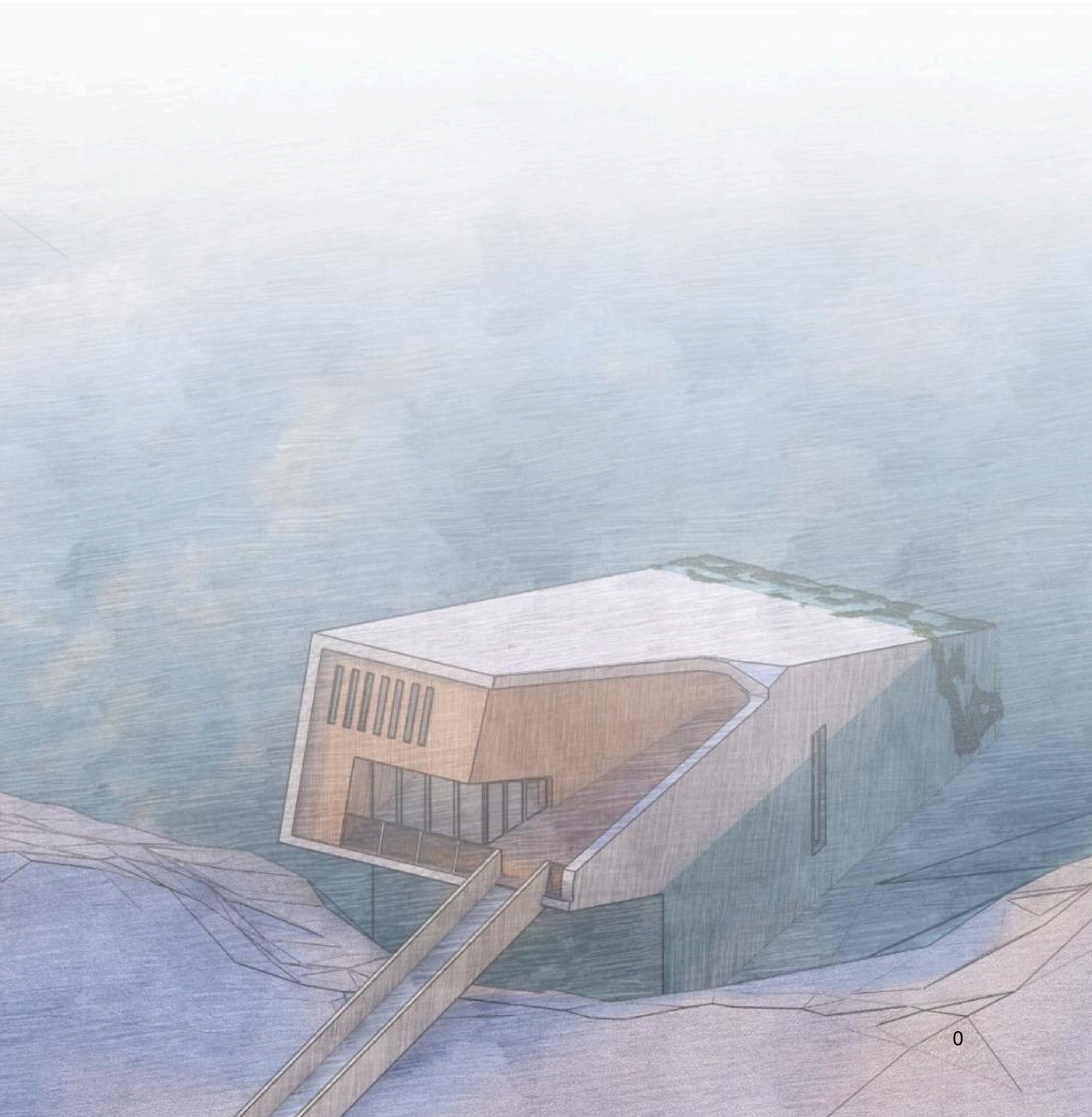
Holistic Technical Report

Advanced Technical Investigations

ATARAXI



Contents

1 - Introduction to Case Study

1.1 - Understanding the Site

I begin by introducing the case study and its context, to form an understanding of the structure and landscape. Included are cross-referenced technical drawings, including site plan, various floor plans, and sections. Real images from the site have been included, providing an insight into its performance and aesthetics, in addition to my interpretation.

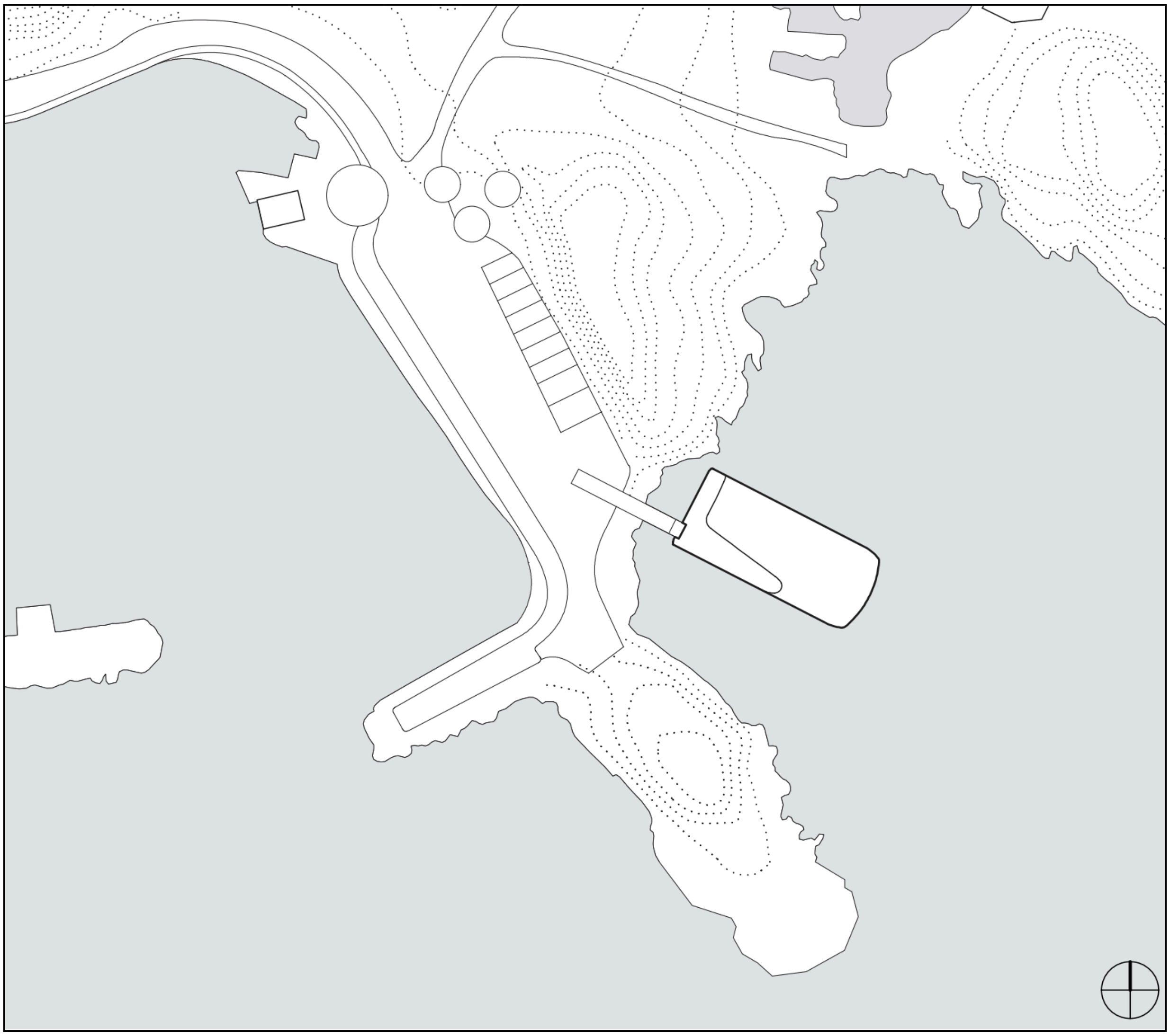


Figure 1: *Site Map (Scale 1:000)*

The site is located in the south of the Lindisnes in Båly, Spangereid, Norway. Few structures accommodate the area, with a forest providing increased privacy, far from the waters edge. Atop the rocky shores, boulders create a diverse terrain, which is levelled out to provide access to the structure. The restaurant, named 'Under,' is connected to the shore via a sloped bridge which leads onto the terrace.

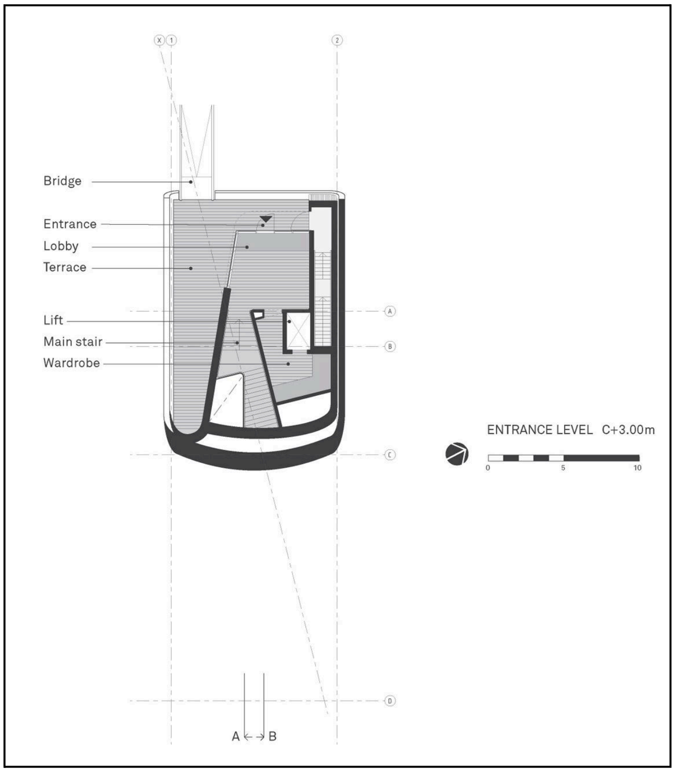


Figure 2: Plan - Entrance Level (Scale 1:500)

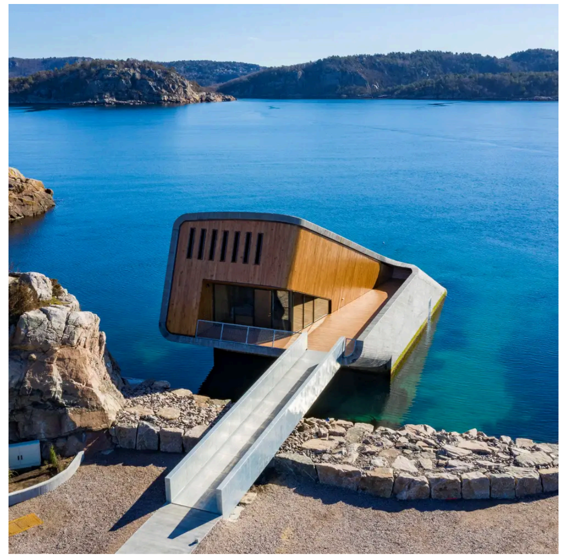


Figure 7: Exterior View

The exterior features a unique concrete shell design with a timber insert. Protruding from the water, it is accessible via a bridge.

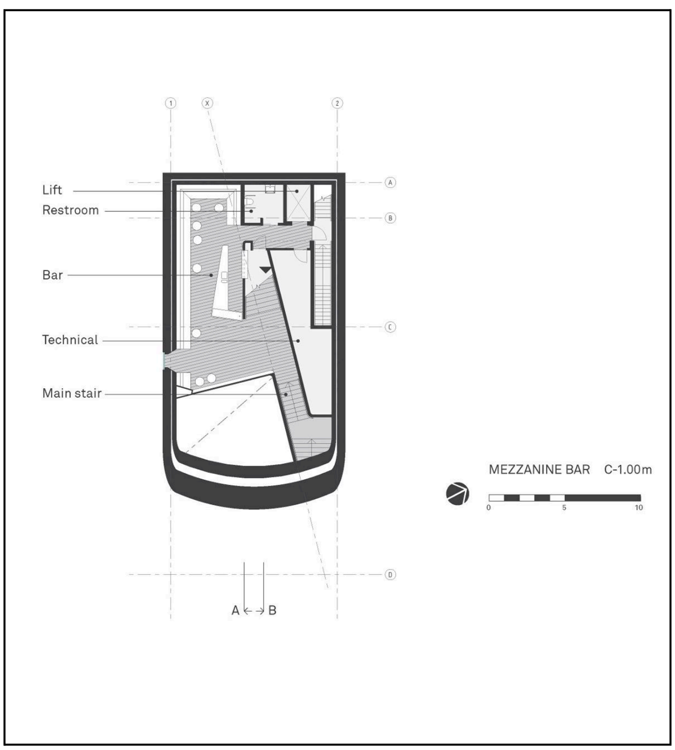


Figure 3: Plan - Mezzanine Bar (Scale 1:500)

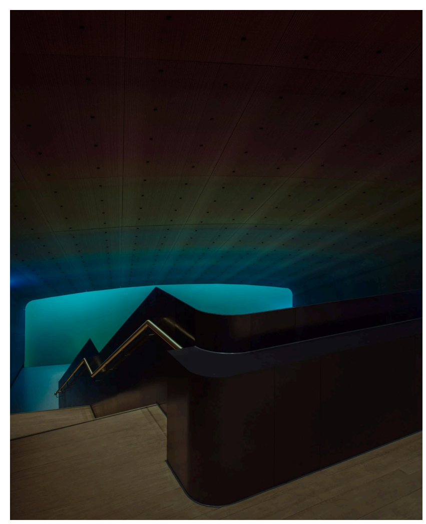


Figure 8: Staircase View

The main staircase leads users to a gradual unveiling of the ocean colours as they luminously paint the interior space.

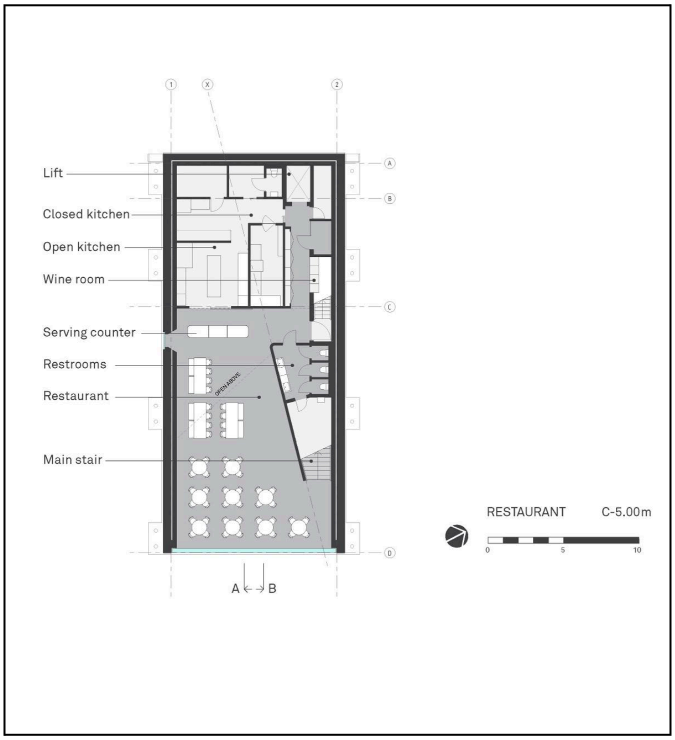


Figure 4: *Plan - Restaurant (Scale 1:500)*

Figure 9: *Main Window*

The structure features an immense glass window in the dining area, which is used as the main light source.

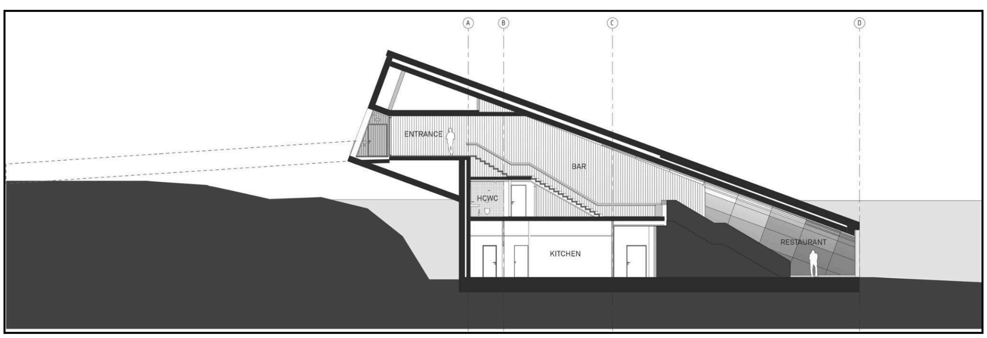


Figure 5: *Section - 1 (Scale 1:500)*

The sections reveal the immense staircase and the rooms which live in its shadow,

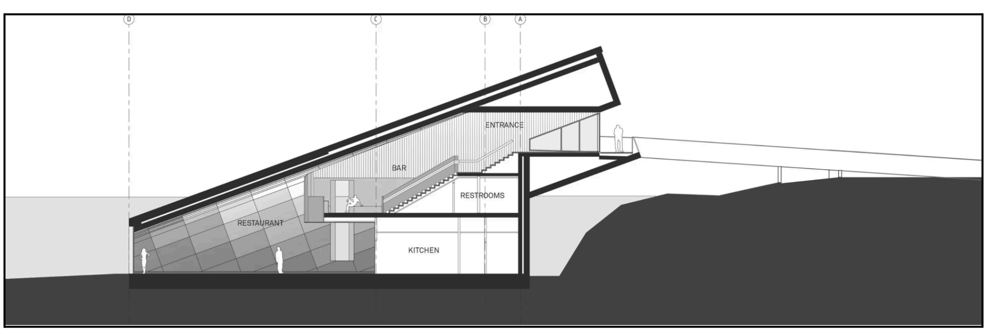


Figure 6: *Section - 2 (Scale 1:500)*

1.2 - My Interpretation

I believe that the architects at Snøhetta set out to create an incredible experience, capable of providing the user a unique perspective on architecture. The distinct and unparalleled structure location is like no other the users have visited. I believe the designers wanted to create a complete immersive aquatic experience, achieved through an exciting play of light with the ocean. This experience is physically exaggerated by the disconnect of the structure from land, rejoined via a bridge, allowing users to step out completely into the experience.

The designers used deep blues and varying light hues which stretch out across the vast textured panelling like paint on a canvas. These breathtaking ocean colours may be seen from afar, atop the grand staircase. Furthermore, algae has taken hold of the structure, increasing biodiversity.

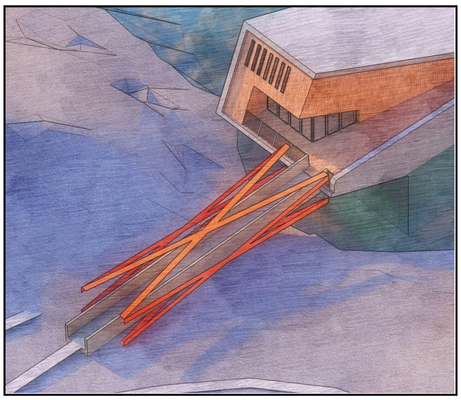


Figure 10: *Disconnect Experience Achieved via a Bridge*

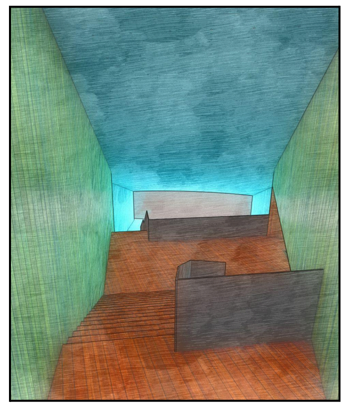


Figure 11: *Play of light - Blues seen from afar*

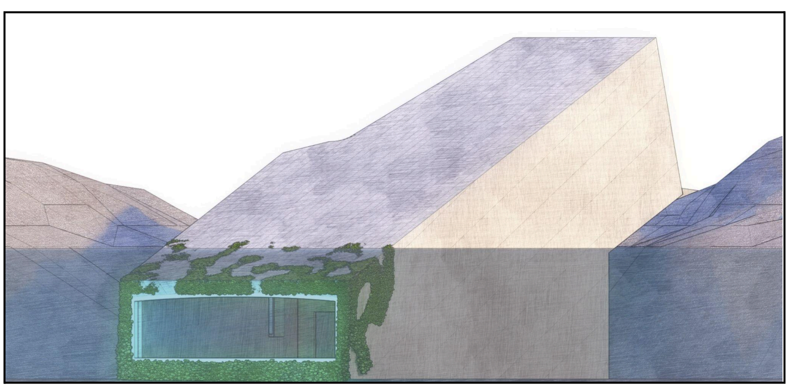


Figure 12: *Algae life flourishing as the design increases biodiversity*

2 - Three analysis sections

2.1 - Environmental Design

2.1.1 - Passive Measures

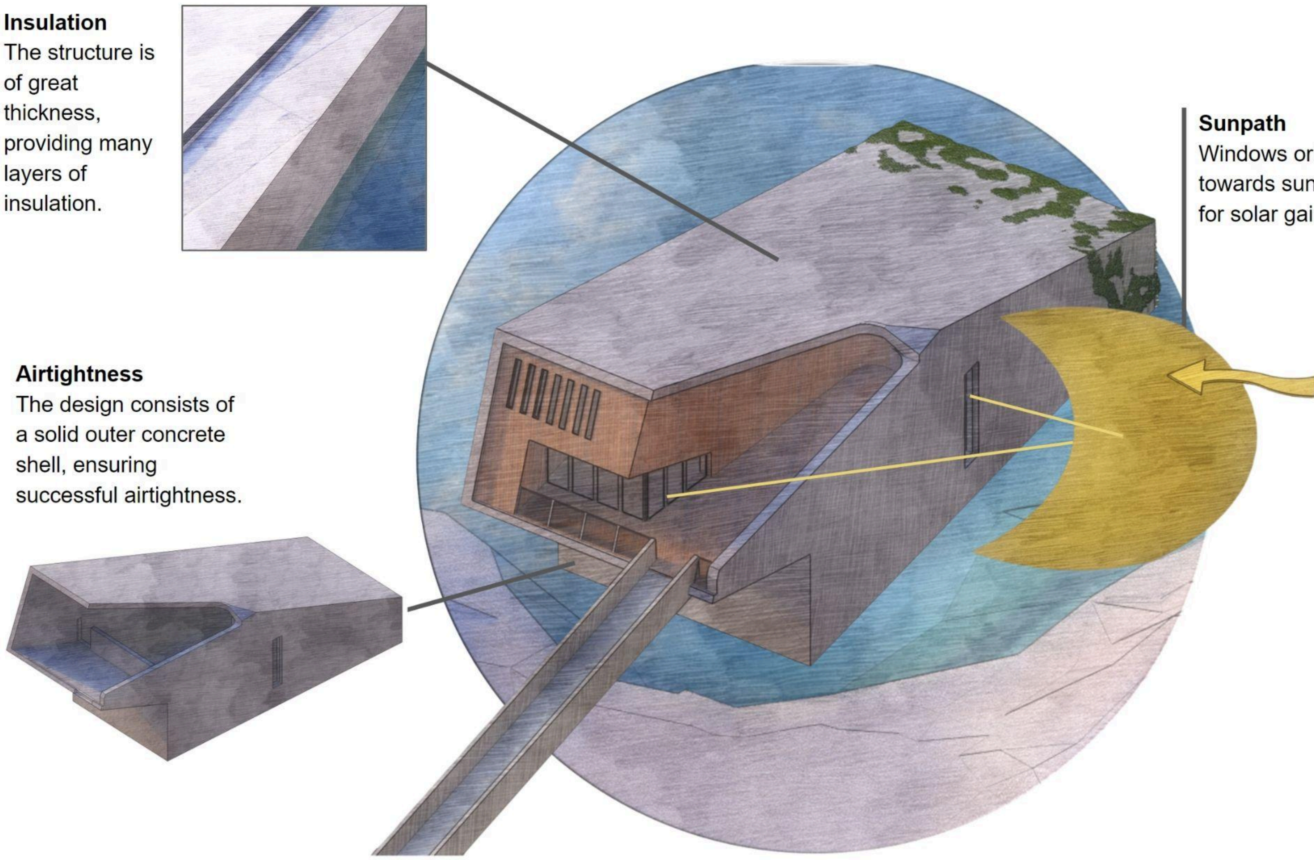


Figure 13: *Annotated Passive Measures*

South and east facing windows catch the afternoon and evening sun, leading to passive solar gain, crucial in a heating dominated environment. The entrance space maximises its daylighting via a shallow room design, enabling almost no shade.

The building uses a large concrete envelope which has been placed into the water and completed on site. Using a 0.5m thick waterproof board-marked concrete leads to an immense barrier for insulation. Timber fittings are installed inside, increasing insulation.

Air sealing on the structure is extremely successful. Concrete allows the structure's airtight performance to be almost perfect, although areas with fixtures decrease its overall effectiveness. Only two window fixtures are underwater, resulting in extremely high airtightness and low breakage risk.

2.1.2 - Active Technology

Due to no confirmed systems disclosed in publicly accessible data, assumptions must be made.

2.1.2.1 - Heating Systems

- Heat pumps - pipe system distributed across the structure, some underfloor (hydronic system)
- Heat pump air vent
- Radiators / heat pump panels
- Kitchen equipment - heat source

2.1.2.2 - Control Systems

- Heating control thermostat for constant temperatures
- Openable doors on top level - manual temperature / ventilation control
- Coloured lighting system underwater - toggle at certain darkness
- Interior automated lighting
- Kitchen ventilation - extraction of heat and gases from the cooking area

2.1.2.3 - Renewable Energy

- No detectable renewable energy systems in use, despite potential for tidal and solar

2.1.3 - Ventilation Air Paths

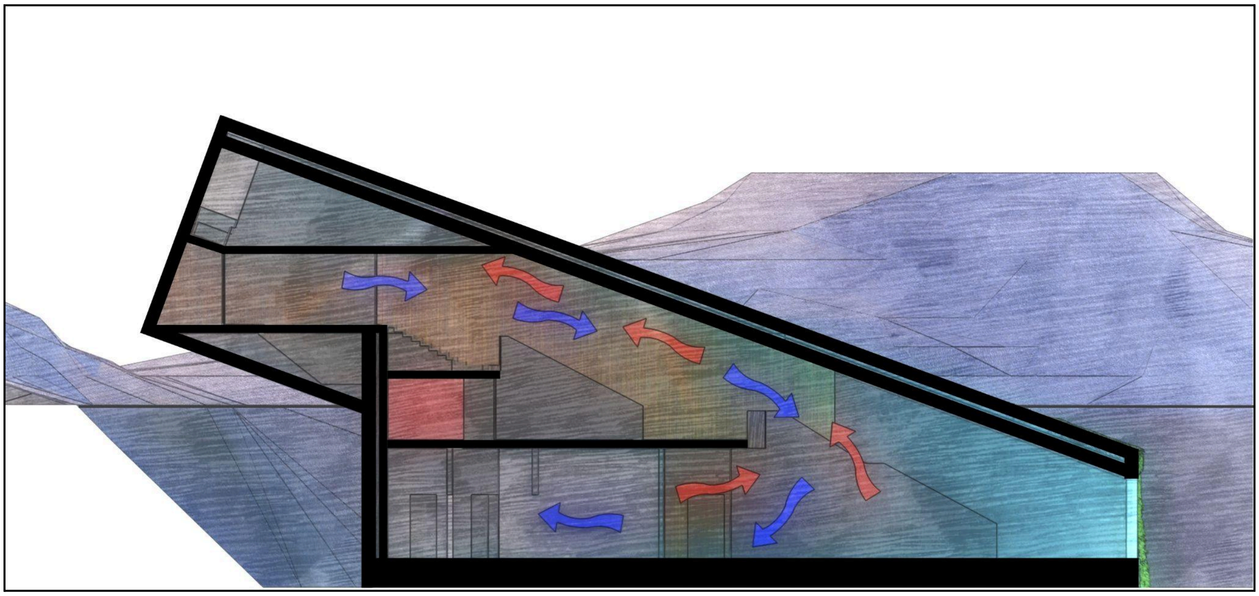


Figure 14: *Ventilation Paths Section View - 1*

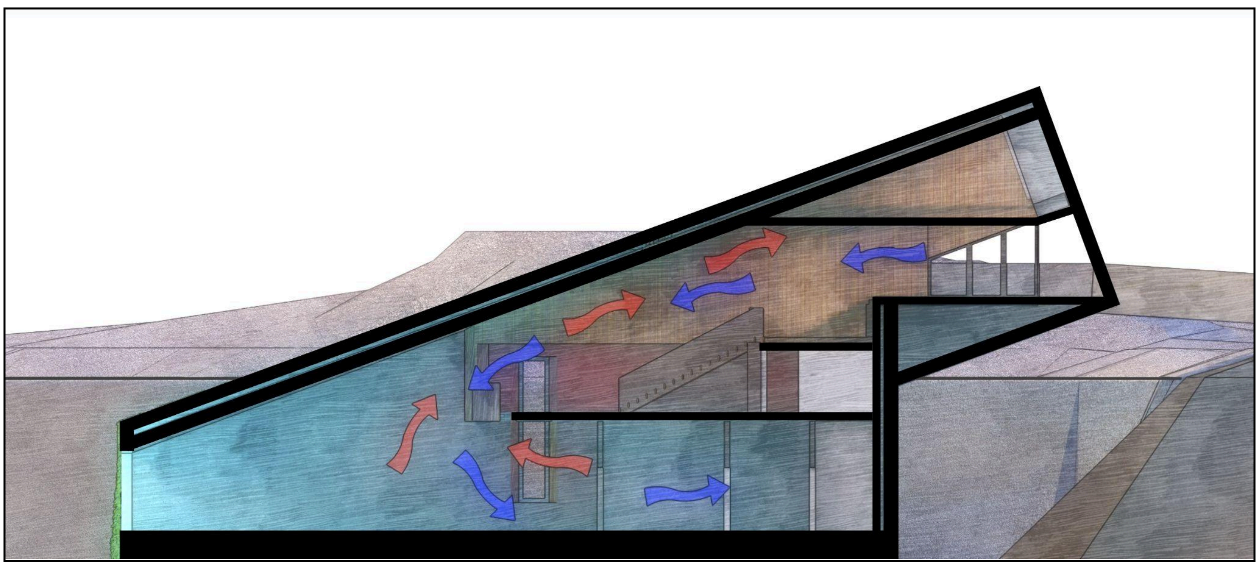


Figure 15: *Ventilation Paths Section View - 2*

A large staircase spans from the entrance to the large window, leaving roughly half the structure hidden underneath. There are only operable openings at the entrance, therefore, air must travel along the staircase. Areas which require ventilation such as the kitchen lack openings, consequently, this design cannot be naturally ventilated.

The structure requires active ventilation systems, suggested by a service room. It is very likely that ventilation systems are in use in the building, and their components are stored here.

There is potential for these components to be completing the heat recovery process, a beneficial factor for the climate.

The dining area can accommodate many customers in a crowded area, which would be very harmful in an area lacking ventilation. Despite this, the ceilings are very high and space is very open, mitigating risk.

Using ventilation rules of thumb calculations, I can assess the building's performance. Calculations must consider the entrance area due to present openings. All other areas are assumed to have failed meeting natural ventilation requirements due to lack of openings.

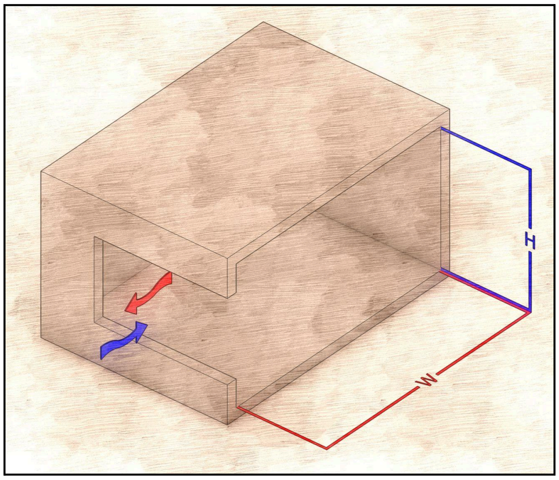


Figure 16: *Rule of Thumb Example*

Single sided ventilation, single opening.
Ratio = W ≤ 2 H

W = 4.6 m *H = 2.5 m*
2 x 2.5 = 5 *4.6 ≤ 5 Pass*

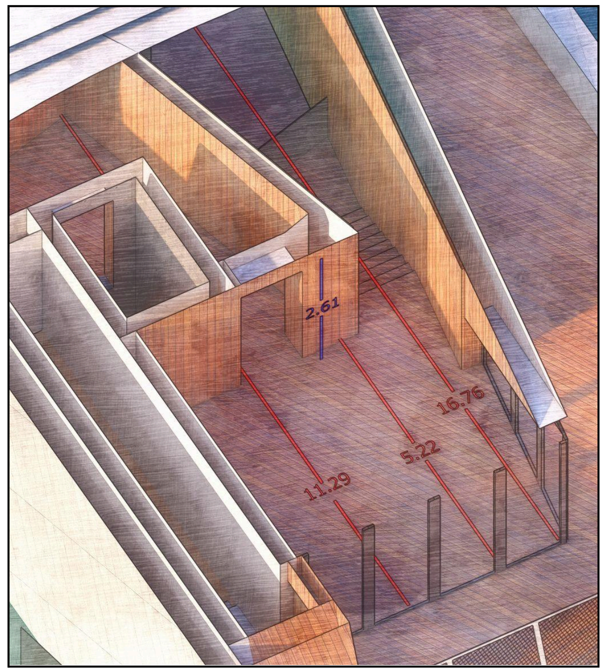
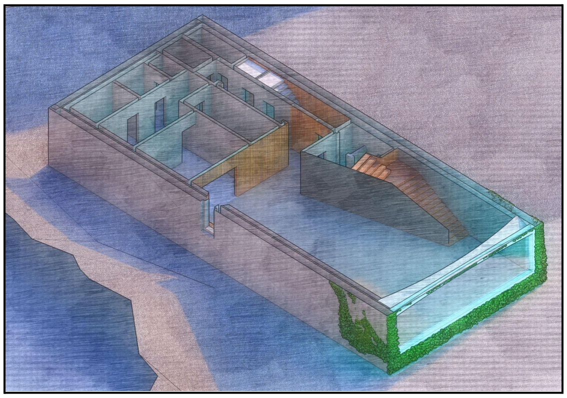


Figure 17: *Measurements on Case Study*

Use the rule of thumb for single sided to determine the entrance performance.

Lobby Room	**Entrance to Elevator**	**Entrance to Stairs**
W = 5.22 m | H = 2.61 m	W = 11.29 m | H = 2.61 m	W = 16.76 m | H = 2.61 m
2 x 2.61 = 5.22	2 x 2.61 = 5.22	2 x 2.61 = 5.22
5.22 ≤ 5.22 Pass	11.29 > 5.22 Fail	16.76 > 5.22 Fail

The lobby is the only section which succeeds according to the ventilation rule of thumb calculations, with the absolute maximum dimensions allowed to be considered successful.



This section cut displays various rooms lacking openings. All air transfer is occurring by travelling along the staircase. In each of these visible areas, the rule of thumb rules cannot be applied, making them failures for natural ventilation. Consequently, mechanical / active ventilation systems are required to ventilate this building optimally.

Figure 18: *Ventilation Issue Graphic*

2.1.4 - Reducing Energy Demand

It’s crucial to reconsider the ventilation system for optimal performance. The building layout opposes natural ventilation, due to the separation of spaces. Perhaps ventilation shafts should be integrated, or drastic changes to geometry like ‘breaks’ in the design to accommodate ventilation tunnels. Drastic changes to the building shape also enable new heating system considerations for varying building geometry.

Windows could be placed along many blank surfaces, providing openings for air exchange, reducing ventilation costs. Window placement must prioritise sunpath to ensure maximum solar gain. Control systems may determine when windows shall be opened to automate and streamline air and heat transfer.

Implementation of renewable energy would be very beneficial, given the prime location for tidal energy generation devices and surface area above water to house solar panels. These sources would help combat energy demands.

2.2 - Daylight / Sunlight

2.2.1 - Estimation of Daylight / Sunlight Properties

I begin with a purely intuitive investigation of the case study.

Positives:

- Challenging site - Structure placed into water and partially submerged
- Unique element - main source of illumination being light that has passed through ocean water like a filter
- Wide window, fully submerged facing south east
- Long narrow window, partially submerged facing south
- Numerous glass doors and windows at entrance facing east
- Long staircase across structure enables users to see the grand view from afar

Negatives:

- No windows along the vast roof structure - lots of surface area not being used for daylighting
- Many rooms are being neglected in terms of lighting - hidden in the shadow of the staircase - complete darkness is acceptable depending on the room type such as for appliance storage. If the room was not built to 'impress,' it will have very poor lighting qualities.

2.2.2 - Basic Daylight / Sunlight Evaluation

Using window to floor area ratio, I can determine the approximate daylight performance of my design. Constructing a basic representation of the case study (figure 19), I can carry out the necessary calculation:

Total glazing area = 30.29 + 3.58 + 16.03 + 3.57 = 53.47 m2
Interior = 745 m2

Window : floor area = Total glazed area / Total interior area = 53.47 / 745 = 0.071 = 7.1%

7.1% is an extremely low value. Building regulations typically recommend between 20 and 25%. The structure's low ratio may imply it is prone to overcooling, due to a lack of window surface area for solar gain, although this may be countered by effective building insulation. This low figure demonstrates the immense neglect that daylighting is under in this case study, although this has been done deliberately. Even if the building structure is incredibly unique and successful in achieving its intention, it will have been judged to have failed daylighting based off of the ratio calculation.

The restaurant features unilateral daylighting, although the structure is of such an irregular form, that simplifying spaces into cuboids for the calculations strays away from the intention of the building.

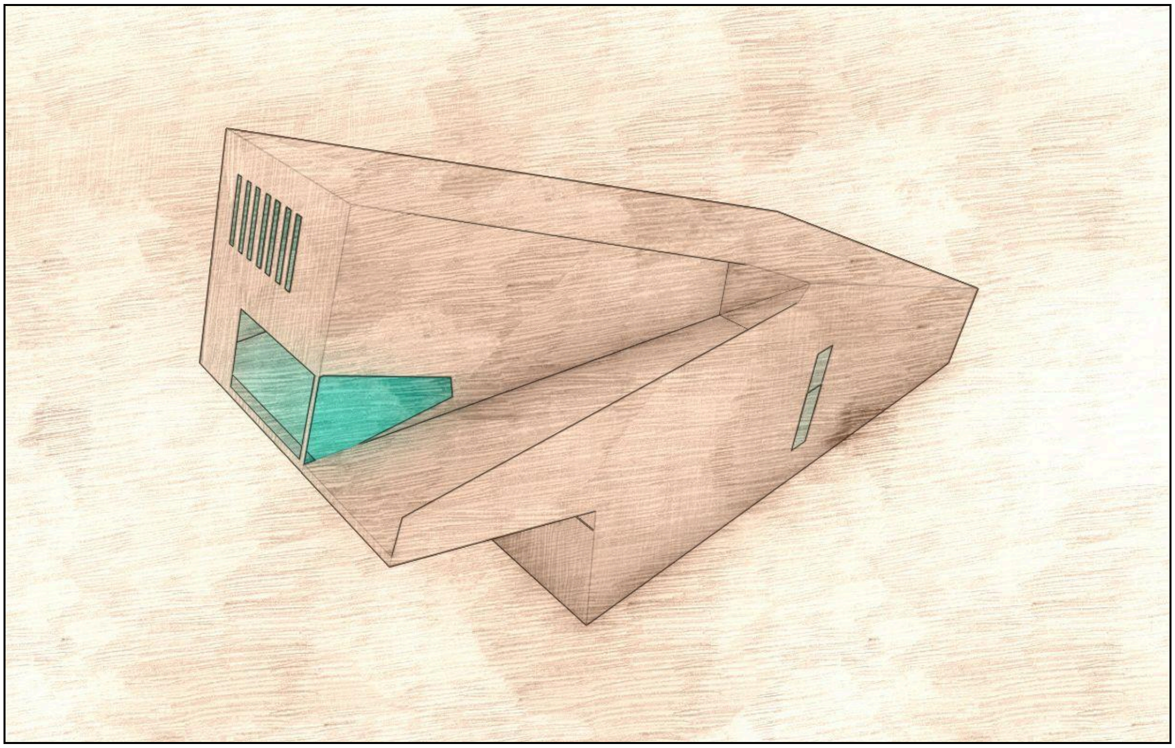


Figure 19: *Simplified Model*

2.2.3 - Detailed Daylight / Sunlight Evaluation

Utilising Sefaira, I conduct daylighting simulations on a 3D model in sketchup. For annual illuminance and direct sunlight simulation, I have oriented the model 117 degrees from North to account for the real sun position and set the location to the exact site in Norway for the most accurate simulation results. The Sefaira daylight factor utilises an overcast sky model, suitable for the site context and calculations. I have used the 'Commercial' benchmark, being the most valid.

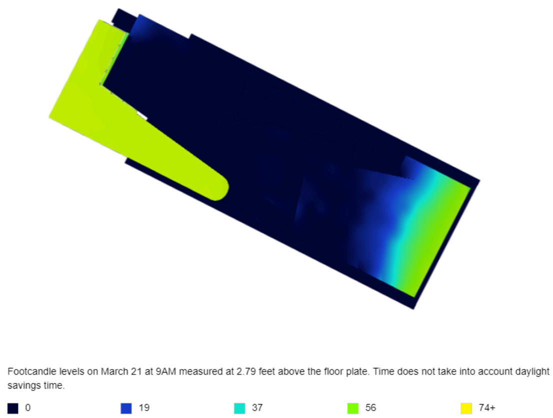


Figure 20: *Initial Simulation of all Levels - Plan View*

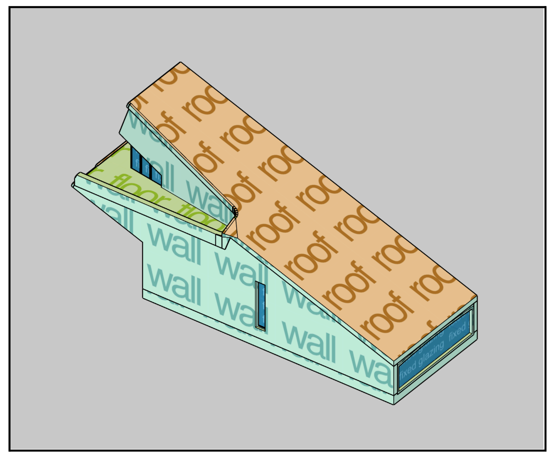


Figure 21: *Simulation - SketchUp*

The majority of the structure is cloaked in darkness. Light may be found at either end, however the fittings are not capable of effectively illuminating the space.

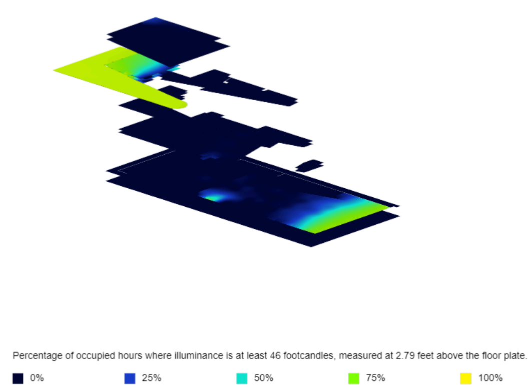
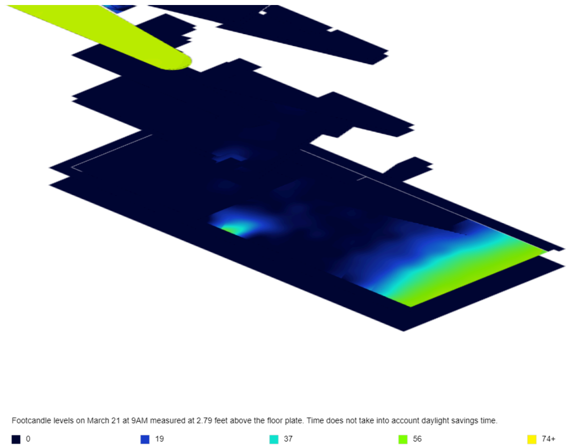


Figure 22: *Simulation - Sefaira*

Main and Side Windows



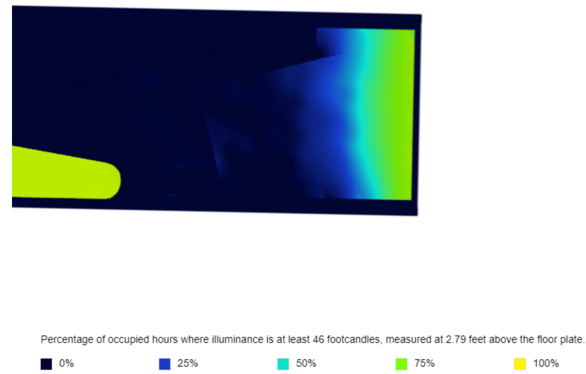
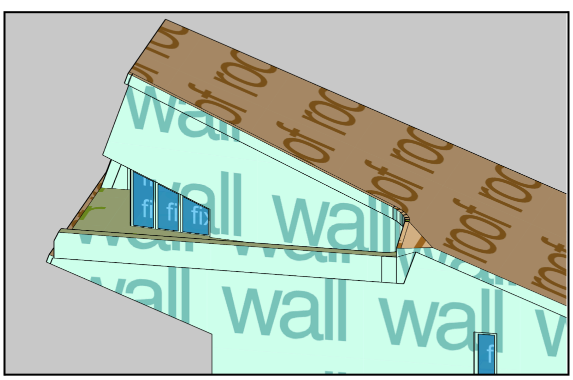


Figure 23: *Sefaira Windows Side View*

Figure 24: *Sefaira Windows Plan View*

- Main window maximises available light via south-facing orientation
- Light intensity gradually decreases the further you are from the window
- Tall, narrow window in the side of the structure stretches up from the dining area onto the mezzanine floor above it, providing lighting from the south - partially submerged fitting

Entrance



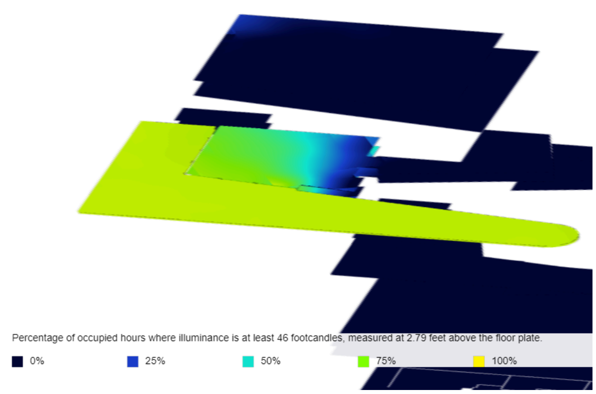


Figure 25: *Sketchup View*

Figure 26: *Sefaira View*

- Entrance is south-west facing - catching afternoon and evening sunlight.
- Terrace area is completely daylit, due to being completely exposed.
- Entire lobby is sufficiently daylit due to low depth and appropriate orientation.
- No artificial lighting is necessary for the lobby area during daylight hours - surpasses the required 400 lux requirement for daytime hours.

Neglected Dark Rooms

Figure 27: *Neglected Dark Areas*

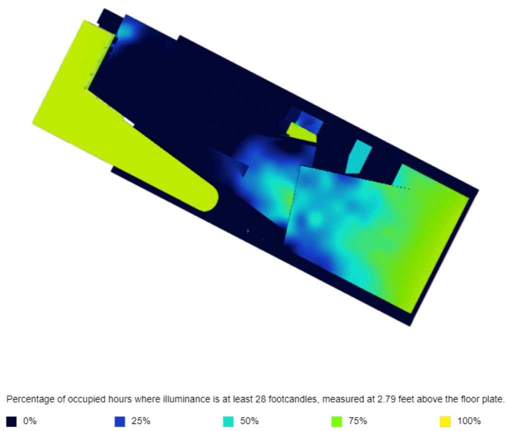
- Focus on manipulating light causes many regions' daylighting to be overlooked. This is evident in rooms underneath the staircase being isolated due to no windows. These areas rely entirely on artificial lighting and occupants are at a safety risk if they fail.

2.2.4 - Modifications to Improve Daylight / Sunlight Performance

I shall determine significant modifications to the design to improve the daylight performance and conduct simulations to assess their quality.

Change 1 - Automated Skylight Control System

Prioritising the structure's 'gimmick' has jeopardised the daylighting of the structure leaving it gloomy, solvable via an automated skylight control system. Skylights enable light to penetrate deep into the layout, disrupting the experience but can also be toggled on/off by being covered. The building manager may prioritise either solar performance or the immersive experience, granting him freedom and control. Unfortunately, these systems can be expensive to integrate.



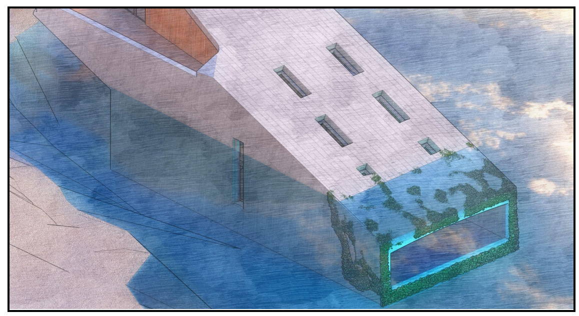
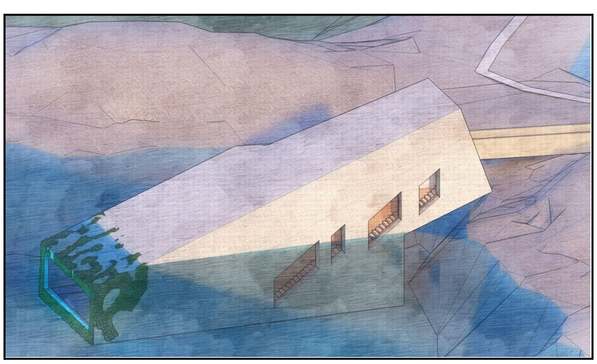


Figure 28: *Skylights - Sefaira Plan View*

Figure 29: *Skylights - Render*

Change 2 - Daylit Staircase

An emergency staircase is completely enclosed in darkness (dangerous), despite being disconnected from the experience. To combat this, a series of windows could be added to provide more views and daylighting. They must remain fixed due to the unpredictable / dangerous nature of the site, eliminating ventilation aid. The performance can be studied in figure 31, displaying additional lighting from the changes. The software cannot visualise on stairs, however the new lighting present proves its success.



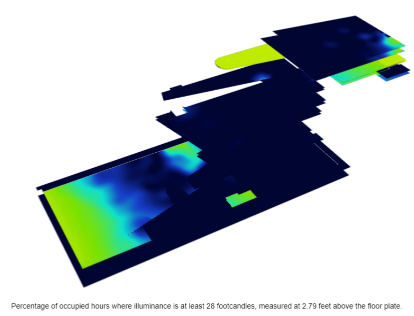


Figure 30: *Staircase - Render*

Figure 31: *Staircase - Sefaira*

Change 3 - Eliminating Darkness

Despite multiple design changes, many areas remain in complete darkness. Therefore, I determined which rooms are viable for additional fixtures (highlighted green in figure 32), and implemented them. Following their inclusion, the new fixtures enabled daylight to reach into spaces that it couldn't before, improving the lighting performance of the building.

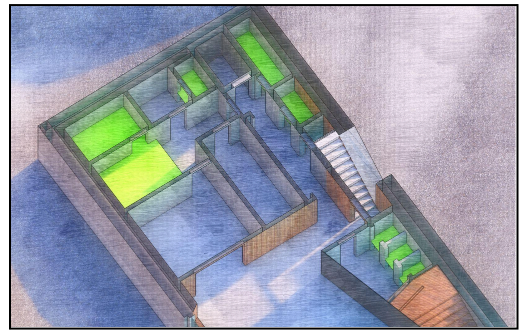


Figure 32: *Highlighted Areas*

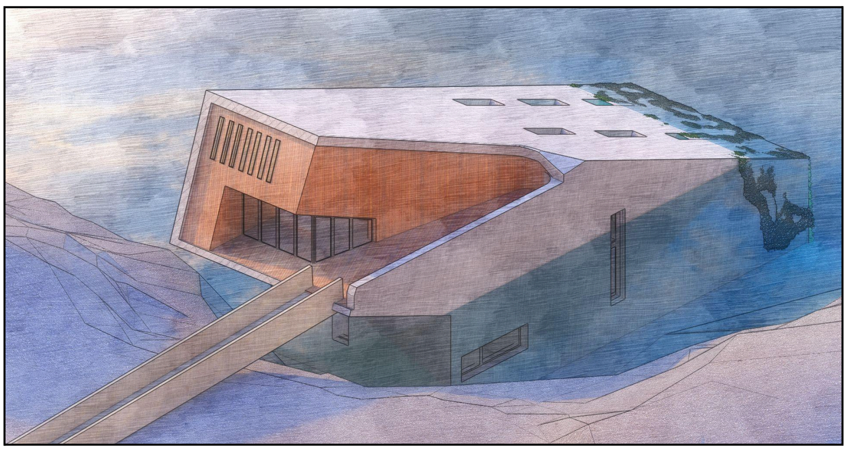


Figure 34: *Additional Windows Render*

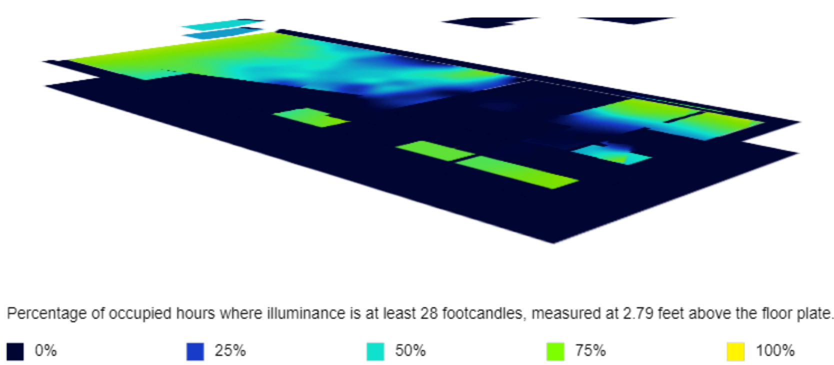


Figure 33: *Additional Windows Sefaira*

2.2.5 - Critical Summary

To conclude this section of the report, I felt a gradual increase in the level of analysis throughout the stages, which I found beneficial in increasing my understanding of light. I found myself in the same position as the designers and had to alter the building orientation, change fixtures, conduct detailed simulations and balance various building elements all in the effort to combat dark spaces.

Upon completion of the changes, I had some realisations. To appropriately daylight the rooms shrouded in darkness, you must disfigure the exterior appearance so much that it loses its original form. Therefore, a conscious decision occurs to either provide improved daylighting and tarnish the aesthetics, or to use artificial lighting and treasure the intended experience: the architects went with the latter. This battle between functionality and beauty is perfectly encapsulated by the final image containing all the changes, which is a certain visual downgrade from the original, yet has the 'bitter-sweet' improved daylighting performance.

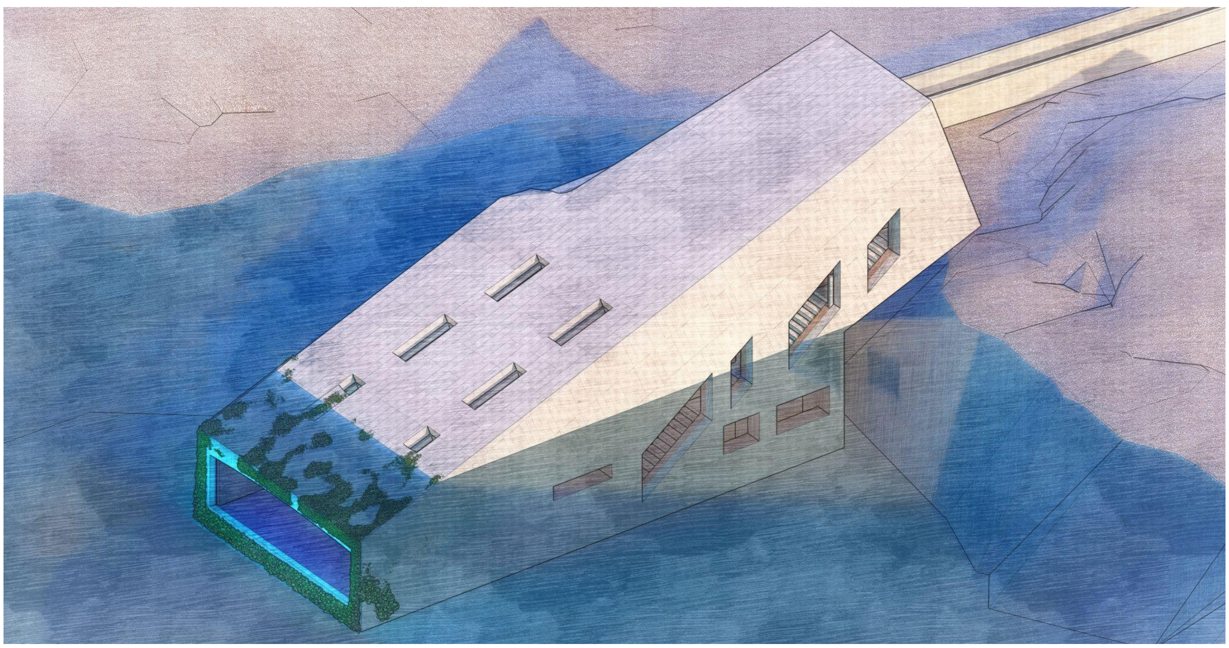


Figure 35: *Structure with Daylighting Additions*

2.3 - Material Design

2.3.1 - Material Characteristics of Main Structural Components

***Figure 36:** Table of Main Structural Components and Reasoning*

Structure		
Type	**Materials**	**Material Reasoning**
Foundation		
	Waterproof Concrete	- Able to create a wide range of complex forms - Provides water protection to structure within - Optimal for climate - thick layers for insulation - Weather resistant - Accessible / affordable
	Bolts	- Secure the structure to the foundation to ensure sturdiness - Counter the horizontal forces of the ocean - waves
	Concrete Bolt Sealant	- Ensures bolts are secured in place permanently - Provides protection to the bolts by fully embedding them
Main Shell		
	Plastic Profile Sealing Membrane	- Provides an additional protective layer to repell any water / moisture - Ensures that the interior contents are dry / safe
	Back Ventilation Roofing Underlay	- Provides a barrier between the roof membrane and the spruce panels
	Spruce Timber Panels	- Act as an additional layer for insulation and rigidity
	Thermal Insulation	- Provide thermal comfort and control to the users - Prevent heat escape / cool entering
	Plasterboard Panel	- Act as one of the final layers of the wall - ready to be painted or have cladding added
	Ceiling Cladding Textile Panel	- The intricate detailing on the panels reacts with the lighting from the water for an impressive visual effect
Timber Walls		
	Oak Boarding	- Exterior layer = visual qualities / weather resistance
	Spruce Battens	- Provide form and stability to structure
	Three-Ply Panel	- By combining various panels, the strength is increased - Provide additional rigidity / stability to structure at relatively low weight as opposed to steel
	Seperating Layer	- Some components must not collide / interact. This is a void in the space.
	Chipboard Panel	- Used for insulation and another wall layer for overall stability
	Spruce Timber w/ 150mm Thermal Insulaton	- Combination of spruce fixture and thermal insulation fitting shows that this is a multi-functional component
	Breather Membrane	- Similar to the seperating layer, certain components must not interact. However, this is not a void.
	Patinated Brass Sheeting	- Already oxygenated brass - Durable and corrosion resistant
	Insect Screen	- Prevent insects from entering the property to maintain internal quality of life and hygeine
	Steel Section	- Used as a support, yet could also be left open as a visual detail.
Ceilings / Floors		
Top Level	Oak Ceiling Boards	- Visual quality - warm material in contrast to very cool space / context
	Reinforced Concrete Screed	- Provide strength and mass to the structure - perfect for utilisation in floors
	Oak Floor Boards	- Visual qualities - Suitable for flooring - offers grip and pattern variety
	PUR Hard Foam Thermal Insulation	- Provide thermal comfort and control with a more structurally-sound material
	Three-Ply Sealing Membrane	- As mentioned prior, stacking ply provides improved structural stability - Used as a sealing membrane due to material resistance to outside factors - very resistant
	Gravel Fill	- Very affordable - Can easily fill in void very fast - Can be compacted to ensure maximum stability
Stairs		
Banister / Railing	Sheet Alloy	- The sheet may be heated and bent to easily manipulate its structure to form curves - Optimal thickness to act as a banister / railing - Affordable, yet high quality appearance
Fixtures		
Entrance Windows	Double Glazed Pane	- Provide views / ventilation - Provide sunlight - Provide access to site
	Aluminium Frame	- Can be anodized to improve weather resistance - Affordable for window fixtures - Optimal sealant
	Blocking / Sealing	- Ensure that outside elements cannot impact / overcome the window element
Main Window	Acrylic Glass Pane	- Acrylic as opposed to regular glass for improved structural properties - Can stack layers to increase strength
	Compression Seal	- Another form of shutting out the outside world and maintaining the current structural form
	Folded Steel Sheet	- Placed underneath window to act as a sloped floor - Prevent users from stepping too close to the glass
Bridge		
	Galvanised Steel	- Weather resistant, strength, can mold into various shapes - Very long product lifespan
	Anti-Slip Steel Panels	- Ensure occupant safety when traversing the potentially wet bridge

2.3.2 - Possible Alternatives for Each Structural Component

Figure 37: *Table of Alternative Materials and Reasoning*

Structure		
Original Material	**Replacement Material**	**Replacement Material Reasoning**
Waterproof Concrete	Hempcrete or use of fly-ash	- Hempcrete is a more sustainable approach to concrete worth exploring - Fly-ash integration can help reduce concrete costs - Very easy, yet effective way of impacting the whole structure due to concrete abundance
Bolts	Stainless Steel	- This will provide a protective layer to ensure that the steel does not corrode - Could leave bolts exposed and not concrete over - This could save costs for future repairs / changes
Concrete Bolt Sealant	Remove	- Ensuring high quality bolts are used will eliminate the need to seal them in
Plastic Profile Sealing Membrane	Experimental Sealing Membrane	- Delving into the scientific industry and trialing new experimental sealing membranes may lead to new discoveries and unparalleled performance - This may be a difficult market to penetrate - Could be very costly
Back Ventilation Roofing Underlay	N/A	
Spruce Timber Panels	Pine	- Experimenting with various wood options could improve the building performance - Potential forest nearby for foraging
Thermal Insulation	Radiating Insulation	- Active insulation which actively heats up the building instead of act as a barrier - Very expensive / experimental - May be prone to overheating
Plasterboard Panel	MDF	- Extremely cheap - Widely accessible
Ceiling Cladding Textile Panel	Complex Textiled Panel	- An even more complex / intricate design may flourish in this building - Potential to change out which texture is in use? - Adaptable design
Oak Boarding	Pine	- Widely available - Different aesthetic qualities - how does pine look with the other materials?
Spruce Battens	Hazel	- Lighter, but may still offer optimal strength qualities
Three-Ply Panel	MDF	- Stacking MDF is possible and should return similar results, hence it is worth exploring - Potentially cheaper, although may have to stack manually
Seperating Layer	N/A	
Chipboard Panel	Blockboard	- Widely available - Could easily transfer to site with other materials - design fluidity
Spruce Timber w/ 150mm Thermal Insulaton	Pine and Radiating Insula	- By combining these two, it is possible to have integrated heating elements inside of the structural walls
Breather Membrane	N/A	
Patinated Brass Sheeting	Copper	- Copper offers similar aesthetic and performance qualities to brass, likely for a lower price
Insect Screen	N/A	
Steel Section	Iron	- Potential to swap out steel elements with iron ones, depending on the load
Oak Ceiling Boards	Pine	- Could offer an interesting aeshetic impact on the rest of the design with pine highlights
Reinforced Concrete Screed	Sand	- By forming an appropriate container and filling it with sand, you are left with an incredibly durable, strong building element - This may be too heavy for anything other than foundations, so design with caution
Oak Floor Boards	Pine	- Continuation of the new aesthetic theme - Widely available near the site, reducing costs and transport times
PUR Hard Foam Thermal Insulation	Firm Active Insulation	- Similar to the active insulation previously mentioned, however this is of higher firmness, allowing it to be more versatile in construction
Three-Ply Sealing Membrane	MDF	- Stacks of MDF provide a very rigid, strong element which could be optimised for utility in flooring - Consider weight factor with building above ground floor
Gravel Fill	Sand	- Widely available almost everywhere - Extremely cheap - Will fill up the area very true to its form due to how finite sand is
Sheet Alloy	Carbon fiber	- May be more difficult to manufacture and work with than a sheet alloy - Offers very impressive visual qualities which may compliment the unique lighting experience
Double Glazed Pane	Thermochromic Glazing	- Implementation of smart materials could take the structure to the next level of performance - Automation of daylighting systems (currently non-existant) could improve the building's performance and spatial quality
Aluminium Frame	Spruce	- Softwood widely available at the site - Very lost cost of production / use / transport
Blocking / Sealing	Steel Blocker	- Using a solid piece of rigid steel could act as an efficient sealent / blocker - The dimensions must be exact to ensure appropriate performance / integration - Could galvanise to combat corrosion
Acrylic Glass Pane	Thermochromic Glazing	- Would require many layers and rigorous to ensure it is safe - Could control the ocean view by manipulating the smart material
Compression Seal	Steel Blocker	- Same premise as before - ensure exact dimensions and appropriate galvanisation / protection
Folded Steel Sheet	Polymer Surface	- To avoid using alloys in the construction, we could consider using 3D printed / polymer materials - Wouldn't hurt if you fell on them which users are prone to do in this area
Galvanised Steel	Aluminium	- Very similar qualities / way of working as steel - Anodize the material to increase its performance in the real world
Anti-Slip Steel Panels	Reactive Material	- Perhaps there are new breakthroughs in anti-slip technology as the area has not been expanded upon in quite some time - There may be a material that will secure you in place to prevent any potential slips / injury

2.3.3 - Embodied Carbon Demand Calculations

***Figure 38:** Table of Embodied Carbon*

Structure		Dimensions		Surface Area (m2)	Thickness (m)	Volume (m3)	Density (kg/m3)	Mass (kg)	Carbon Coefficient (kgCO2e/kg)	Embodied Carbon (kgCO2e)	Waste	
Type	Materials	Length (m)	Width (m)								Material Factor	Additional Carbon (kgCO2e)
Foundation												
	Waterproof Concrete	26.690	12.050	321.615	0.500	6.185	2,400.000	14,843.746	0.198	2,939.062	0.053	155.770
	Bolts	0.070	0.020	0.001	0.050	0.000	7,750.000	0.021	1.310	0.027	0.053	0.001
	Concrete Bolt Sealant	0.050	0.050	0.003	0.020	0.000	2,400.000	0.005	0.198	0.001	0.053	0.000
Main Shell												
	Waterproof Board-Marked Concrete	33.900	35.780	1,213.020	0.500	23.327	2,400.000	55,985.538	0.198	11,085.137	0.053	587.512
	Plastic Profile Sealing Membrane	33.100	33.240	1,100.200	0.050	2.116	950.000	2,009.981	4.200	8,441.919	0.100	844.192
	Back Ventilation Roofing Underlay	32.800	33.230	1,090.000	0.150	6.288	1,000.000	6,288.462	1.650	10,375.962	0.120	1,245.115
	Spruce Timber w/ 200mm Thermal Insulaton	32.500	32.620	1,060.000	0.550	22.423	750.000	16,817.308	0.350	5,886.058	0.111	653.352
	Spruce Timber w/ 50mm Thermal Insulaton	32.200	30.760	990.500	0.150	5.714	450.000	2,571.490	0.350	900.022	0.111	99.902
	Plasterboard Panel	31.100	31.670	985.000	0.013	0.474	700.000	331.490	0.380	125.966	0.290	36.530
	Ceiling Cladding Textile Panel	24.440	9.580	234.240	0.025	0.225	700.000	157.662	0.740	116.670	0.150	17.500
Timber Walls												
	Oak Boarding	39.200	17.240	675.720	0.023	0.598	625.000	373.595	0.370	138.230	0.111	15.344
	Spruce Battens	39.000	11.690	456.000	0.036	0.631	425.000	268.338	0.350	93.918	0.111	10.425
	Three-Ply Panel	38.200	11.780	450.000	0.023	0.398	510.000	203.019	0.520	105.570	0.122	12.880
	Seperating Layer	37.600	11.760	442.000	0.020	0.340	0.000	0.000	0.004	0.000	0.000	0.000
	Chipboard Panel	36.400	12.120	441.000	0.019	0.322	620.000	199.807	0.390	77.925	0.132	10.286
	Spruce Timber w/ 150mm Thermal Insulaton	31.000	12.940	401.000	0.350	5.398	700.000	3,778.654	0.350	1,322.529	0.111	146.801
	Chipboard Panel	31.000	12.940	401.000	0.019	0.293	620.000	181.684	0.390	70.857	0.132	9.353
	Breather Membrane	23.000	14.760	310.000	0.020	0.238	225.000	53.654	4.200	225.346	0.100	22.535
	Patinated Brass Sheeting	23.000	14.760	310.000	0.030	0.358	8,890.000	3,179.885	2.460	7,822.516	0.122	954.347
	Insect Screen	4.700	0.760	3.580	0.030	0.004	35.000	0.145	0.010	0.001	0.010	0.000
	Steel Section	0.250	0.150	0.038	0.020	0.000	7,750.000	0.224	1.370	0.306	0.053	0.016
Interior Walls												
Entrance Level	Plasterboard Panel	2.680	4.675	12.530	0.072	0.035	700.000	24.289	0.380	9.230	0.290	2.677
	Chipboard Panel	2.680	3.929	10.530	0.028	0.011	620.000	7.031	0.390	2.742	0.132	0.362
	Mineral Wool Thermal Insulaton	2.680	1.828	4.900	0.100	0.019	130.000	2.450	5.530	13.549	0.120	1.626
Mezzanine Level	Plasterboard Panel	2.680	3.075	8.240	0.072	0.023	700.000	15.973	0.380	6.070	0.290	1.760
	Chipboard Panel	2.680	2.328	6.240	0.028	0.007	620.000	4.166	0.390	1.625	0.132	0.214
	Mineral Wool Thermal Insulaton	2.680	0.970	2.600	0.100	0.010	130.000	1.300	5.530	7.189	0.120	0.863
Restaurant Level	Plasterboard Panel	2.680	5.067	13.580	0.072	0.038	700.000	26.324	0.380	10.003	0.290	2.901
	Chipboard Panel	2.680	4.321	11.580	0.028	0.012	620.000	7.732	0.390	3.015	0.132	0.398
	Mineral Wool Thermal Insulaton	2.680	2.052	5.500	0.100	0.021	130.000	2.750	5.530	15.208	0.120	1.825
Ceilings / Floors												
Top Level	Oak Ceiling Boards	8.100	7.730	62.640	0.018	0.043	625.000	27.104	0.370	10.028	0.111	1.113
	Reinforced Concrete Screed	8.100	7.730	62.640	0.300	0.723	2,100.000	1,517.815	0.198	300.527	0.053	15.928
	Oak Floor Boards	8.100	7.730	62.640	0.030	0.072	625.000	45.173	0.370	16.714	0.111	1.855
Entrance Level	Oak Ceiling Boards	9.310	7.730	71.930	0.018	0.050	625.000	31.124	0.370	11.516	0.111	1.278
	Reinforced Concrete Screed	15.050	7.400	111.410	0.150	0.643	2,100.000	1,349.775	0.198	267.255	0.053	14.165
	Polished Seperation Layer	15.050	7.400	111.410	0.050	0.214	0.000	0.000	0.004	0.000	0.000	0.000
	PUR Hard Foam Thermal Insulation	15.050	7.400	111.410	0.150	0.643	40.000	25.710	4.200	107.982	0.220	23.756
	Three-Ply Sealing Membrane	15.050	7.400	111.410	0.050	0.214	950.000	203.538	4.000	814.150	0.100	81.415
	Oak Floor Boards	14.050	7.670	107.740	0.030	0.124	625.000	77.697	0.370	28.748	0.111	3.191
Mezzanine Level	Oak Ceiling Boards	13.590	2.790	37.860	0.018	0.026	625.000	16.382	0.370	6.061	0.111	0.673
	Reinforced Concrete Screed	13.590	11.650	158.350	0.150	0.914	2,100.000	1,918.471	0.198	379.857	0.053	20.132
	Polished Seperation Layer	13.590	11.650	158.350	0.050	0.305	0.000	0.000	0.004	0.000	0.000	0.000
	PUR Hard Foam Thermal Insulation	13.590	11.650	158.350	0.150	0.914	40.000	36.542	4.200	153.478	0.220	33.765
	Three-Ply Sealing Membrane	13.590	11.650	158.350	0.050	0.305	950.000	289.293	4.000	1,157.173	0.100	115.717
	Oak Floor Boards	14.050	6.850	96.300	0.030	0.111	625.000	69.447	0.370	25.695	0.111	2.852
Restaurant Level	Oak Ceiling Boards	10.580	3.460	36.650	0.018	0.025	625.000	15.858	0.370	5.868	0.111	0.651
	Reinforced Concrete Screed	26.390	11.850	312.722	0.150	1.804	2,100.000	3,788.741	0.198	750.171	0.053	39.759
	Polished Seperation Layer	26.390	11.850	312.722	0.050	0.601	0.000	0.000	0.004	0.000	0.000	0.000
	PUR Hard Foam Thermal Insulation	26.390	11.850	312.722	0.050	0.601	40.000	24.056	4.200	101.033	0.220	22.227
	Three-Ply Sealing Membrane	26.690	12.050	321.615	0.050	0.618	950.000	587.565	4.000	2,350.260	0.100	235.026
	PUR Hard Foam Thermal Insulation	26.390	11.850	312.722	0.150	1.804	40.000	72.167	4.200	303.099	0.220	66.682
	Gravel Fill	26.690	12.050	321.615	0.150	1.855	1,680.000	3,117.187	0.005	14.962	0.100	1.496
Stairs												
Steps	Oak	10.280	2.880	29.620	0.160	0.182	625.000	113.923	0.370	42.152	0.111	4.679
Landing	Oak	1.830	2.880	5.280	0.160	0.032	625.000	20.308	0.370	7.514	0.111	0.834
Support	Oak	10.280	0.850	8.738	0.150	0.050	625.000	31.507	0.370	11.658	0.111	1.294
Banister / Railing	Sheet Alloy	42.140	1.300	54.780	0.020	0.042	7,750.000	326.573	1.370	447.405	0.053	23.712
Elevator Shaft												
	Reinforced Concrete	10.730	2.100	2.700	0.300	0.031	2,400.000	74.769	0.198	14.804	0.053	0.785
Fixtures												
Entrance Windows	Double Glazed Pane	14.980	1.690	3.570	0.028	0.004	2,500.000	9.612	14.600	140.328	0.053	7.437
	Aluminium Frame	15.400	2.100	1.050	0.030	0.001	2,710.000	3.283	8.240	27.054	0.010	0.271
Front Doors	Double Glazed Pane	2.550	8.300	16.030	0.028	0.017	2,500.000	43.158	14.600	630.102	0.053	33.395
	Aluminium Frame	2.690	8.640	4.910	0.075	0.014	2,710.000	38.383	8.240	316.276	0.010	3.163
Side Window	Triple Glazed Pane	4.700	0.760	3.580	0.052	0.007	3,500.000	25.060	17.000	426.020	0.053	22.579
	Aluminium Frame	5.000	1.060	1.730	0.100	0.007	2,710.000	18.032	8.240	148.583	0.010	1.486
	Blocking / Sealing	0.070	1.060	0.074	0.100	0.000	140.000	0.040	1.400	0.056	0.100	0.006
Main Window	Acrylic Glass Pane	10.650	2.800	30.290	0.250	0.291	1,180.000	343.675	24.000	8,248.200	0.053	437.155
	Blocking / Sealing	10.650	0.070	0.746	0.100	0.003	170.000	0.487	1.400	0.682	0.100	0.068
	Compression Seal	10.650	0.050	0.533	0.050	0.001	130.000	0.133	1.600	0.213	0.100	0.021
	Folded Steel Sheet	10.650	0.100	1.065	0.020	0.001	7,750.000	6.349	1.370	8.698	0.053	0.461
Bridge												
	Galvanised Steel	1.710	2.250	1.610	23.640	1.464	7,850.000	11,491.313	1.450	16,662.404	0.053	883.107
	Anti-Slip Steel Panels	23.640	1.850	43.734	0.010	0.017	7,850.000	132.043	1.370	180.899	0.053	9.588
								133,229.014		83,914.279		6,946.212
												Total Embodied Carbo
												90,860.491

In a new table, I have calculated the embodied carbon demand for the building via geometric material data calculations. Understanding the dimensions of each material component is crucial in calculating an accurate final value. Some dimensions (length / width columns) appear flawed, however this occurs due to these numerical values not considering complex shapes and voids in materials. Dimensions were determined via experimentation and analysis of the 3D model of the structure, in combination with provided technical drawings.

Coefficients and material factors derive from texts from various reputable authors and legislations such as BSRIA and their ICE guide. The total embodied carbon came out to 90,860 kgCO2e with a total building mass of 133,229kg.

2.3.4 - Charts

Using data derived from accessed drawings and my 3D model, I can represent various statistics regarding the structure, including volume, mass and embodied energy. Exact values may be accessed via the table.

2.3.4.1 - Volume of Each Structural Component

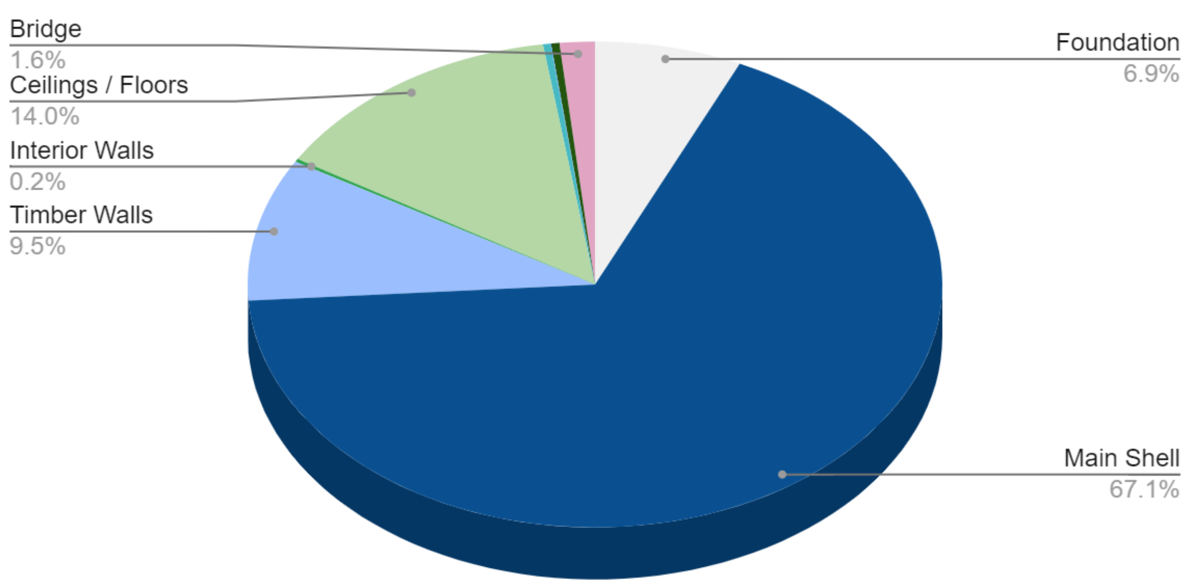


Figure 39: *Pie Chart - Volume*

The main shell encloses the majority of the design, hence why its volume is so high in proportion to other components. Furthermore, the foundation is composed of a mix of components across a large space, hence the high volume.

2.3.4.2 - Weight of Each Structural Component

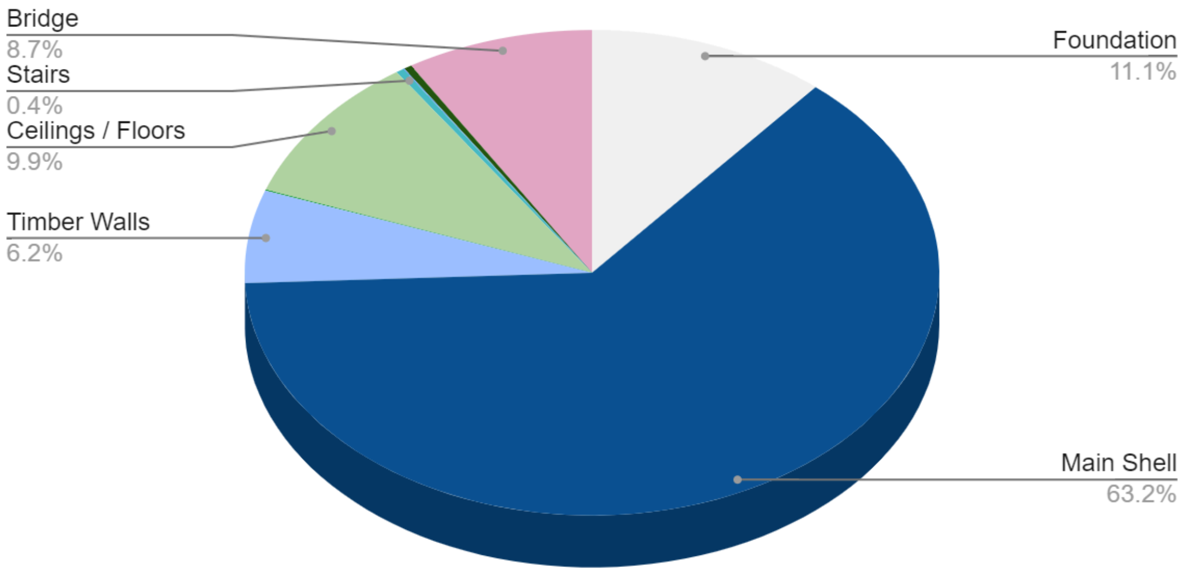


Figure 40: *Pie Chart - Mass*

This chart sees a continuation in the dominance of the main shell, due to its immense scale enabling its colossal weight. The foundation follows suit, with immense weight being necessary to maintain positioning and stability. The bridge makes a drastic increase in its presence on the chart, due to the bridge being solid galvanised steel. Galvanisation ensures protection against weathering and an increase to lifespan, ideal for a component in such harsh conditions.

2.3.4.3 - Embodied Energy of Each Structural Component

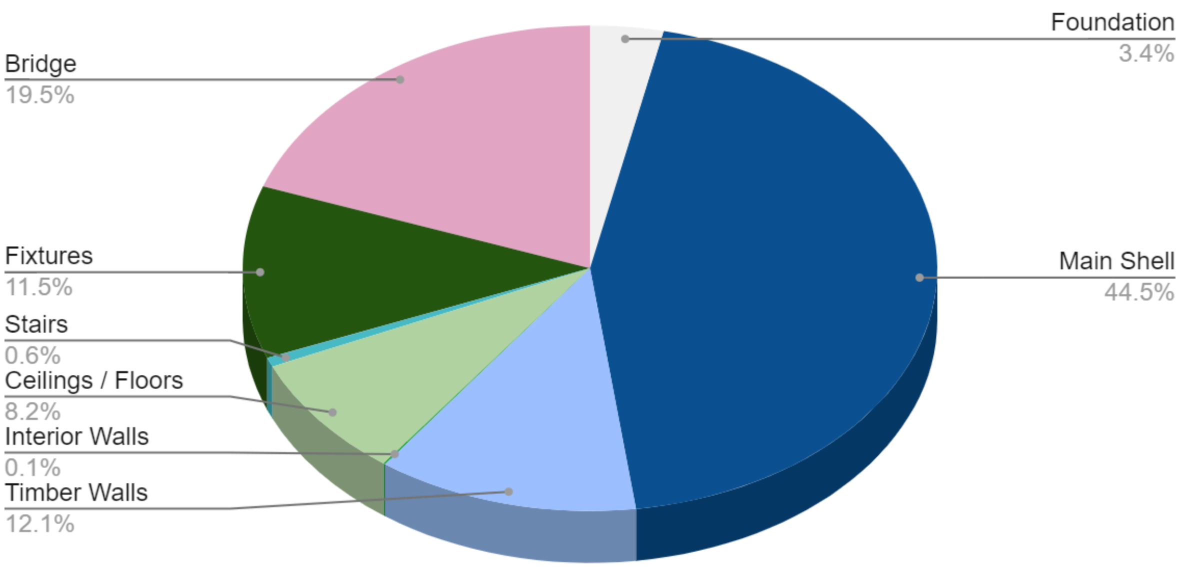


Figure 41: *Pie Chart - Embodied Energy*

Embodied energy is determined by various coefficients, which correspond with their respective material. This coefficient is higher in particular materials than others, such as it being 0.198 in concrete and 1.450 in galvanised steel, resulting in the bridge having such an immense proportion of the pie chart in relation to its actual scale, unlike the main concrete shell. Another example of this shift is in the fixtures being responsible for 11.5% of embodied carbon. This is due to the extremely high carbon coefficients the materials possess, specific to customised underwater window fittings. The main shell margin has decreased in size compared to previous charts, suggesting how concrete has lower carbon capacities than other materials being used in the structure.

2.3.5 - Possible Embodied Carbon Energy Impact Calculations

Typical UK homes average at 80,000kg of CO_2e, a worryingly high value. The case study has been calculated to have 83,914kg of CO_2e, coming in just above the house example. Considering this structure is to be used commercially and can house a large number of occupants, it appears that the building performs exceptionally well. This may be due to the peculiar structure, consisting of a concrete shell which encases the fragile and versatile components, which would be in far greater numbers in a traditional home.

Whilst the structure succeeds in general, its drawbacks must be considered. A galvanised steel bridge is optimal for site access due to its strength and weather resistant properties, however is particularly expensive to the environment and financially, as seen in figure 41. A compromise may be found, perhaps with a lighter, cheaper metal with lower embodied carbon, however it may need to be maintained frequently, unlike with galvanisation.

Specialist fixtures such as the submerged windows must be specifically designed for the structure and its dimensions (not standardised), and are very expensive. Submerged windows have additional technical considerations, causing them to be increasingly environmentally harmful / higher embodied carbon to reach optimal performance.

The environmental welcoming of this structure is visually noticeable, with algae already flourishing, demonstrating its connection with the site.

2.3.6 - Reducing Embodied Energy Demand

The structure could benefit from re-consideration of certain materials to reduce its embodied carbon value, without compromising the structural and aesthetic performance established by its designers. I would consider changing the main glazing for a smart material such as photochromic in order to further control the environment at a lower cost. Additionally, opting for fly-ash in concrete mix or using hempcrete could spark massive decreases in the embodied carbon.