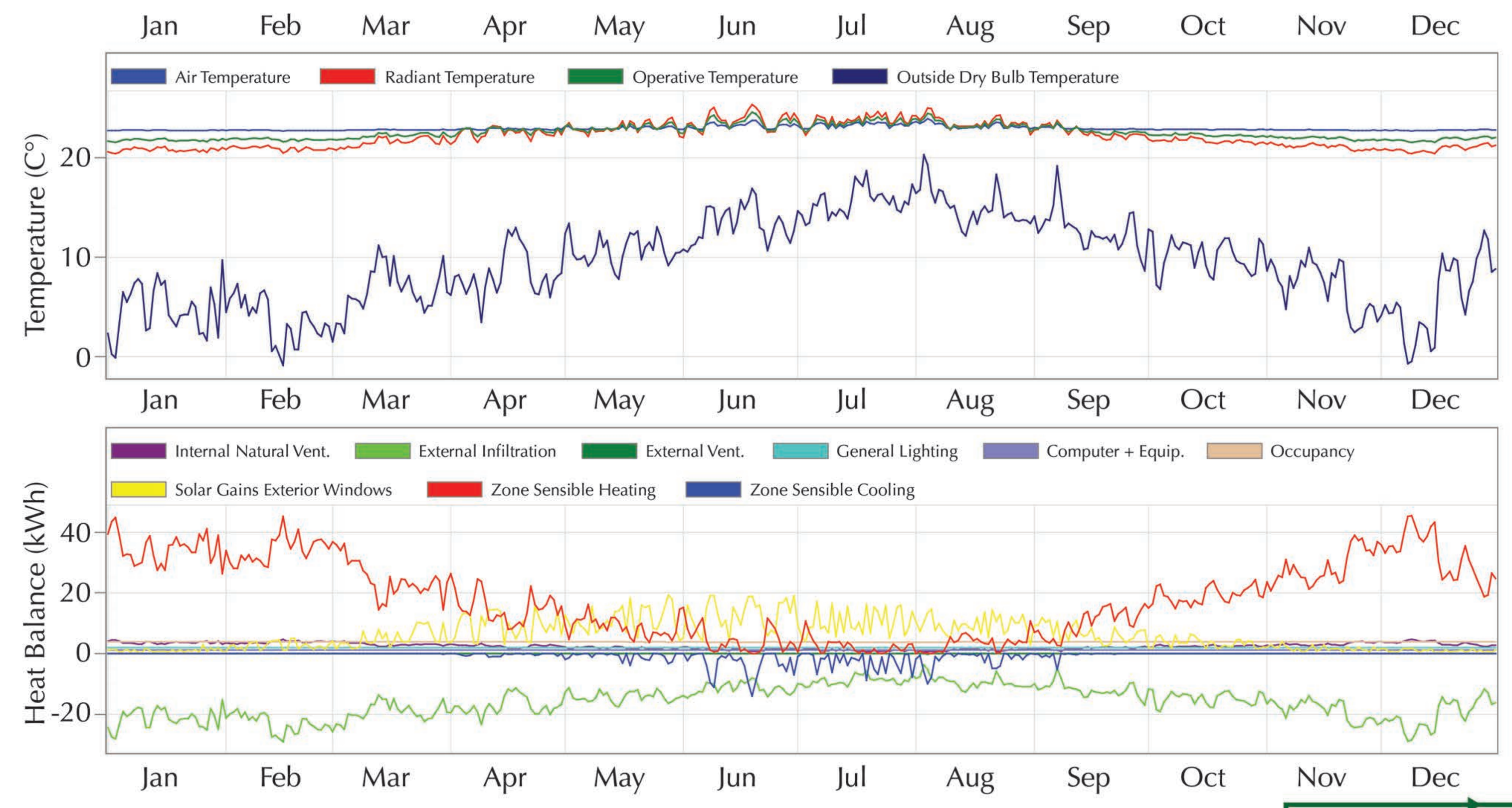
HVAC System

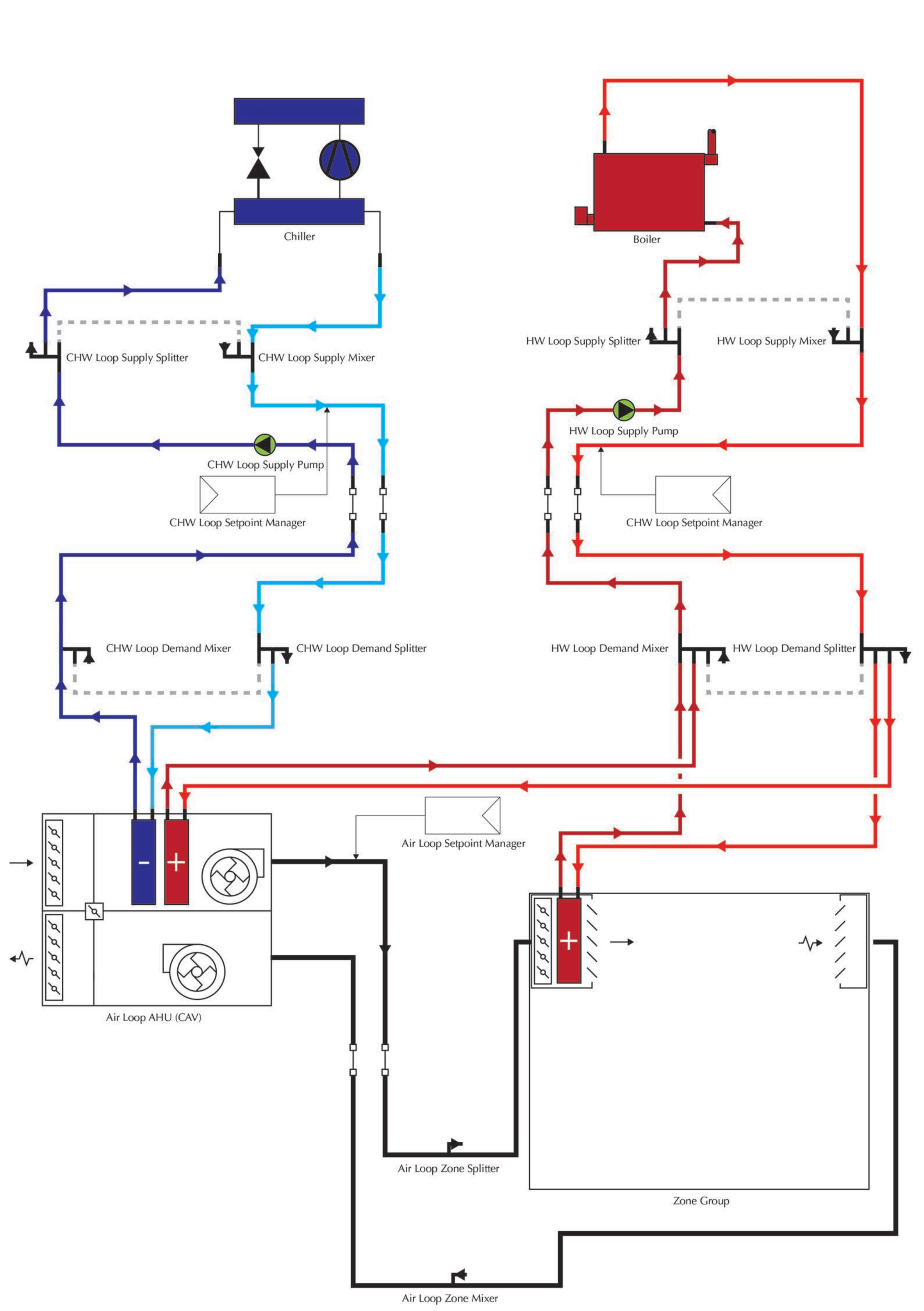
Within this section, the evolution of the HVAC system's design for the building is explored, highlighting distinct developmental phases. This intricate journey exemplifies the significance of harmonising energy consumption with the multifaceted functionality of a building, optimising its environmental footprint in the process.

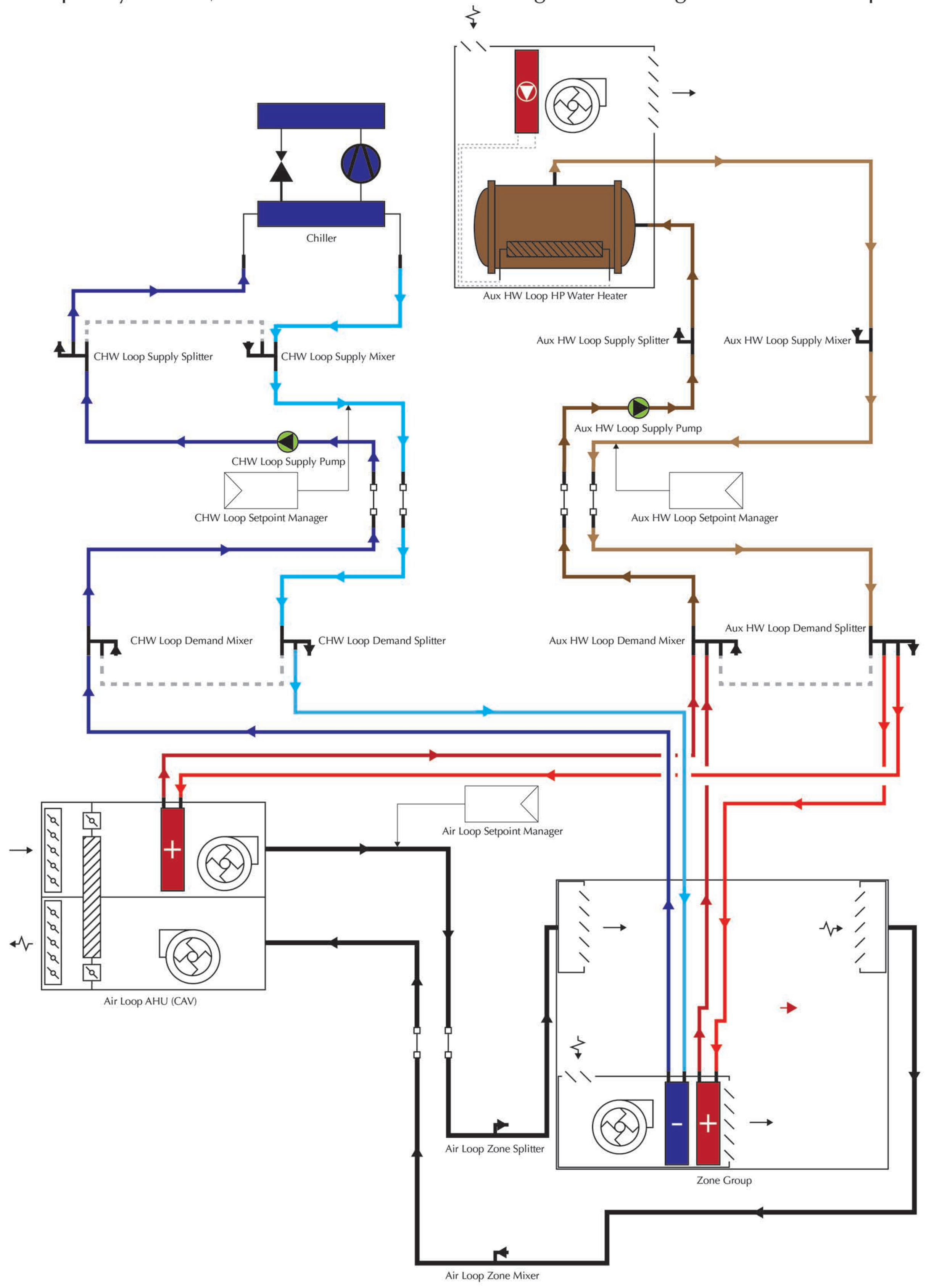
The initial consideration centred around a Variable Air Volume (VAV) system paired with an Air-cooled Chiller & Boiler Heater. While this VAV system had the capacity to deliver 60°C hot water, its overall energy consumption stood considerably high. Several factors contributed to this inefficiency. The boiler's energy performance, for instance, left room for improvement. Additionally, the lack of a heat recovery mechanism in the VAV resulted in elevated cooling loads. Given the building's multifunctional spaces – encompassing areas such as guest rooms, conference centres, educational hubs, and more – the adaptability of the VAV system to diverse temperature requirements posed significant challenges. Transitioning from this, attention shifted towards the Fan Coil Unit integrated with an Air-cooled Chiller & Heat Pump. This adaptation, delivering 60°C hot water, displayed a marked reduction in energy consumption. The efficiency of the heat pump, now accompanied by a heat recovery mechanism, rendered this system more congruous with the building's intricate needs. Subsequently, attention was channelled to integrate the Fan Coil Unit with an Air-cooled Chiller that harnessed heat from the Water Electrolysis Chamber. This innovative approach to repurpose heat, which otherwise would have been lost, established an efficient means to provide 80°C hot water. Notably, even though there appeared to be an energy loss on paper, it's imperative to recognise that the effective energy expenditure for heating was practically null, given the recuperative heat source. Moreover, although the total energy consumption remains above the ASHRAE standard, the deviation is marginal. Furthermore, it should be noted that the heat from the water electrolysis chamber is essentially waste heat, further underscoring the efficiency of this iteration.

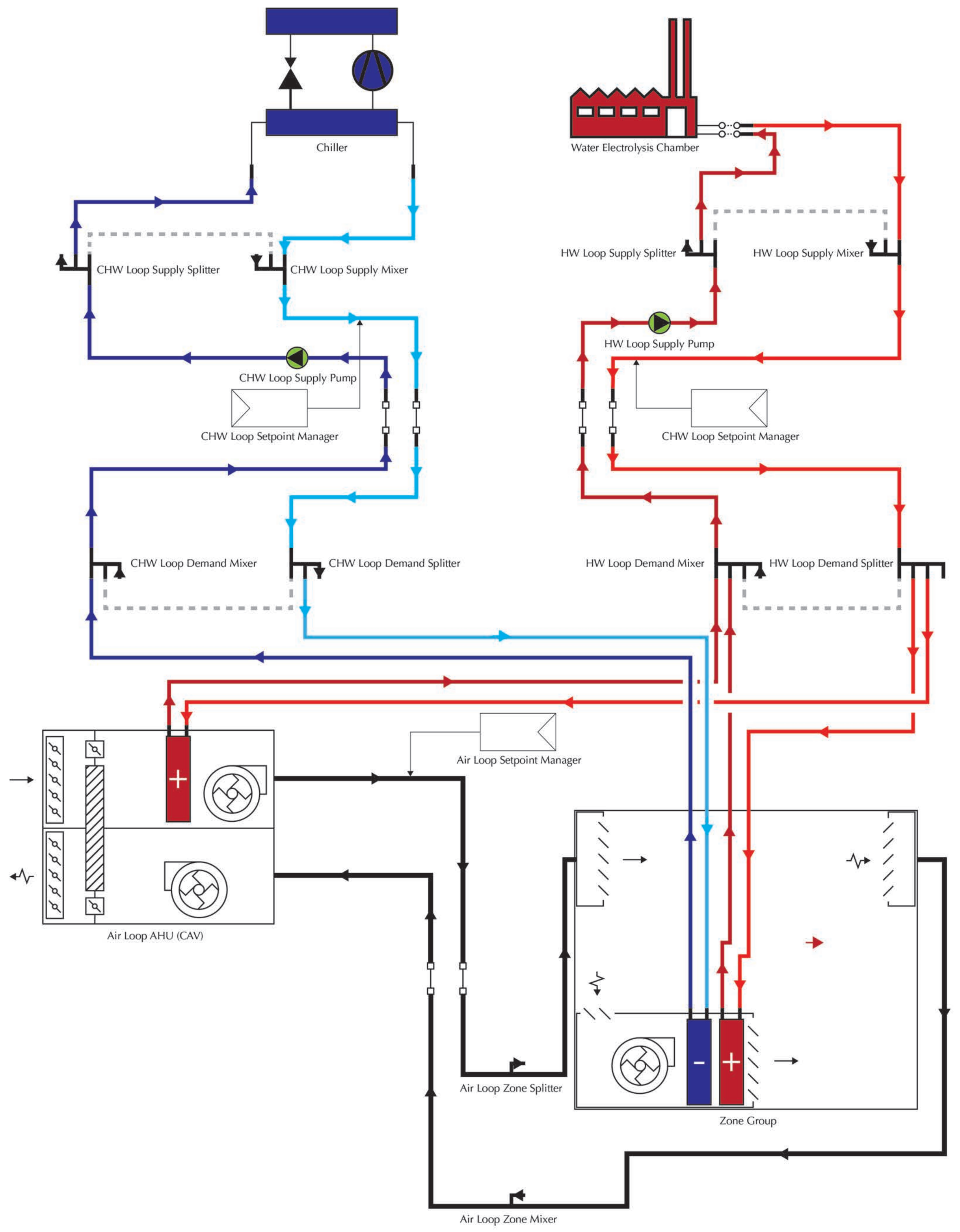
The final adaptation saw the introduction of an HVAC system incorporating a Water-cooled Chiller, utilising heat from the Water Electrolysis Chamber's heat exchanger. This system's terminal unit showcased a fan coil, reminiscent of a test tube, bolstered by an independent AHU with heat recovery capabilities. Operating on a variable flow rate, both the heated and chilled water circuits assured heightened efficiency and adaptability. The incorporation of a water-cooling tower further mitigated cooling energy requirements.

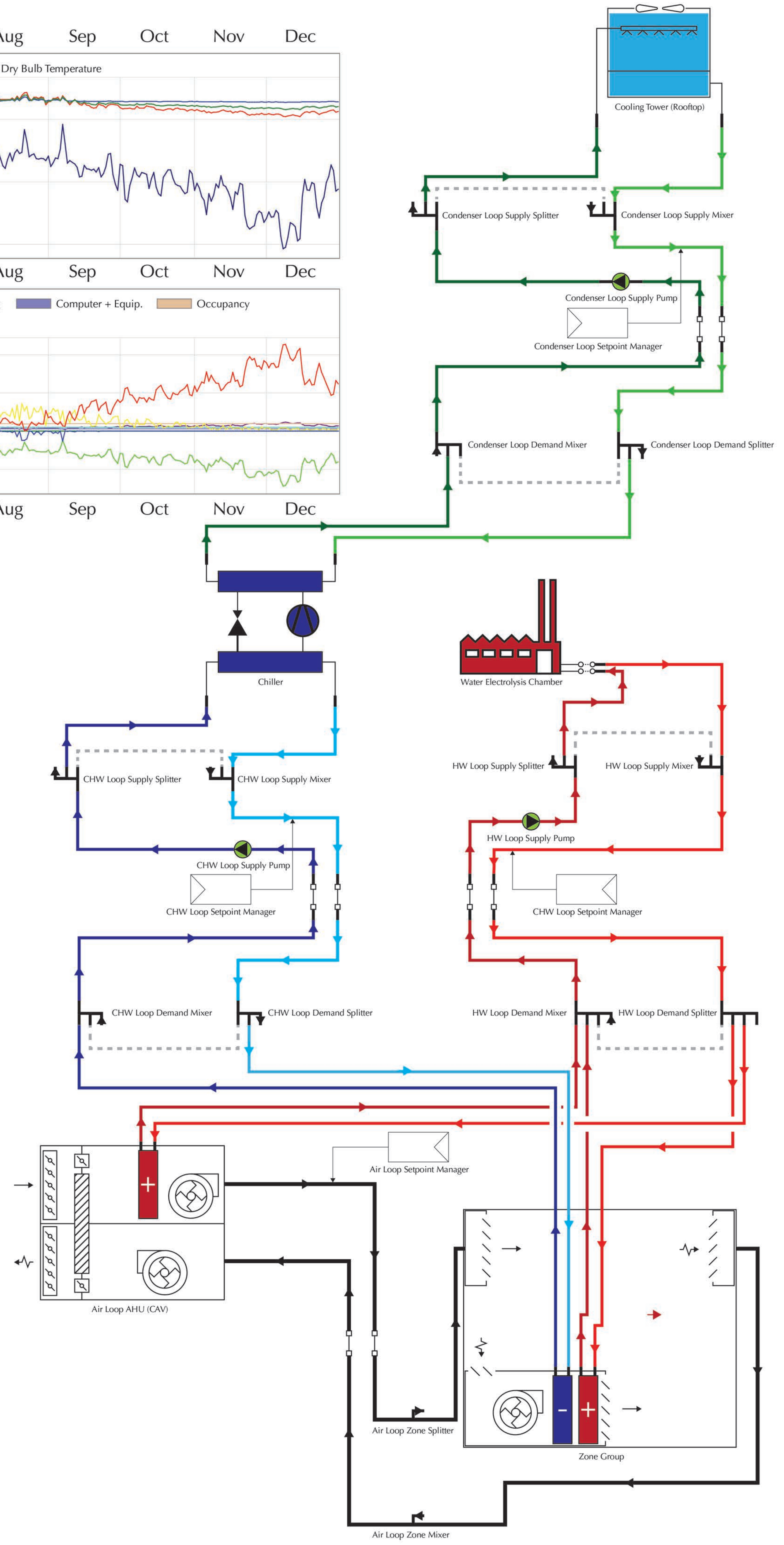
While the cooling system might initially appear superfluous due to its sporadic operation, it remains integral to the building's framework. There are instances during peak summer where room temperatures surpass set comfort levels, particularly in certain south-facing rooms. Moreover, specific sensitive areas, such as labs, necessitate stringent temperature control. Furthermore, bearing in mind that a sizable portion of this edifice functions as a luxury retreat or hotel, it becomes crucial to provide occupants with the luxury of temperature modulation. Thus, the presence of a cooling system, however infrequently utilised, stands testament to the building's unwavering commitment to optimal comfort.









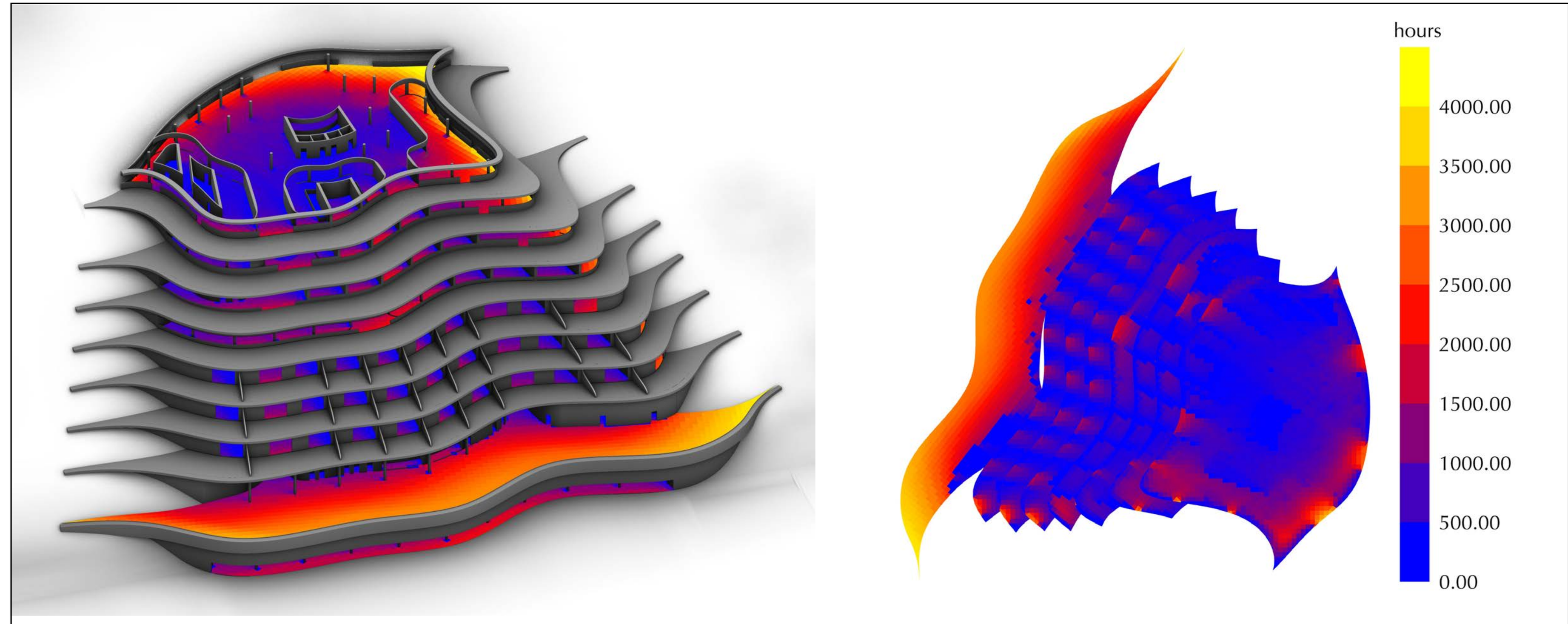


Result (annual)	**VAV** (Air-cooled Chiller & Boiler)	**Fan Coil** (Air-cooled Chiller & Heat Pump)	**Fan Coil** (Air-cooled Chiller & Water Electrolysis Heat)	**Fan Coil** (Water-cooled Chiller & Water Electrolysis Heat)	**ASHRAE** (Standard 100-2015)
Hot Water Temperature (C°)	60	60	80	80	/
Heating Consumption (kWh/m²)	301.65	82.37	106.83 (0)	104.62 (0)	/
Cooling Consumption (kWh/m²)	8.16	2.62	2.62	0.58	/
Total Consumption (kWh/m²)	309.81	84.99	109.45 (2.62)	105.20 (0.58)	67.81
Total Consumption (kWh)	3,218,922.55	883,046.10	1,137,185.50 (27,315.65)	1,093,028.00 (6,026.2)	704,545.90

Building Services Overview

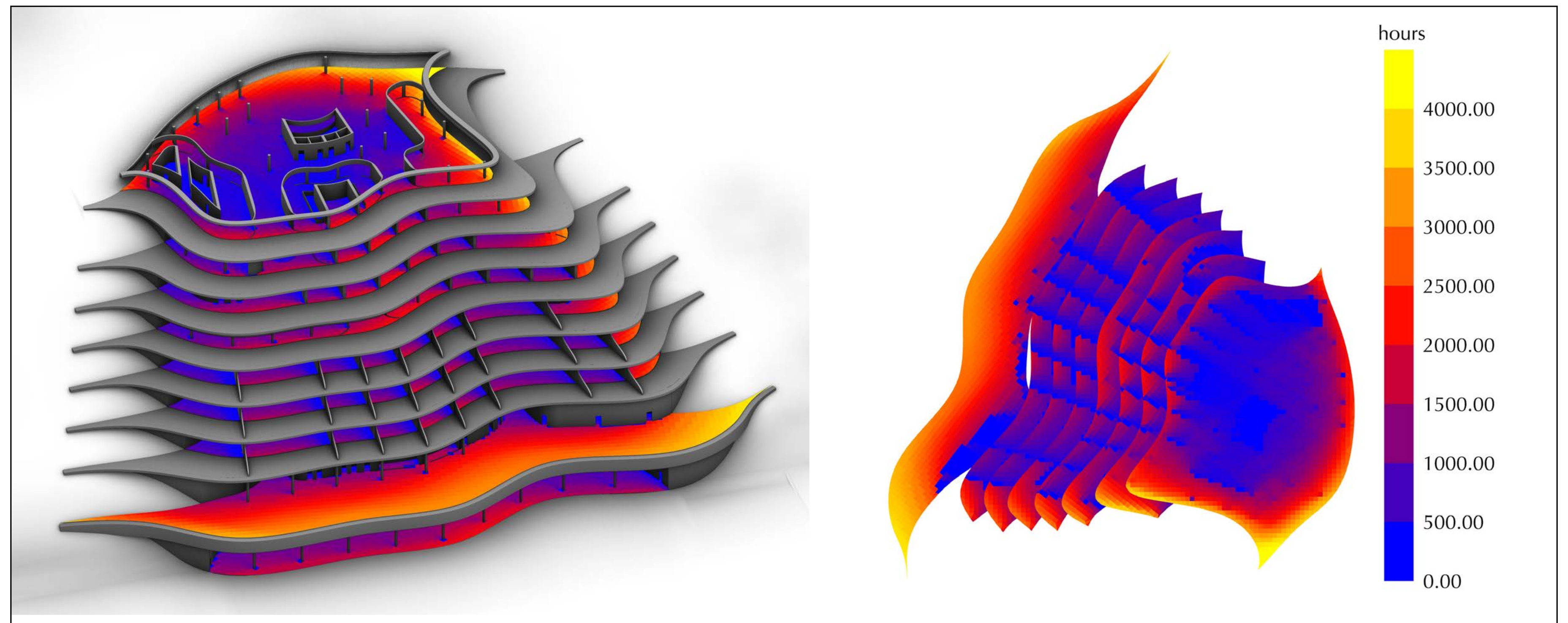
Shading & Glazing

Sunlight Hours Analysis



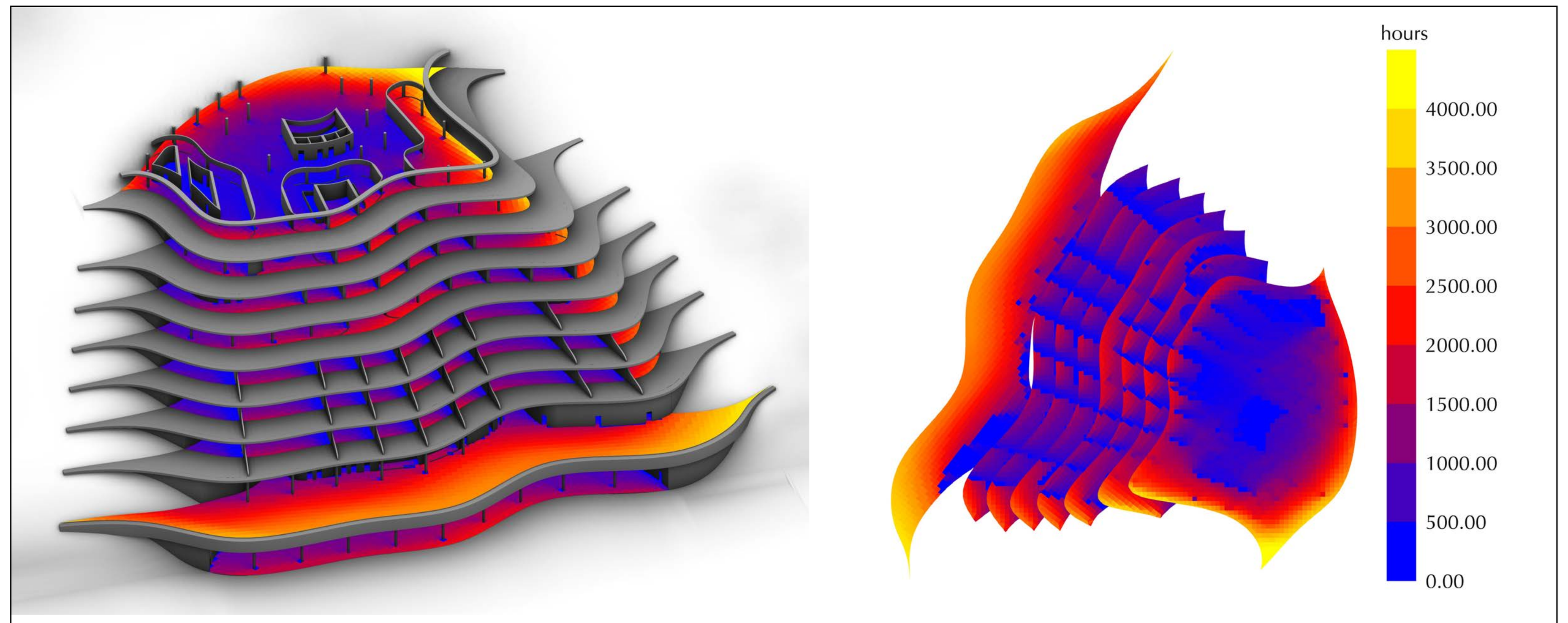
50% Glazing
100cm Overhang

567.08
Average Annual Sunlight Hours



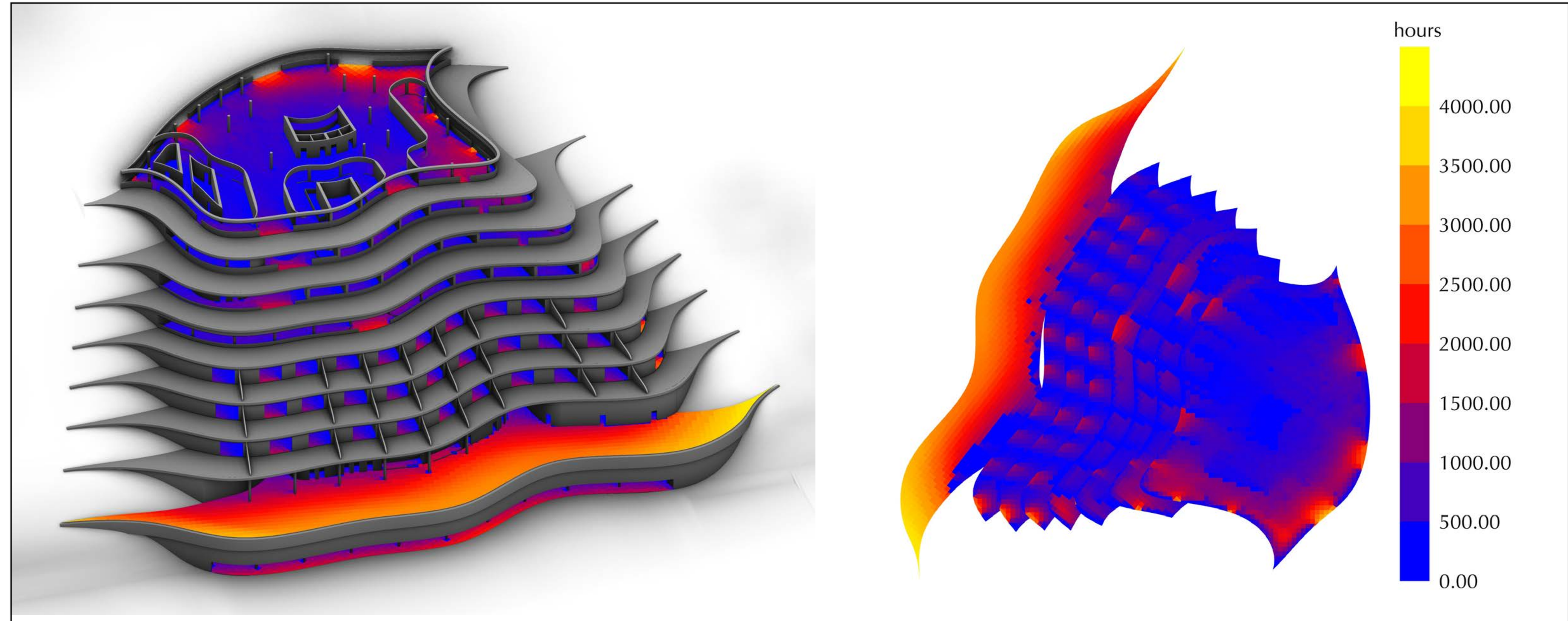
80% Glazing
100cm Overhang

863.67
Average Annual Sunlight Hours



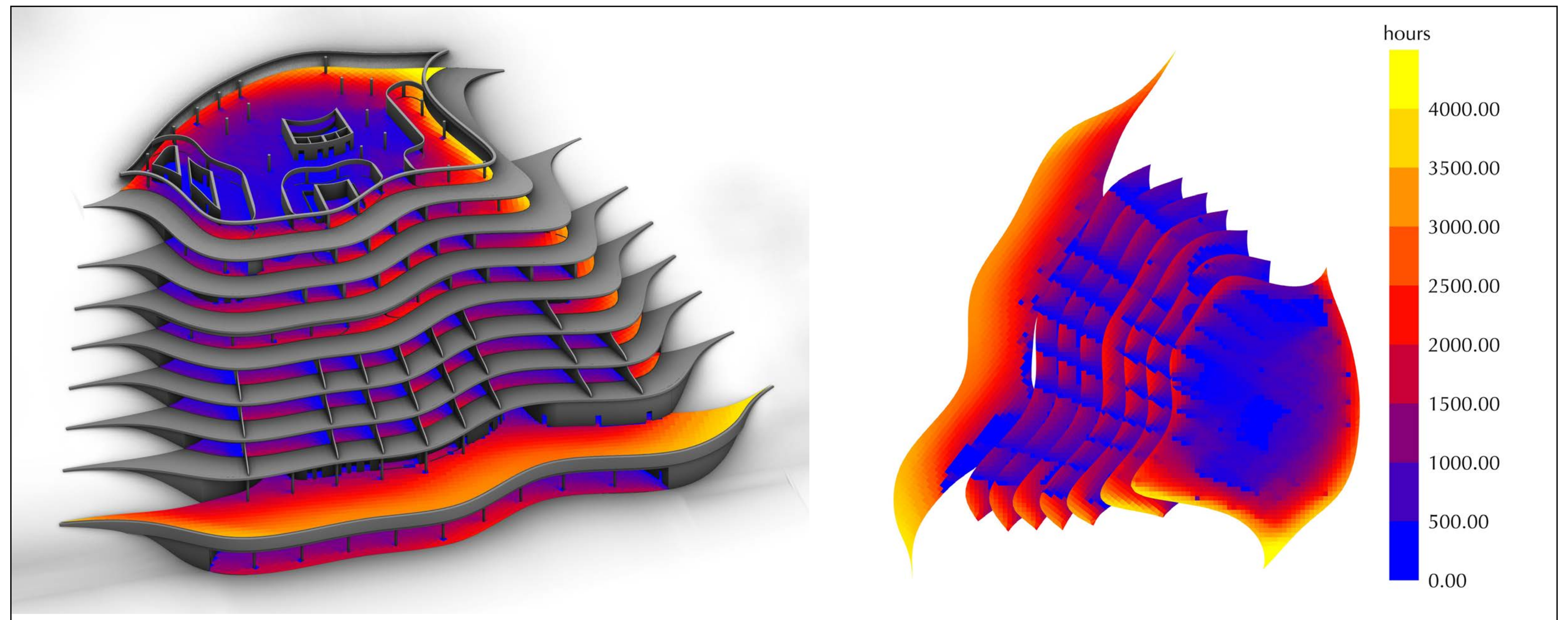
95% Glazing
100cm Overhang

968.05
Average Annual Sunlight Hours



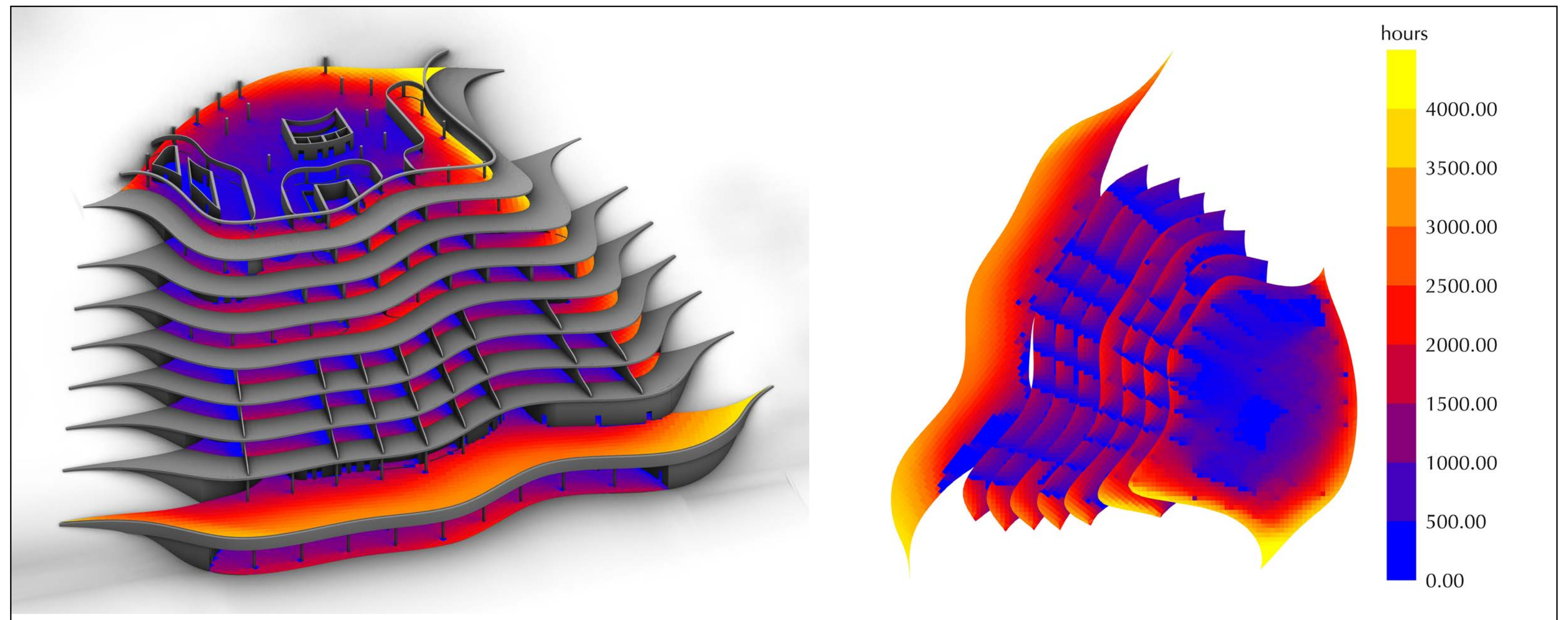
50% Glazing
50cm Overhang

584.17
Average Annual Sunlight Hours



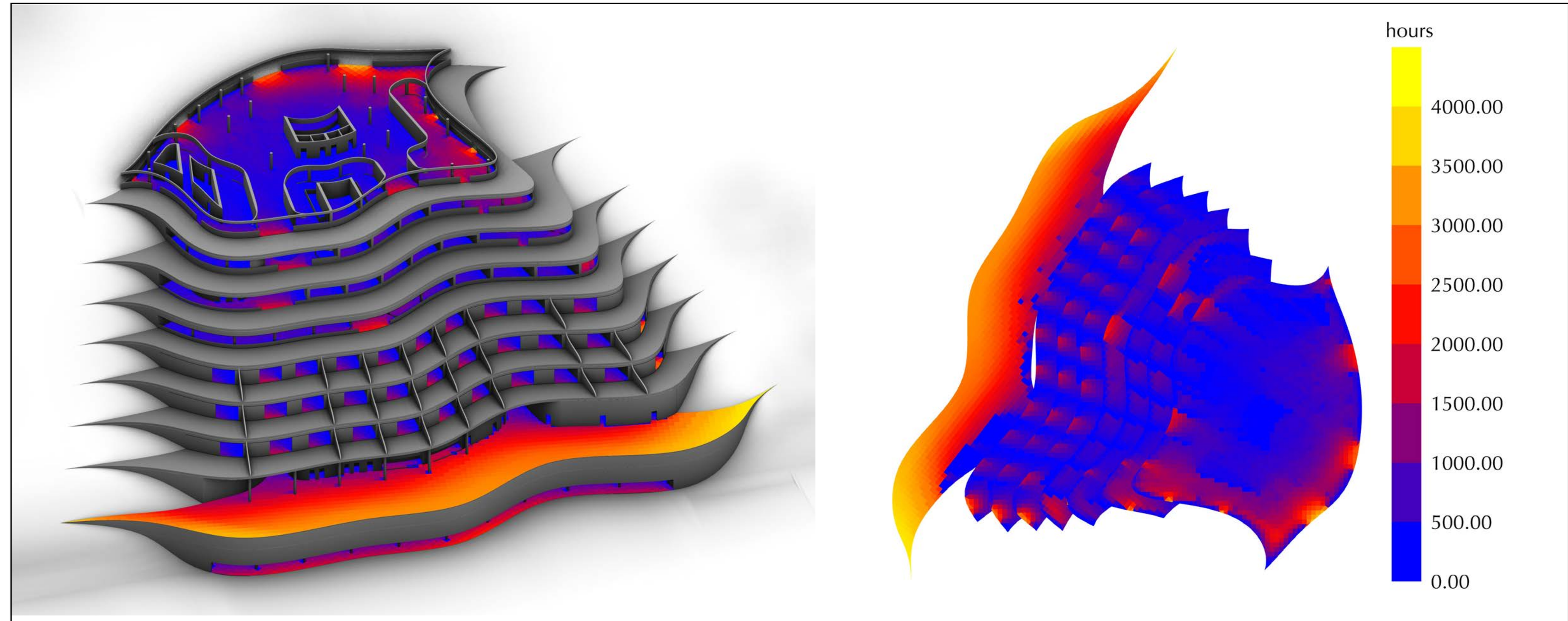
80% Glazing
50cm Overhang

889.32
Average Annual Sunlight Hours



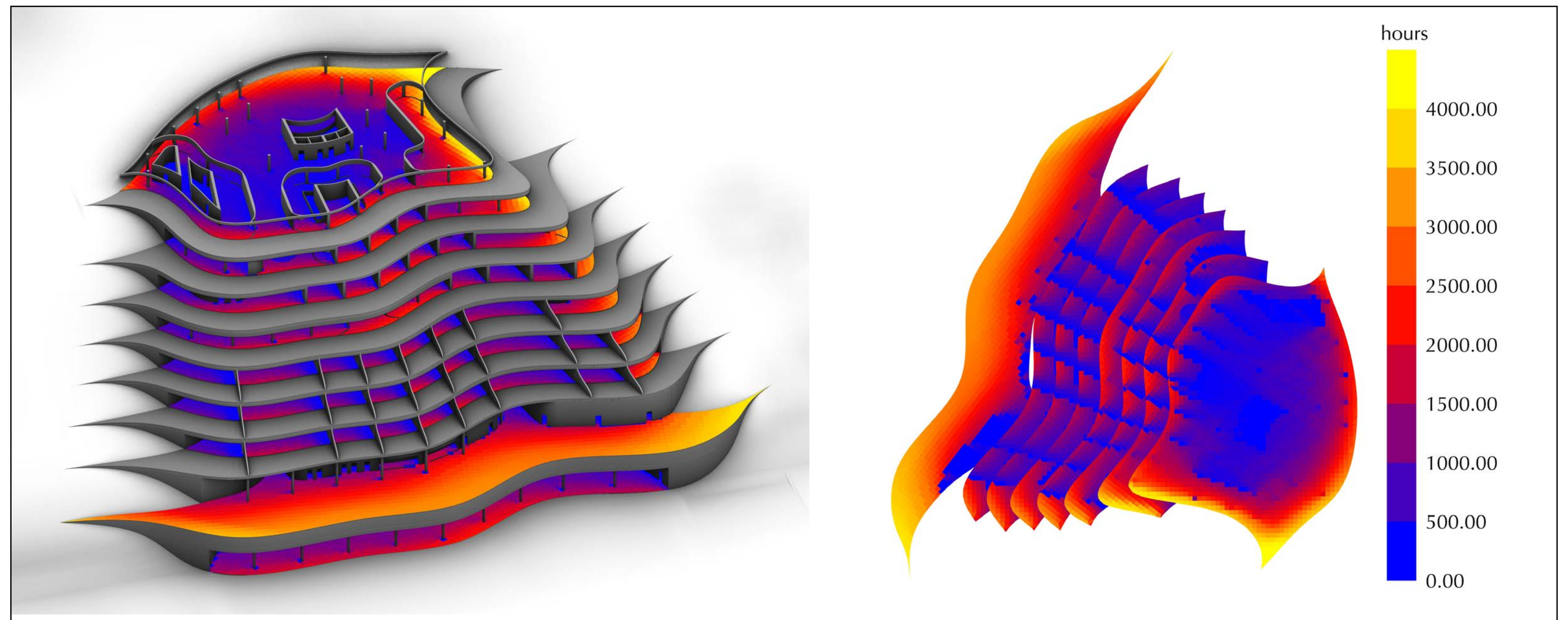
95% Glazing
50cm Overhang

989.29
Average Annual Sunlight Hours



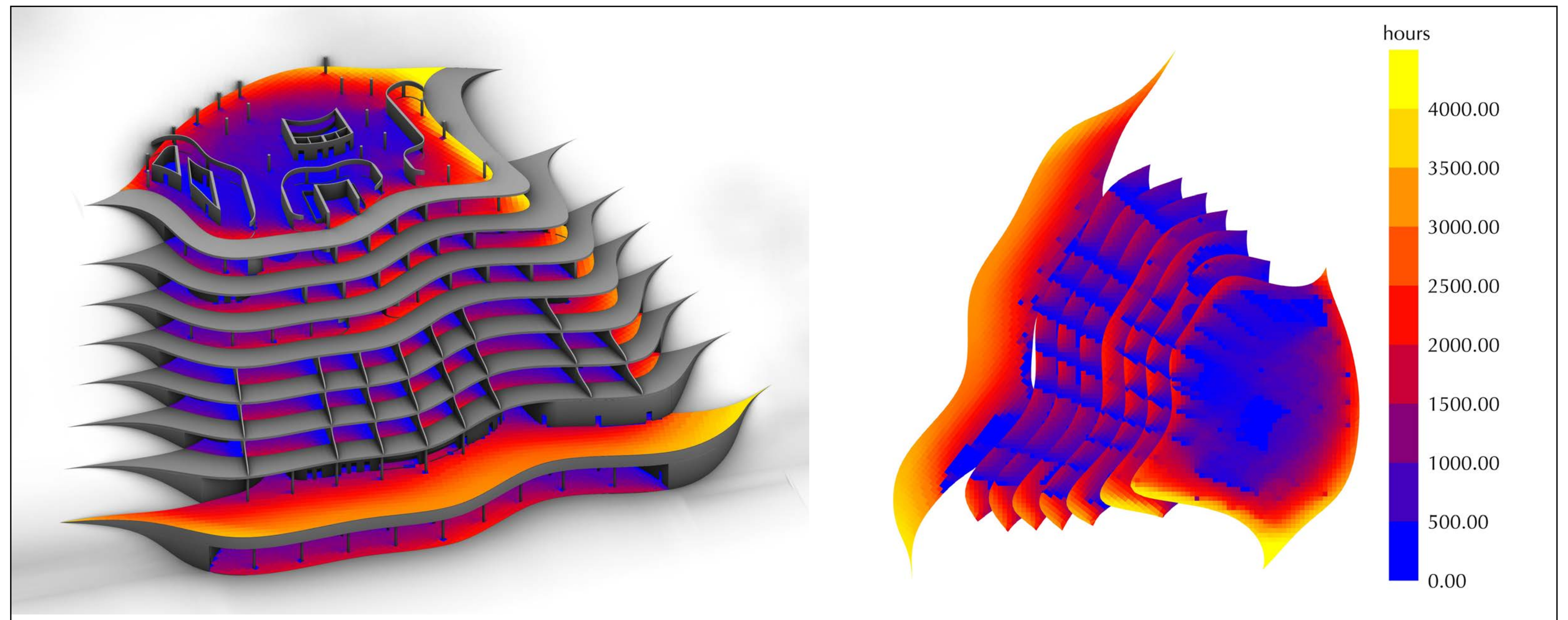
50% Glazing
No Overhang

595.85
Average Annual Sunlight Hours



80% Glazing
No Overhang

907.44
Average Annual Sunlight Hours



95% Glazing
No Overhang

1,004.76
Average Annual Sunlight Hours

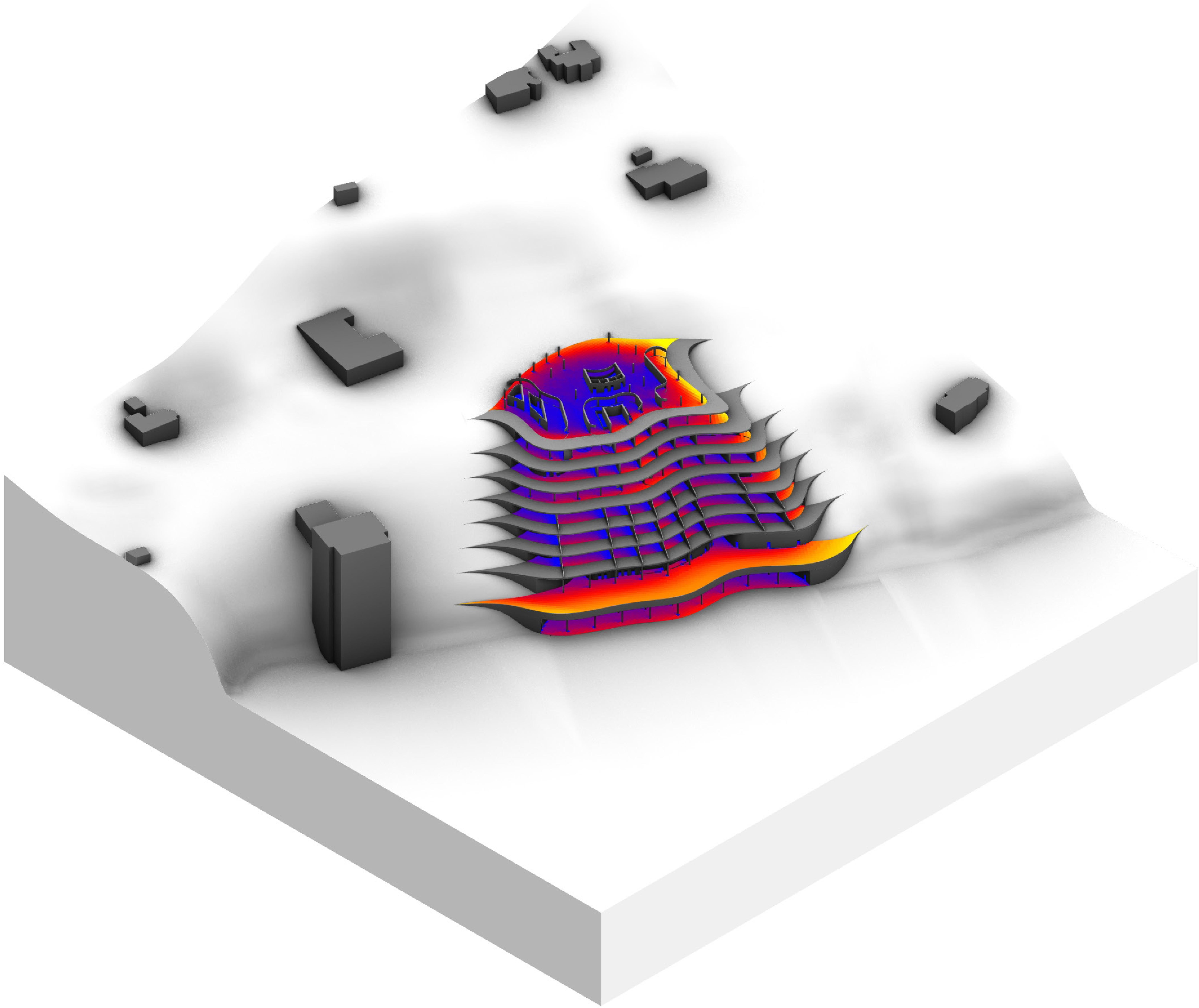
Shading & Glazing

Sunlight Hours Analysis

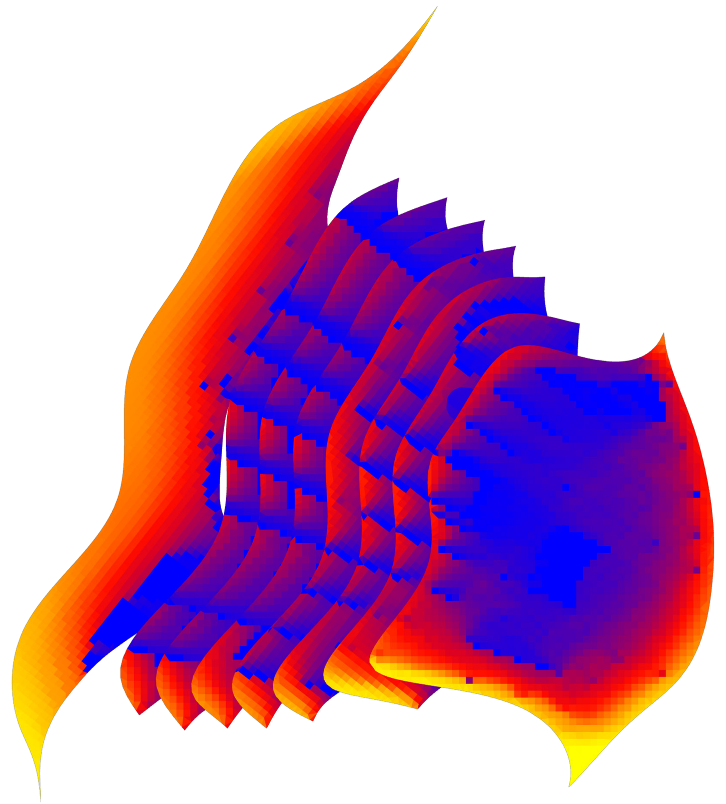
The building's strategic placement, coupled with an absence of surrounding high-rise structures, ensures almost unobstructed access to sunlight, with only nearby trees serving as potential shade providers. A combination of three glazing ratios (50%, 80%, and 95%) and three overhang lengths (0, 50cm, and 100cm) underwent sunlight hours analysis to ascertain the optimal façade decoration in terms of shading and glazing. Given the building's primary W-to-NW orientation, none of the glazing ratios, even though they exceed conventional standards, achieved the ASHRAE-recommended average annual sunlight hours.

From a daylighting perspective, the combination of a 95% glazing area with no overhang yields the highest average annual sunlight hours among all options, clocking in at 978.76. This makes it the preferred choice for maximizing natural light. When considering energy efficiency, a 50% glazing area offers superior energy conservation and reduced heat loss. However, its sacrifice in sunlight hours is considerable. An 80% glazing area strikes a balance between light and energy efficiency, but the sunlight hours of the 95% glazing area significantly surpass it. Given the aesthetic advantages of larger glazing areas, the building ultimately adopts the 95% glazing with no overhang approach.

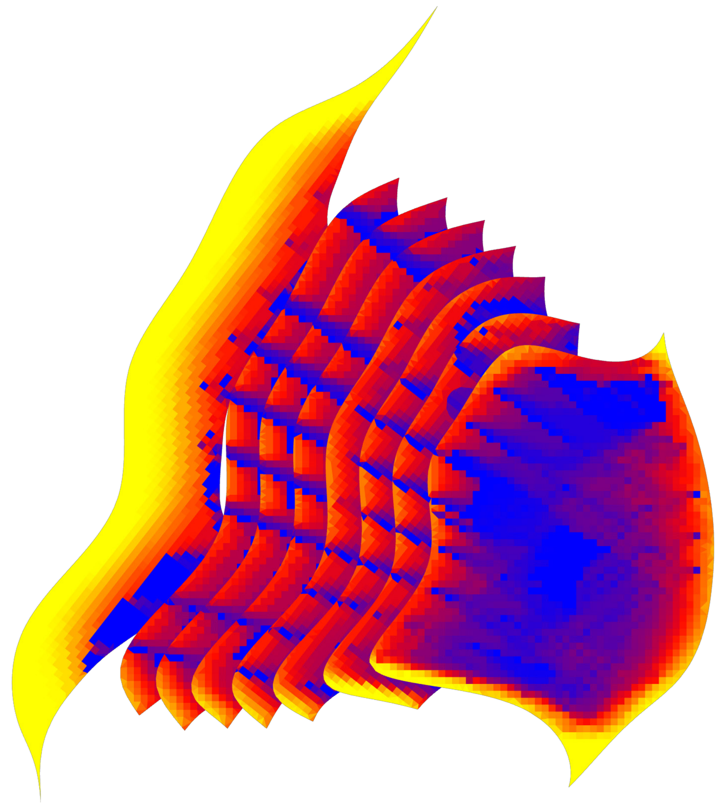
The building's south-facing segments, which accommodate the classroom, cafeteria, café, and premier guest room, bask in consistent sunlight year-round. In contrast, L1, featuring the pool and sunbathing areas, revels in year-round daylight, while support spaces like circulation paths and changing rooms are tucked away in shaded areas. The WNW and W orientation, combined with the presence of load-bearing walls and balcony dividers, restricts sunlight penetration, particularly during winter. Only a handful of rooms facing WSW and SW benefit from better sunlight exposure. This results in a reduced cooling load but a considerably amplified heating demand.



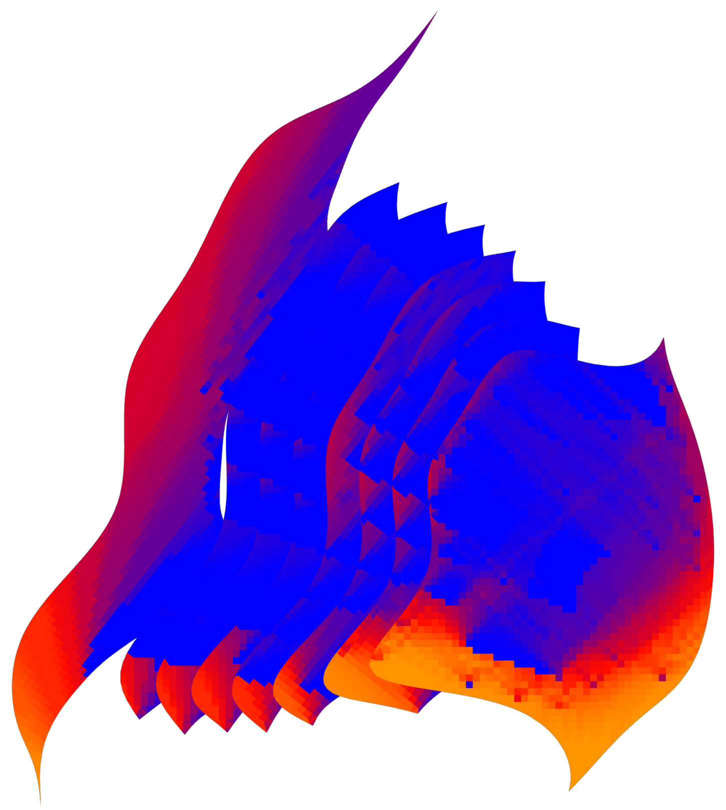
Annual



Annual

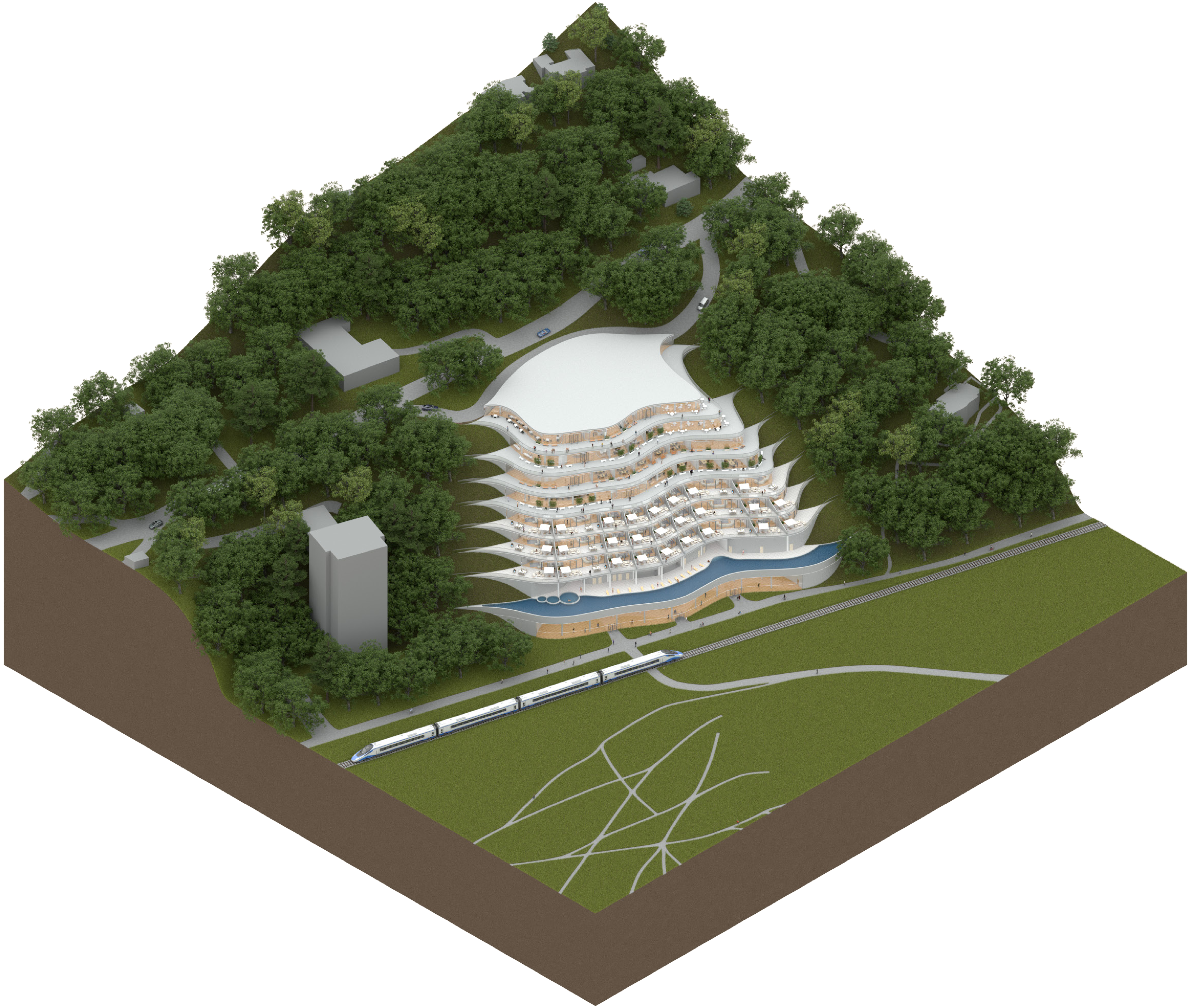


Summer



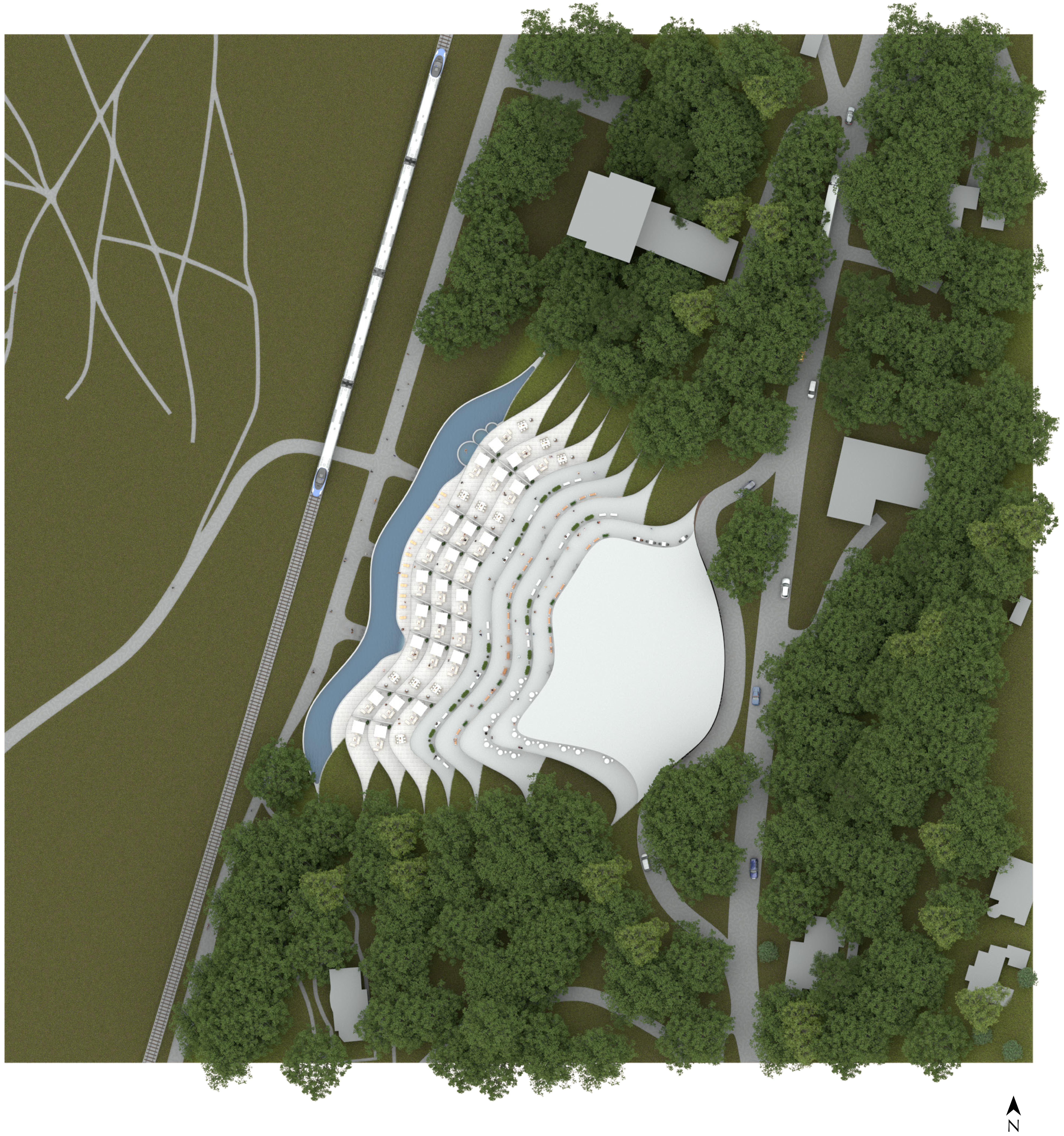
Winter

Casting & Decoration

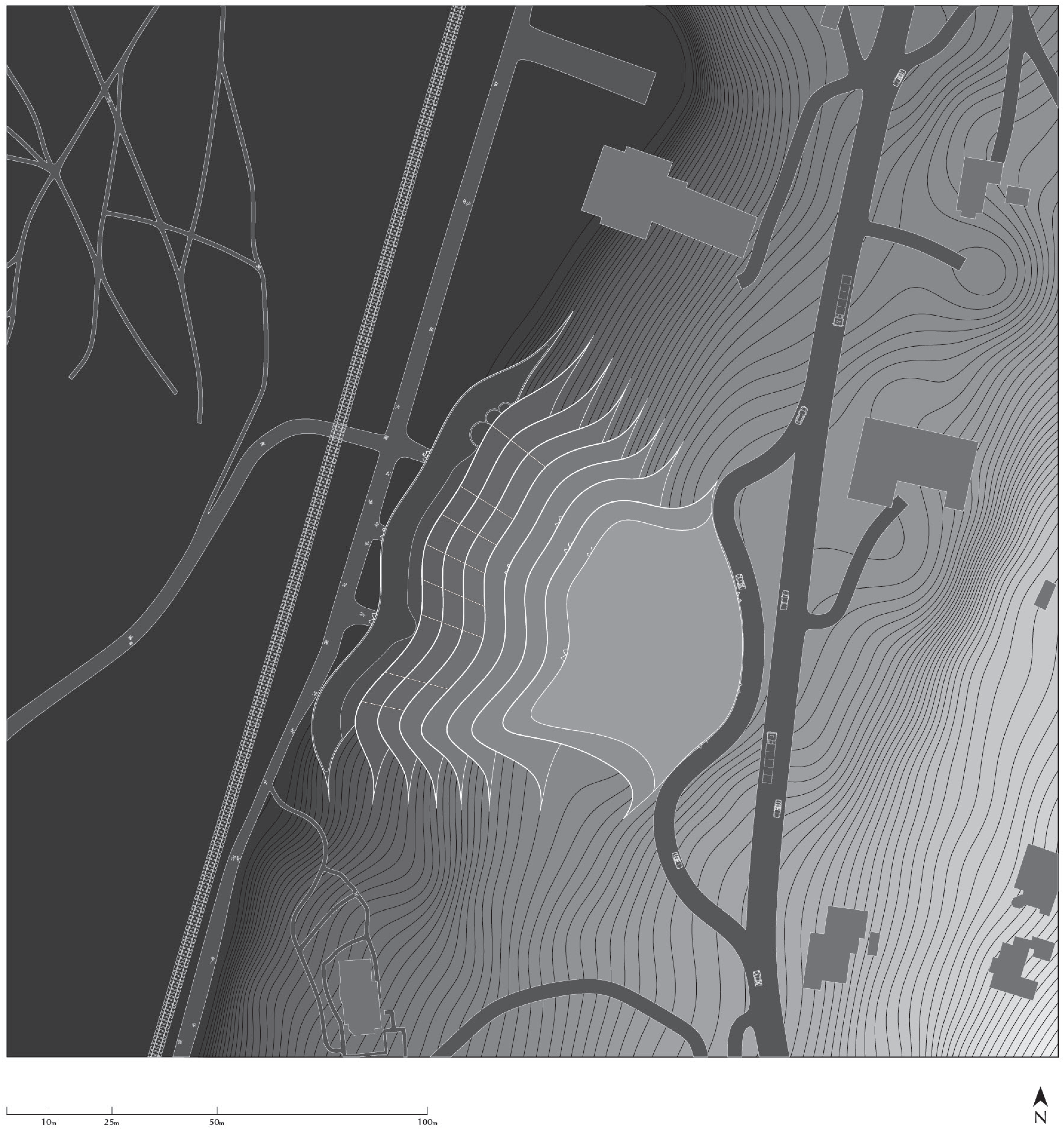


Greater Site Plan

Site Plan



Site Plan



Floor Plan - G

Houses the main concierge, the management office, and the plant rooms for centralised administrative functions. Also accommodates the water electrolysis chamber, Sabatier reaction chamber, and nuclear battery for straightforward maintenance and management.

Floor Plan - L1

Serves as the wellness hub, featuring a luxurious pool and vitality pool for relaxation and rejuvenation. Additionally, it provides spa-like amenities including a sauna and steam room, ensuring a holistic wellness experience for the guests.

Floor Plan - L2

Dedicated to providing comfortable and luxurious guest accommodation.

Floor Plan - L3

Dedicated to providing comfortable and luxurious guest accommodation.

Floor Plan - L4

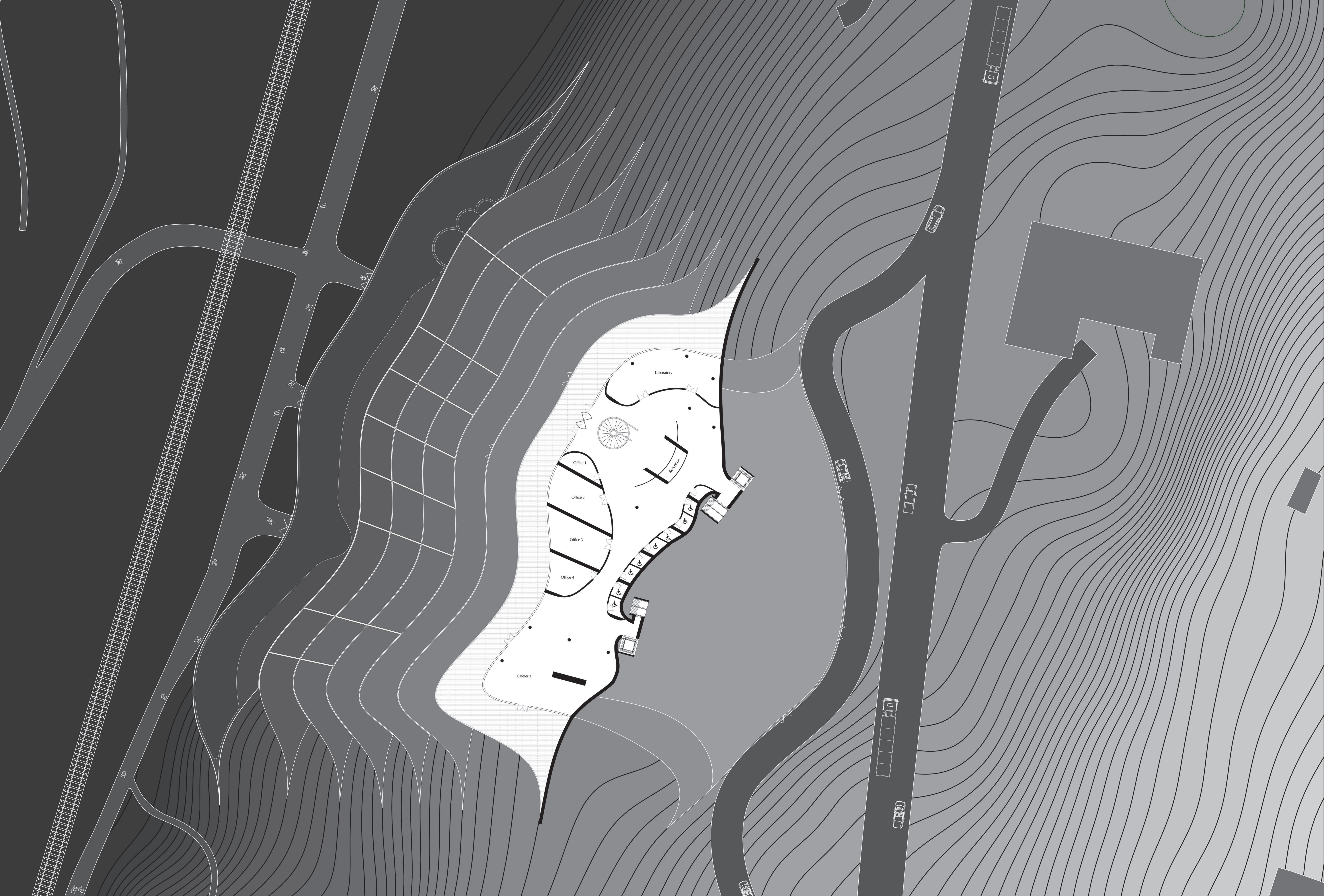
Dedicated to providing comfortable and luxurious guest accommodation.

Floor Plan - L5

Serves as a versatile business conference centre, offering spaces for conferences, meetings, and various types of gatherings.

Floor Plan - L6

Primarily functions as an educational centre, offering workshops, training programmes, and courses on sustainable living. Interconnected with L7 through a set of spiral stairs.



Floor Plan - L7

Acts as a R&D centre, focusing on developing new technologies related to air and water purification. Includes a laboratory and offices, and operates in conjunction with L6 as a combined space. The reception for this educational space is located here.

Floor Plan - L8

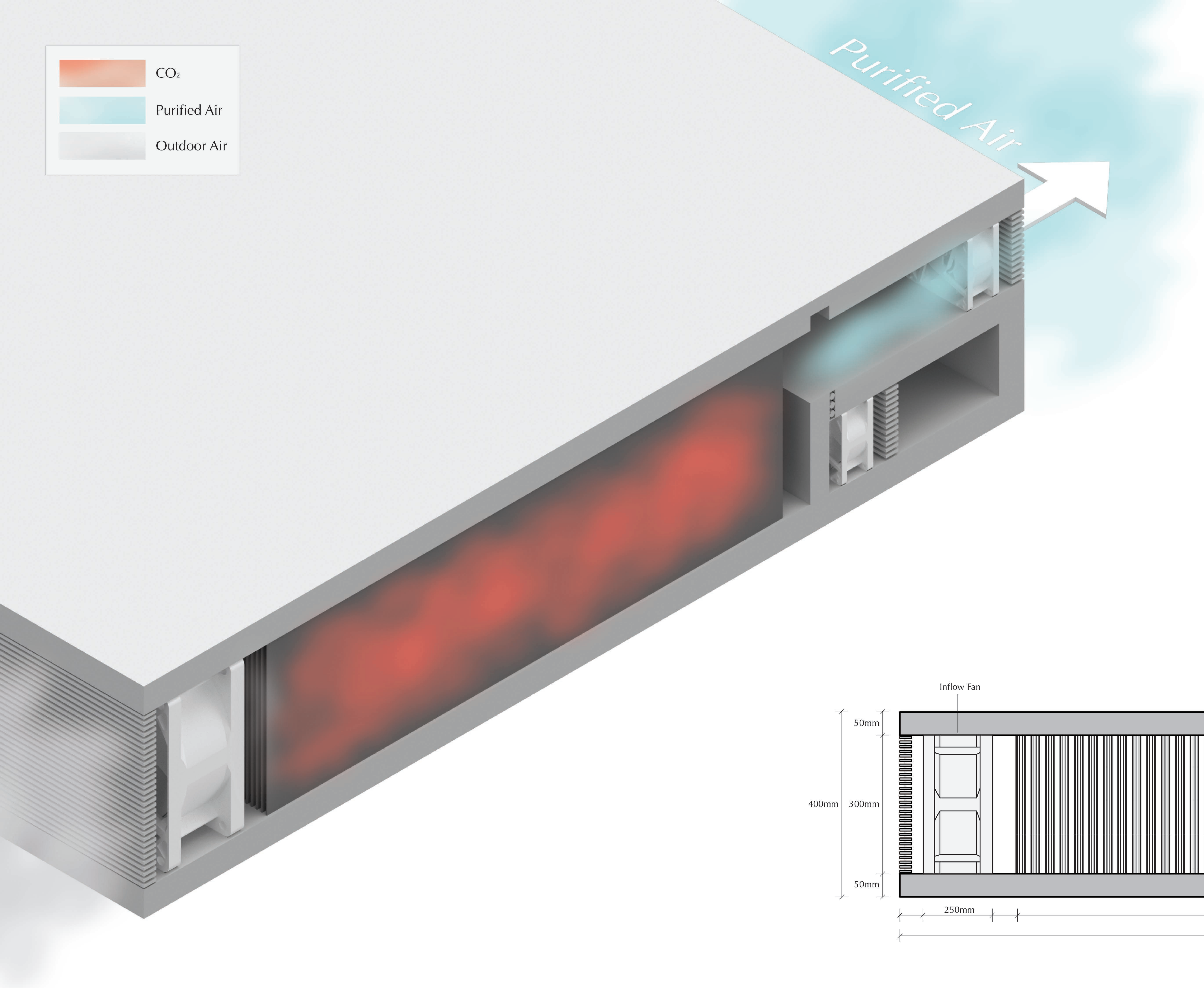
Provides dining and leisure spaces for occupiers and locals, serving as a communal hub. Also contains the liquid methane chamber, strategically located for easy access and regular collection.

Section

38.00 m
34.00 m
30.00 m
26.00 m
22.00 m
18.00 m
14.00 m
8.00 m
5.50 m
0.00 m
L8
Secondary Concierge
Restaurant & Café
L7
R&D Centre
L6
Educational Centre
L5
Conference Centre
L4
Guest Rooms
L3
Guest Rooms
L2
Guest Rooms
L1
Aqua Oasis
G
Main Concierge
Plant Rooms

Typical Floor Section
L2 - L4

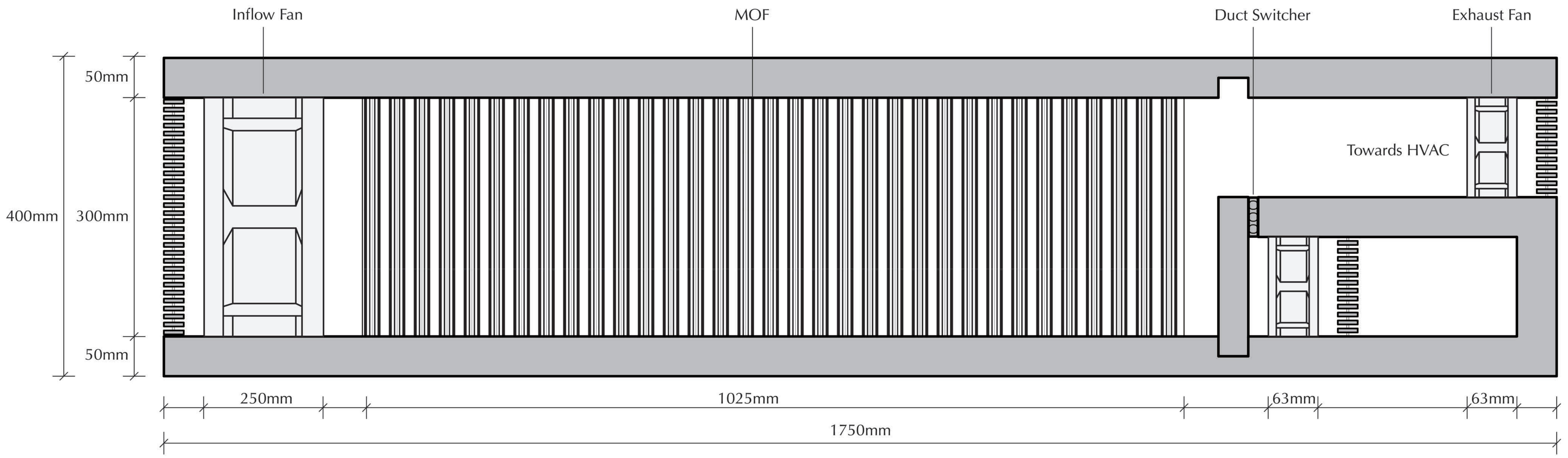
Typical Room



Air Purification Device

The air purification device integrates the carbon capture technique pioneered by MIT. This cutting-edge method utilises an electro-swing adsorption system featuring charged electrodes and a specialised metal-organic framework (MOF). As ambient air enters the carbon capture chamber, the MOF structure, under the influence of a positive charge, selectively captures and retains CO_2 molecules.

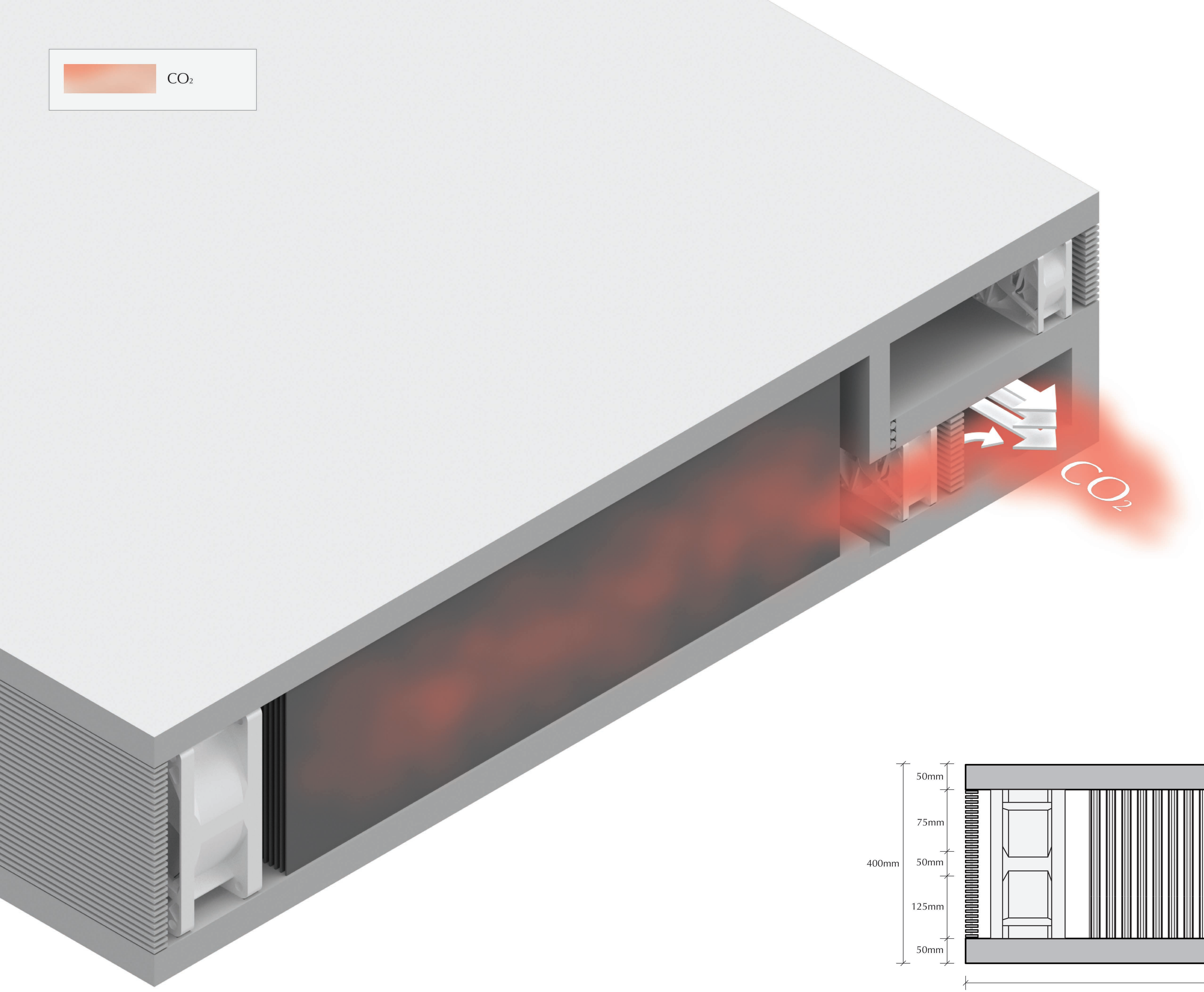
After CO_2 is securely held within the carbon capture chamber, the purified air, characterised by a reduced CO_2 concentration, is directed towards the HVAC system. Here, it merges with the continuous air intake under a controlled ratio, adjustable by the user. This allows the user to manipulate the degree of improvement in the indoor CO_2 concentration level. For instance, if a significant reduction in indoor CO_2 levels is desired, the proportion of purified air introduced into the HVAC system can be increased. This innovative feature provides users the power to actively manage and improve their indoor air quality, contributing to a healthier indoor environment.

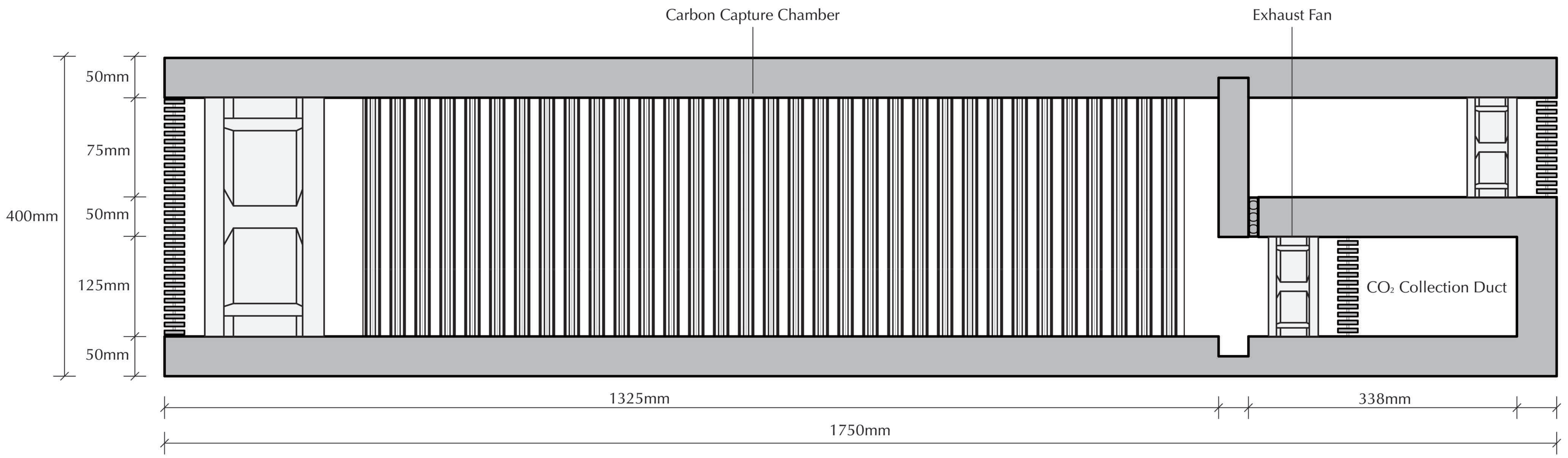


Air Purification Device

When the carbon capture chamber has reached its capacity, or the requirement for further reduction of indoor CO_2 levels via purified air has been satisfied, a transition in the duct system is initiated. The duct switcher severs the route to the HVAC system and instead, establishes a connection to the CO_2 duct. This is where CO_2 from all over the building is accumulated and channelled towards the CO_2 collection chamber for the Sabatier reaction.

Upon reversing the electrical charge, the metal-organic framework (MOF) effectively releases the trapped CO_2. This CO_2 is subsequently expelled into the CO_2 duct. To safeguard against any potential backflow, a series of exhaust fans are strategically positioned at the end of the duct. These fans ensure a consistent direction of airflow, facilitating the efficient and secure transportation of the collected CO_2.



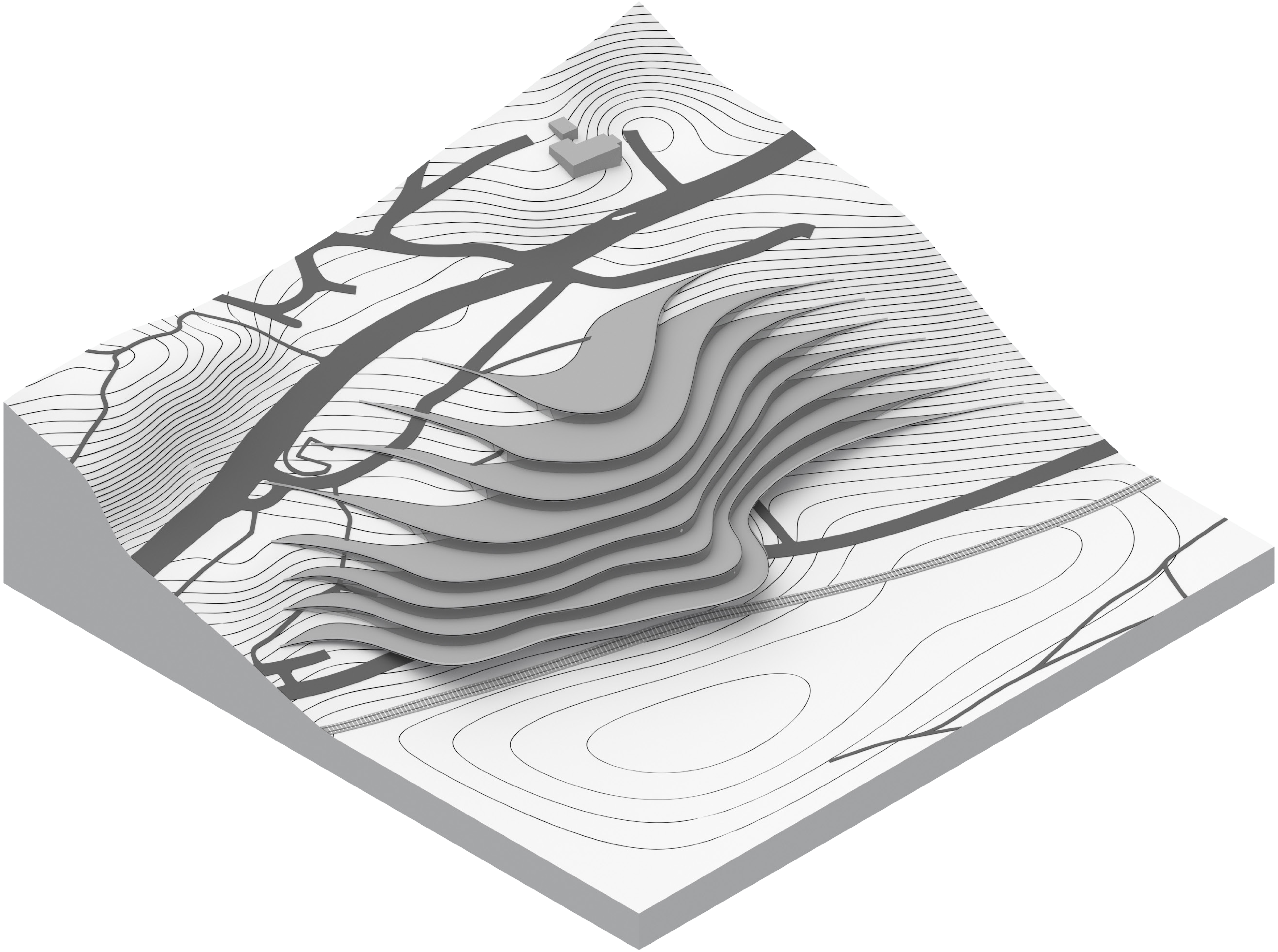


Typical Room Section

Appendix

Appendix

Initial Proposal

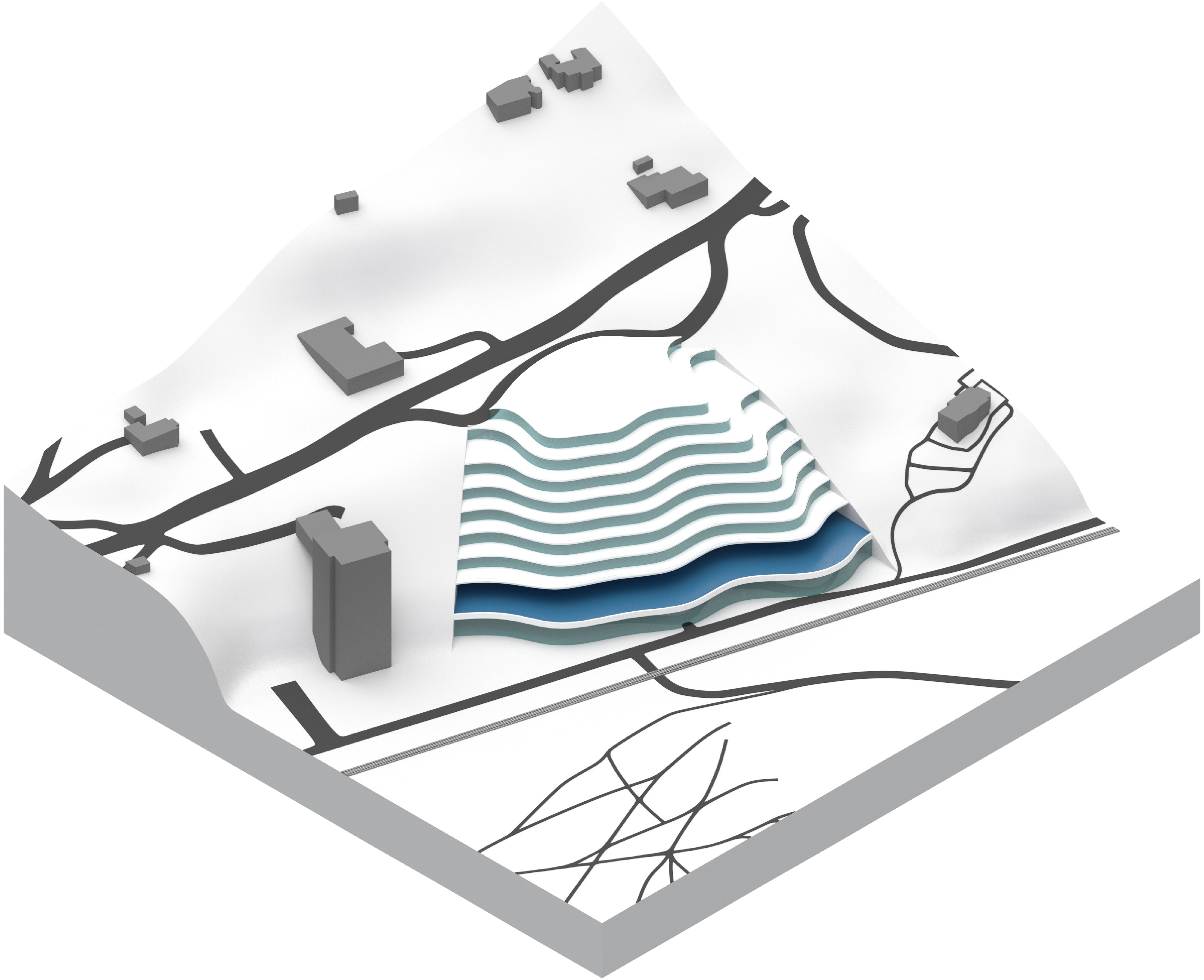


Appendix

Discarded Proposal 1

Appendix

Discarded Proposal 2



Appendix

Floor Activities Assignment

Floor	Purpose	Covered Area m^2	Uncovered Area m^2
L8	Cafe & Restaurants and Bar Upper Concierge	2,089	607
L7	R&D Centre	1,098	556
L6	Education Centre	1,029	485
L5	Conference Centre	1,023	497
L4	Guest Rooms	1,065	520
L3	Guest Rooms	1,038	535
L2	Guest Rooms	988	568
L1	Pool Sauna & Steam Room	491	1,042
G	Concierge & Plant Rooms	2,060	0
Total		10,390	4,810
		15,200	

Floor	Activity	Area m^2	Description
L8	Restaurants	1,300	Dining areas, kitchen, and storage
	Café	639	Seating area, coffee bar, and storage
	Upper Lobby	100	Reception area and concierge
	Toilets	50	Restroom facilities for guests and locals
L7	Reception	100	Reception area for R&D centre
	Lab	600	Research laboratories and collaboration spaces
	Private Offices	348	Offices for researchers and staff
	Cafeteria	50	Small dining area for R&D centre staff
	Toilets	100	Restroom facilities for R&D centre staff
L6	Lecture Theatre	300	Large room for presentations and lectures
	Classooms	329	Spaces for hands-on learning and group activities
	Breakout Areas	200	Casual seating for discussions and relaxation
	Administration	170	Offices and support spaces for the education centre
	Toilets	30	Restroom facilities for the education centre
L5	Conference Rooms	600	Large rooms for conferences, meetings, and events
	Meeting Rooms	300	Small rooms for team meetings and discussions
	Breakout Areas	98	Casual seating for discussions and relaxation during events
	Toilets	25	Restroom facilities for conference attendees
L4-L2	Guest Rooms	3,091	Accommodation for guests with en-suite facilities
L1	Pool	1,233	Out-door pool for training and leisure purposes
	Changing Room	200	Changing rooms for the public
	Spa & Sauna	50	Wellness facilities for relaxation and rejuvenation
	Toilets	50	Restroom facilities for pool, gym, spa, and sauna users
G	Lobby	1,860	Reception area, concierge, plant room & nuclear battery
	Plant Rooms	200	Restroom facilities for guests and staff in the lobby