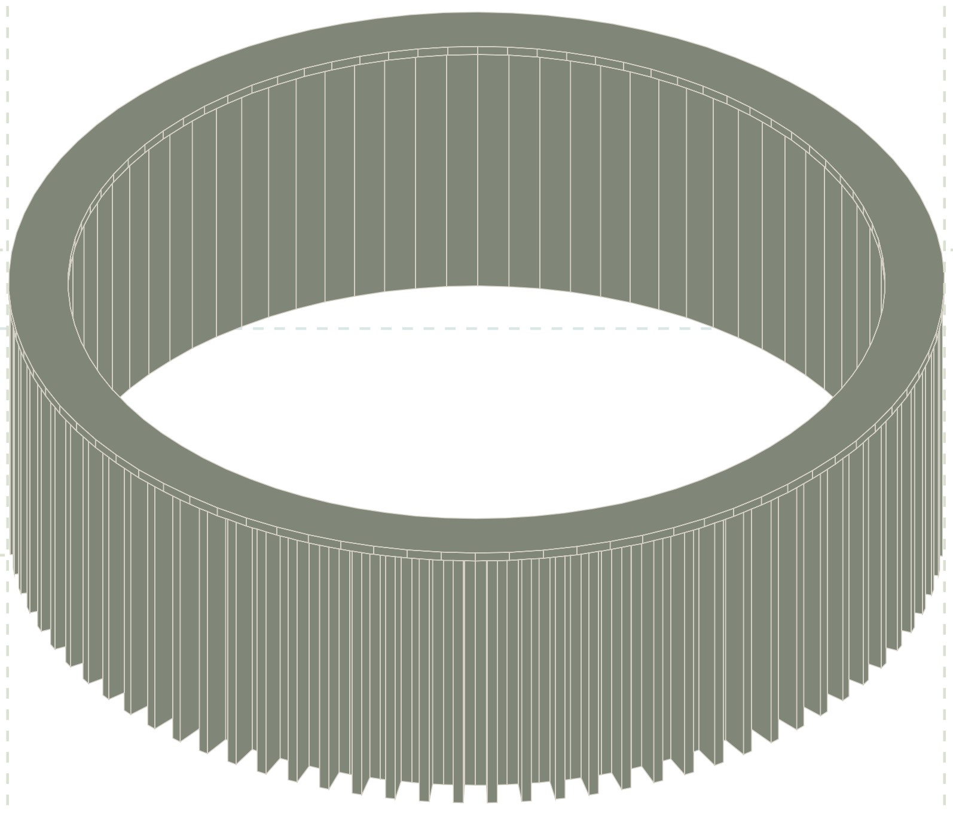
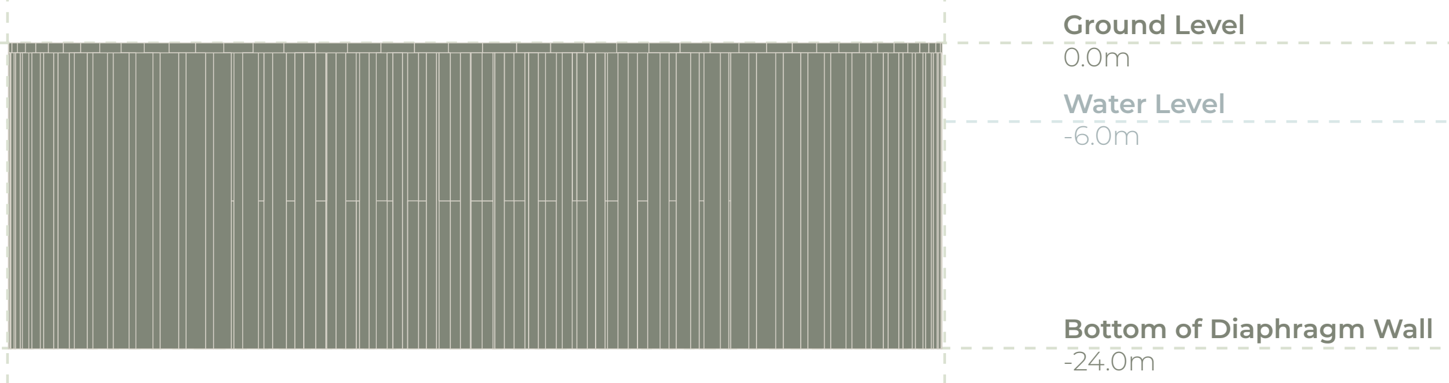
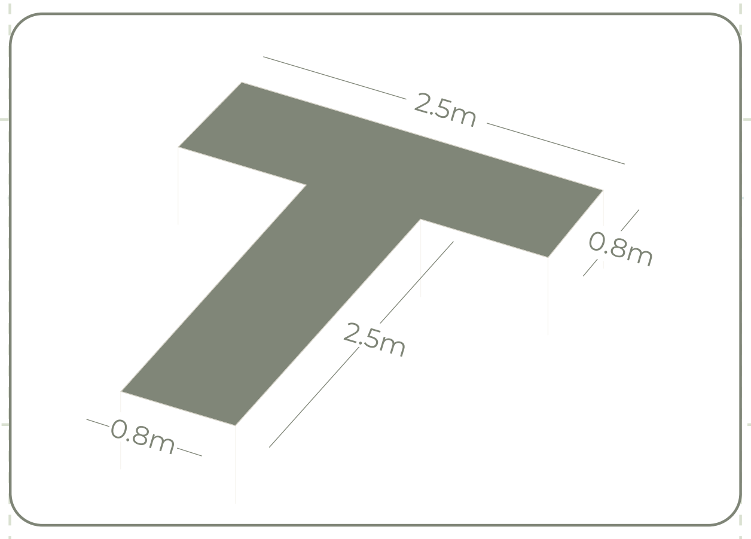
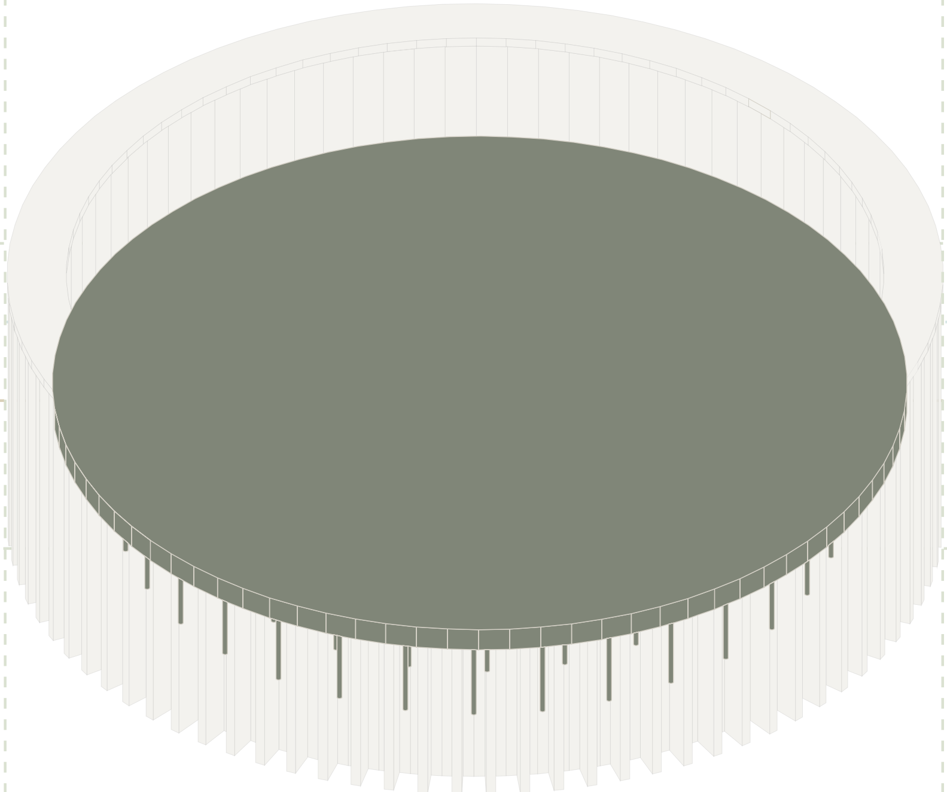
Designing Below Ground



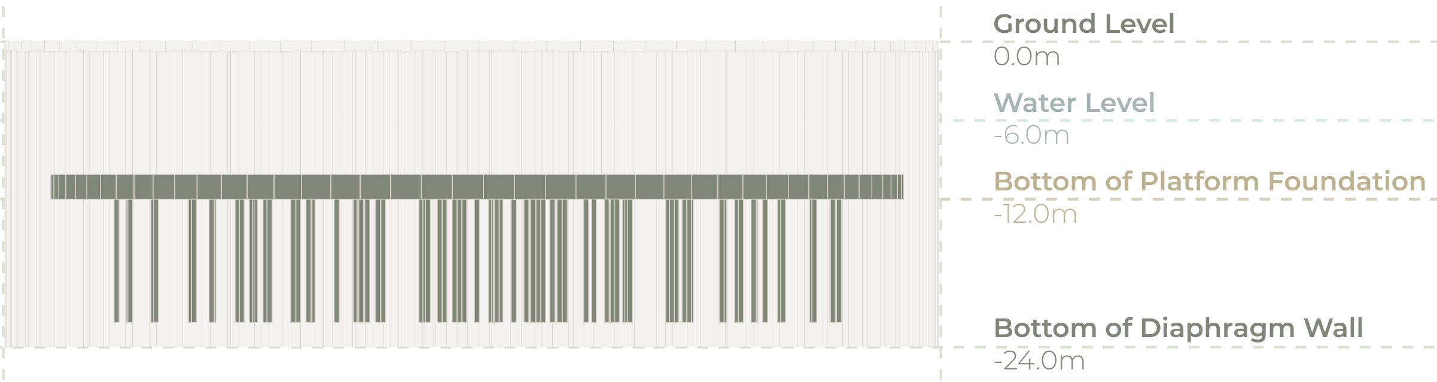
DOME RING

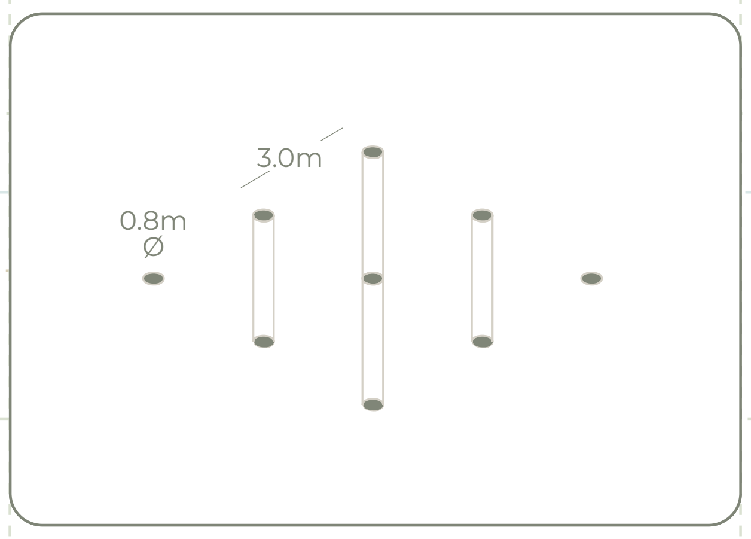


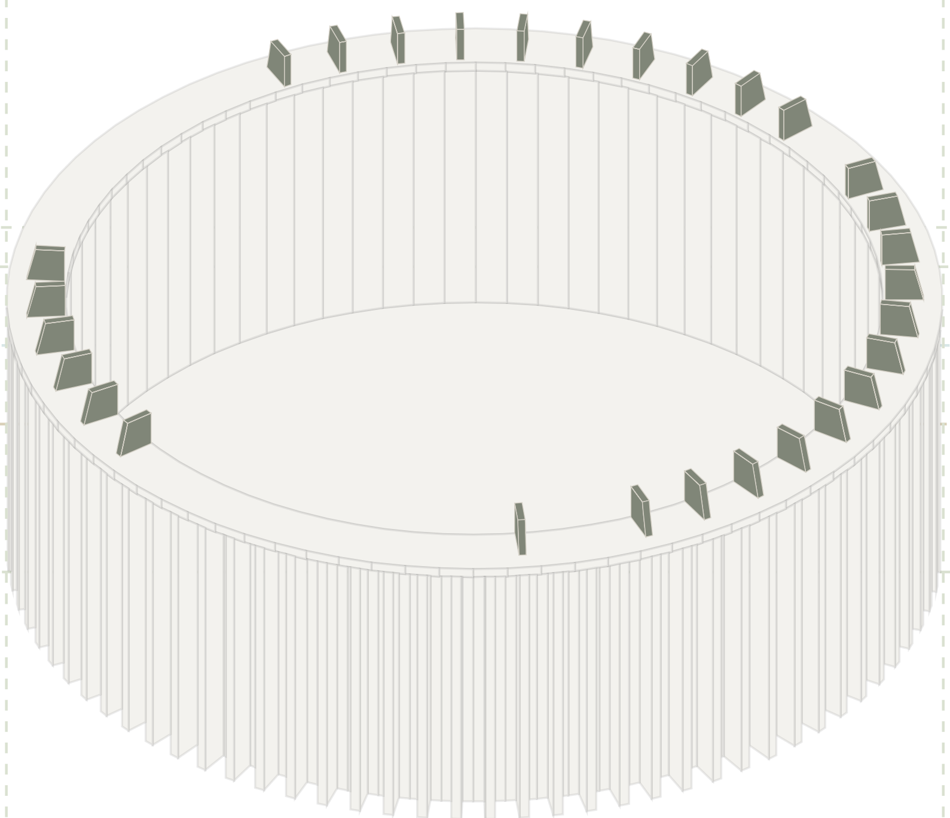




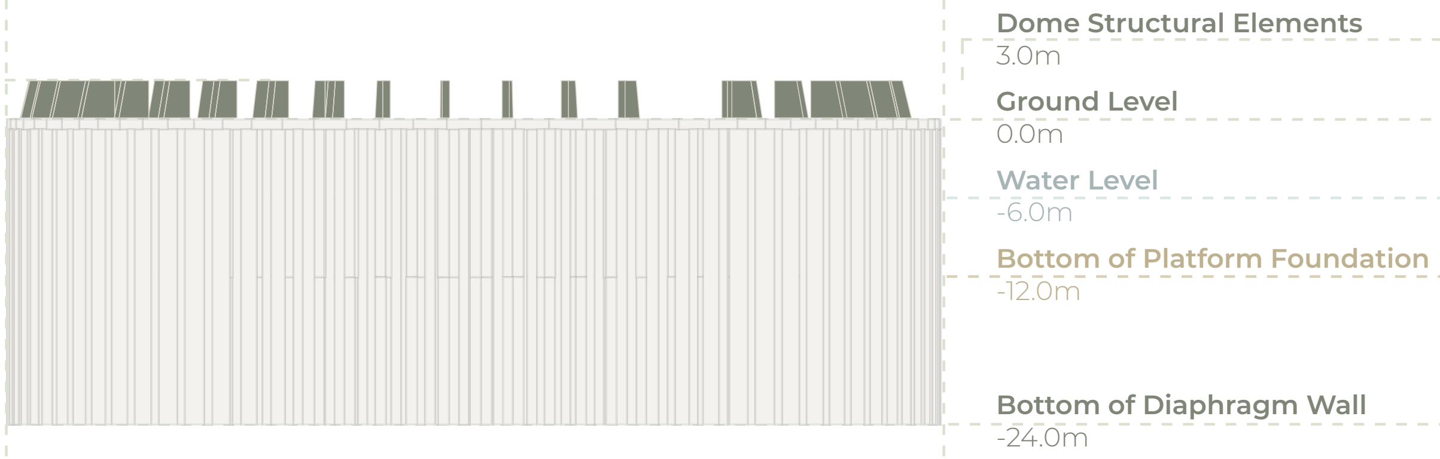
PLATFORM FOUNDATION

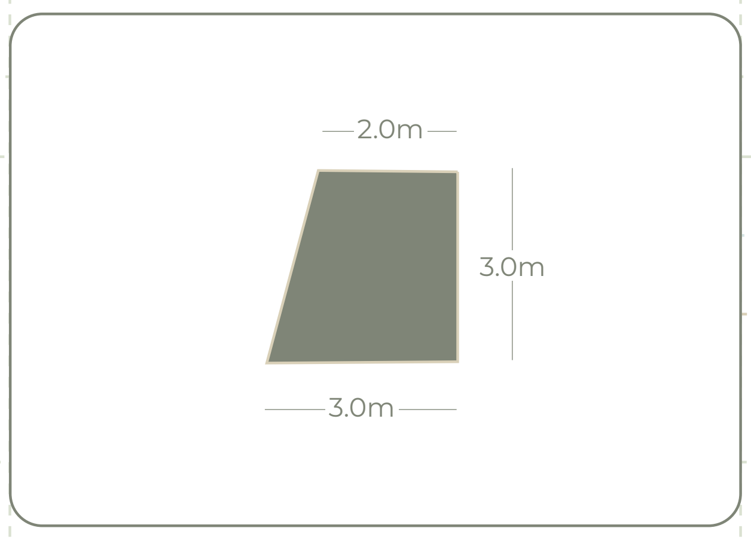


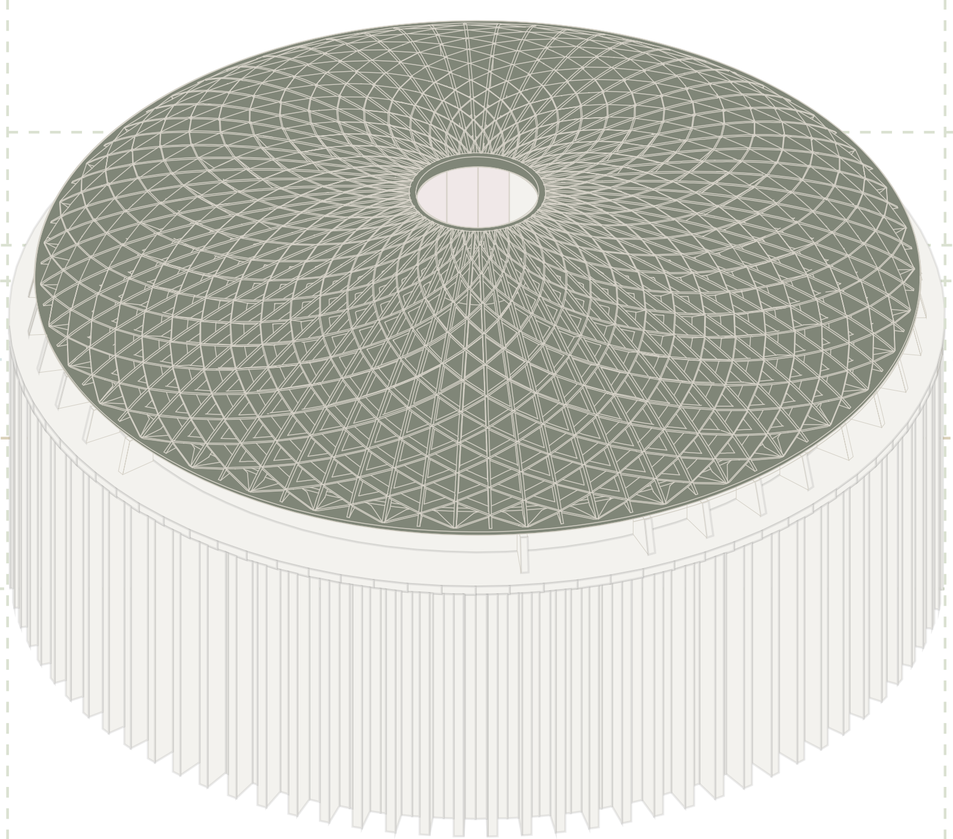




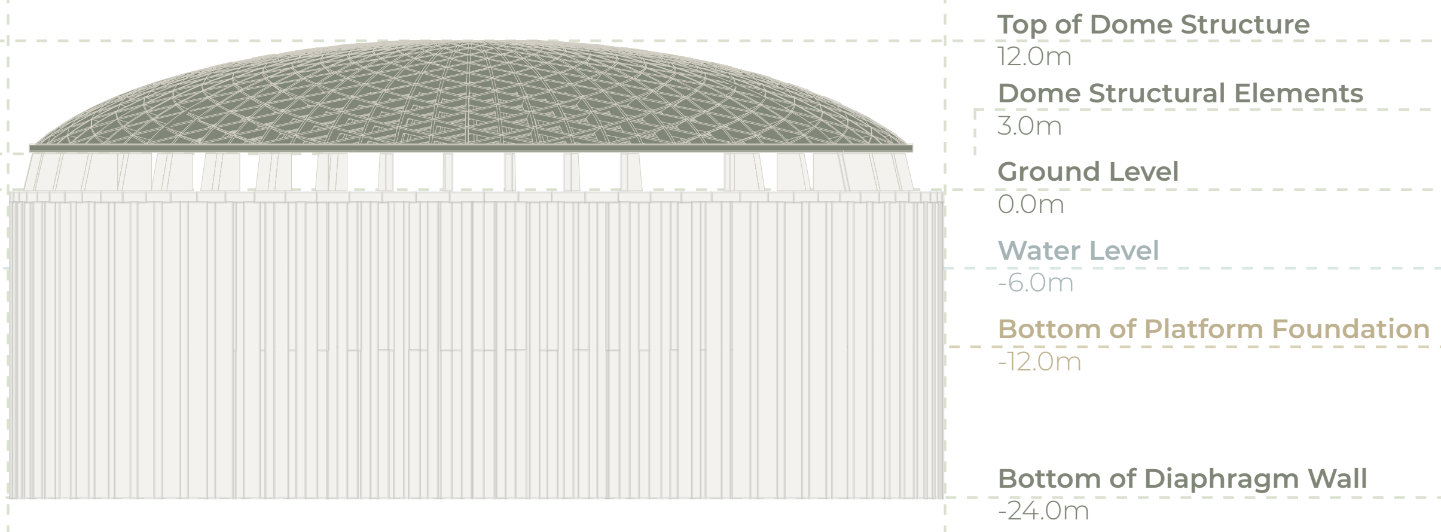
DOME COLUMNS

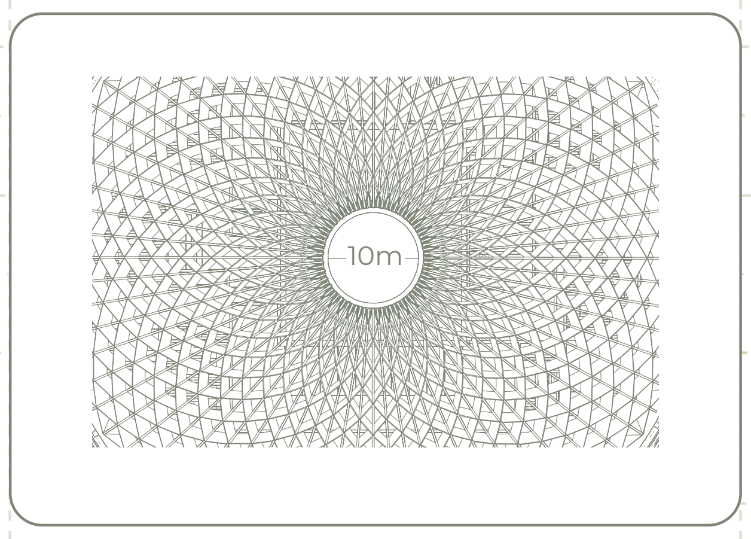






DOME STRUCTURE





Music Hall Structural System

The structural system of the Music Hall is based on a reinforced concrete frame, composed of concrete shear walls, beams, and columns. This system ensures overall stability and load transfer, with vertical loads carried through beams and columns to the foundations, while shear walls provide resistance to horizontal actions and contribute to the global stiffness of the building.

Within the main auditorium, the roof and ceiling system is supported by a series of steel trusses spanning above the performance space. This solution allows for a wide, column-free interior while limiting structural depth and controlling deformations. The steel trusses were analytically verified using MIDAS Gen, where dead and live loads were applied and evaluated under both Serviceability and Ultimate Limit States. Different steel profiles were compared under identical conditions to assess displacements and stress utilization, leading to the selection of an optimized solution.

The material heaviness of the structural system was intentionally chosen to resonate with the physical and symbolic weight of the ground. The use of reinforced concrete expresses a direct relationship with the soil, anchoring the Music Hall to the site and reinforcing the idea of the ground as an active, resonant element rather than a neutral base.

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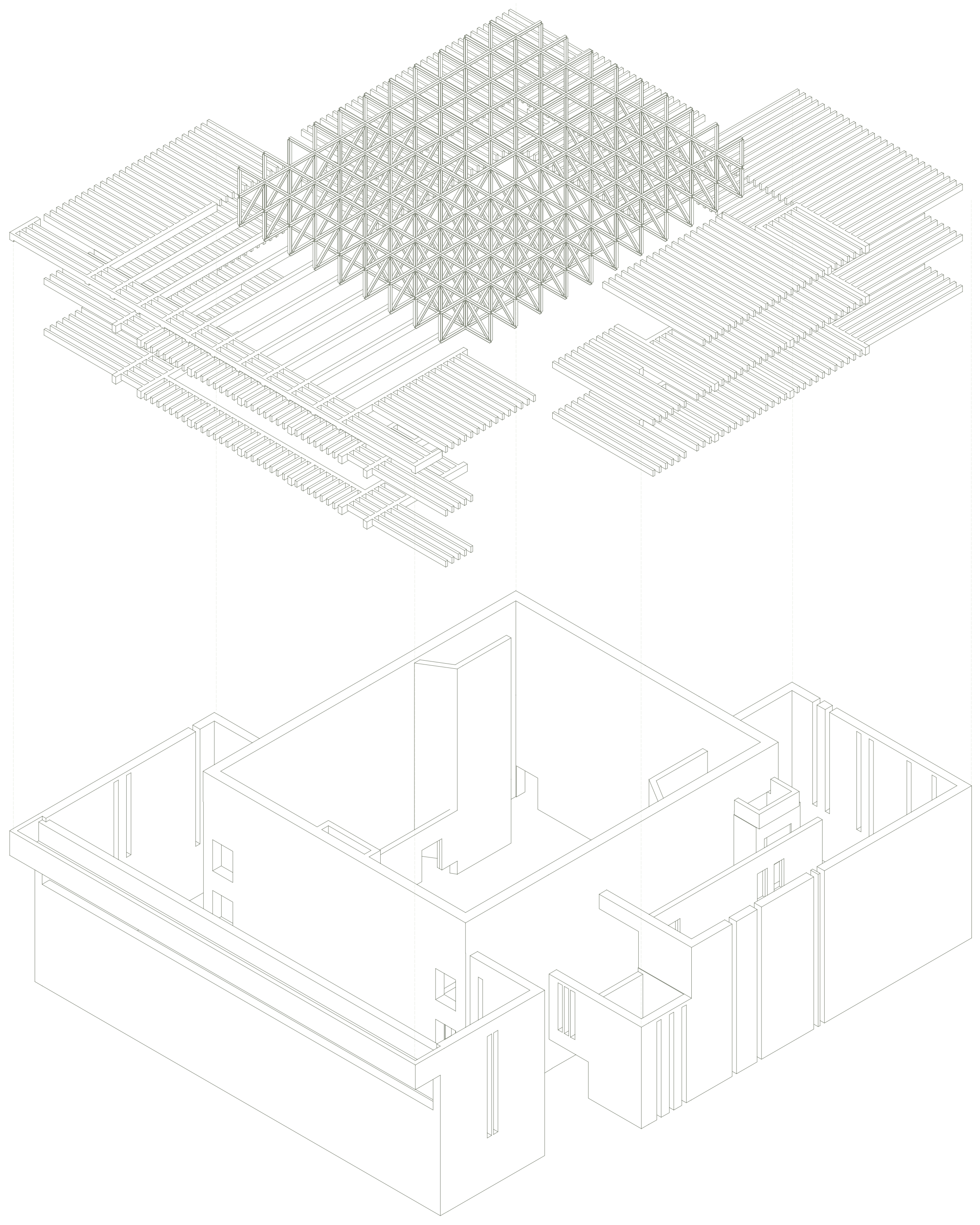
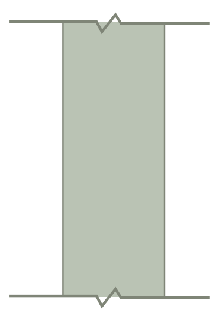
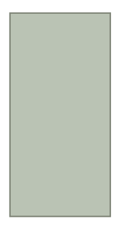


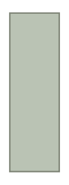
Concrete Shear wall
300mm thick



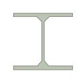
Primary Beam
CLS 300x500

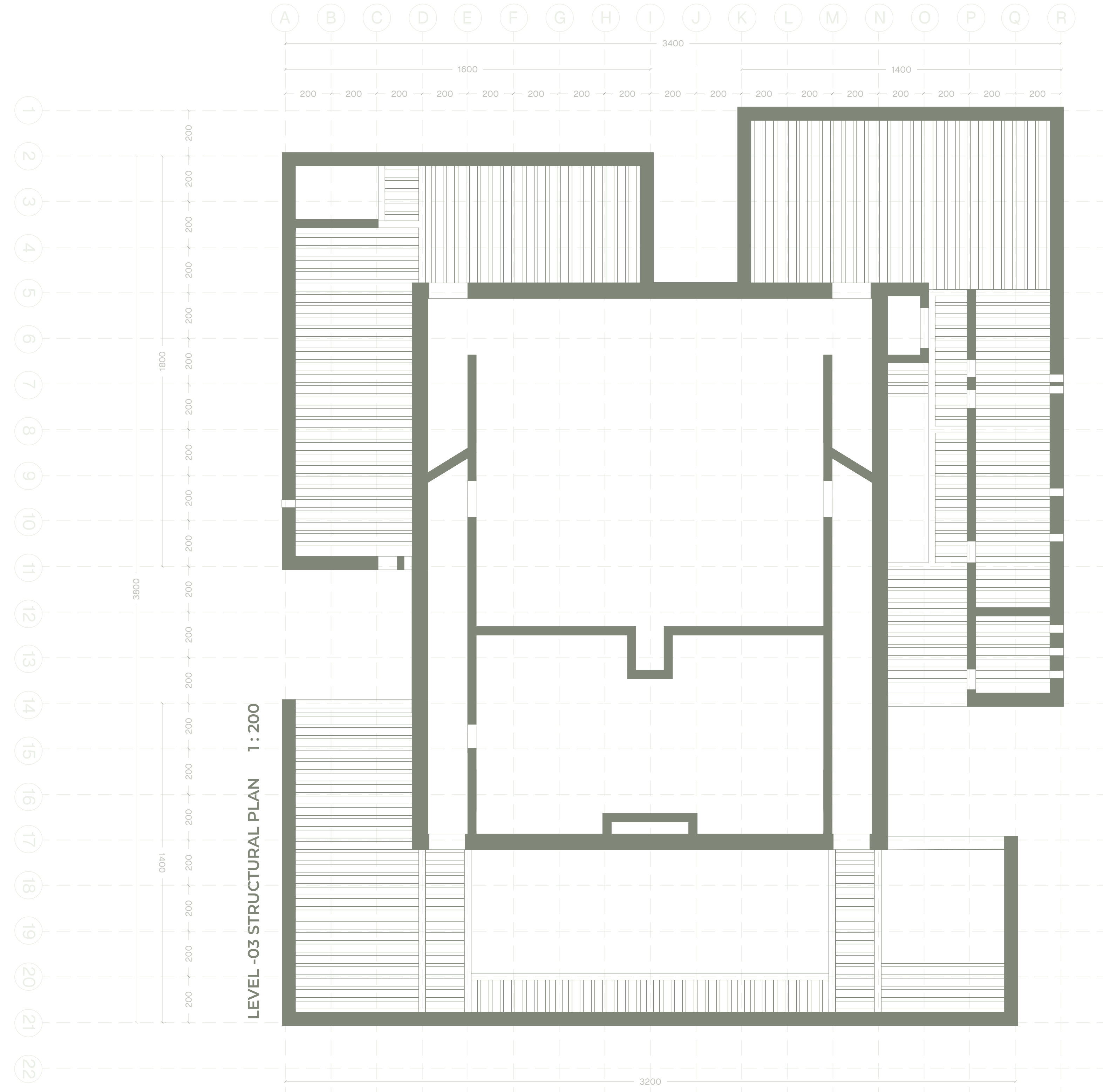


Secondary Beam
CLS 150x400

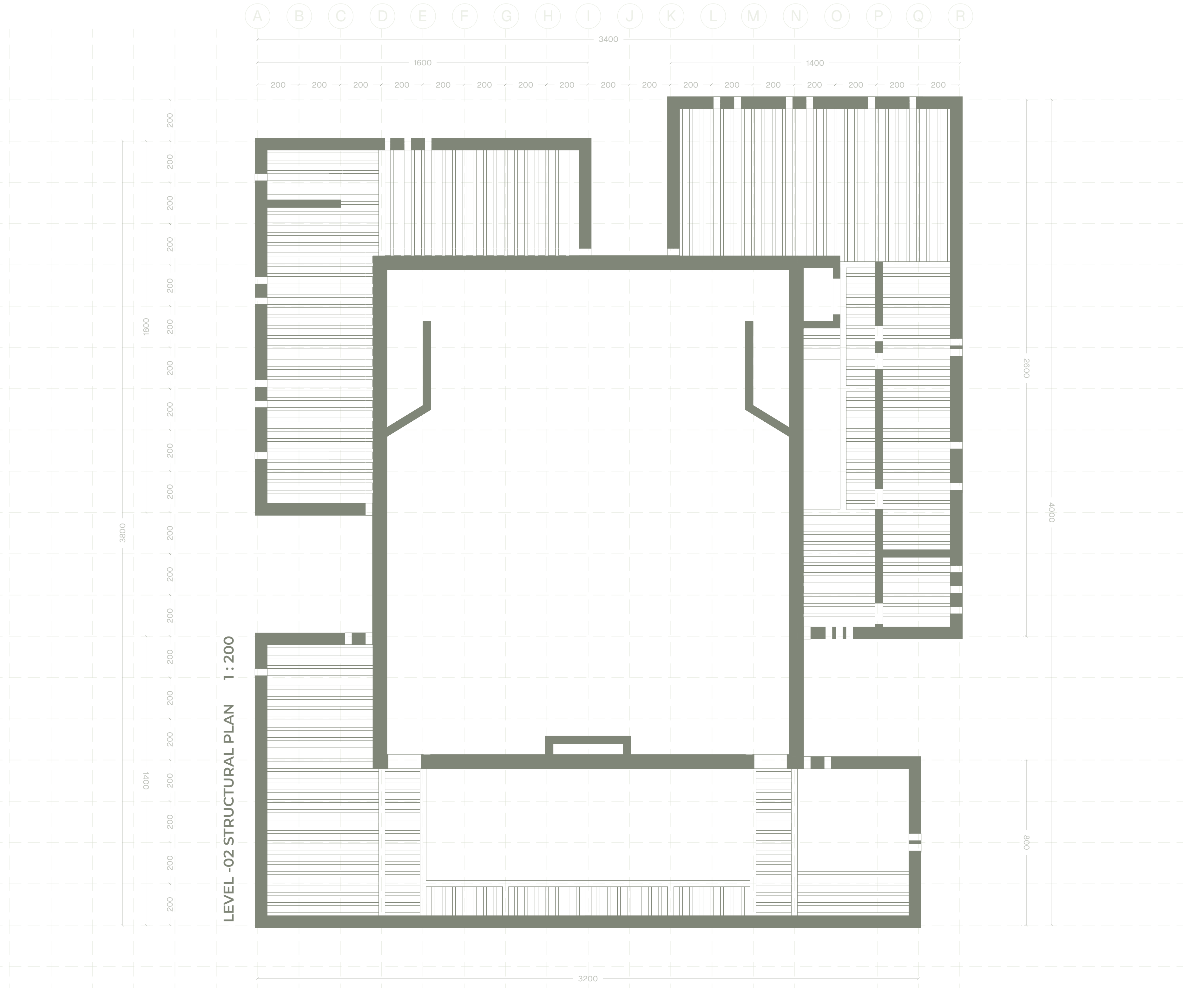


Truss System
HEA 160

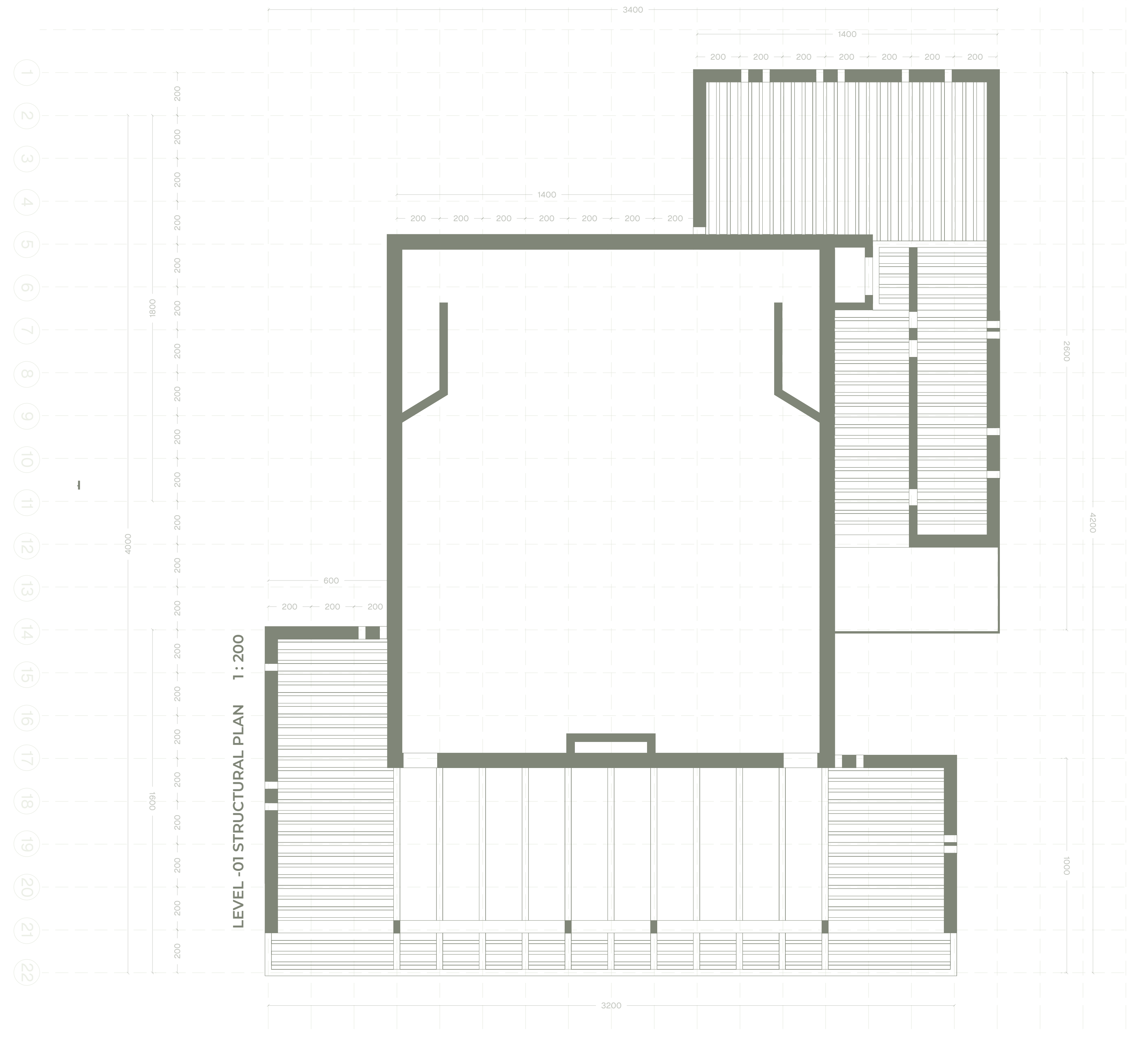




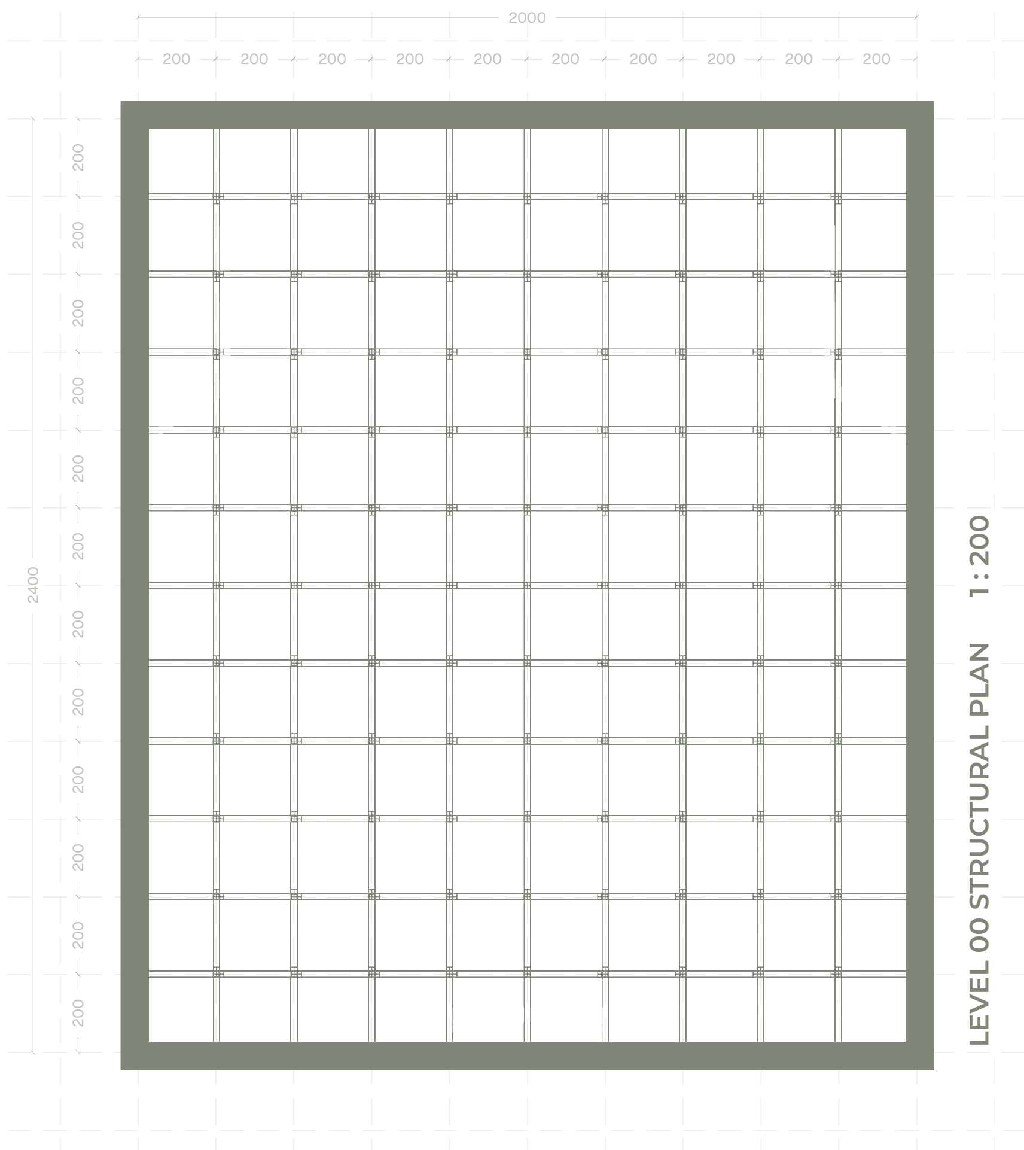
LEVEL -03 STRUCTURAL PLAN 1 : 200



LEVEL -02 STRUCTURAL PLAN 1 : 200



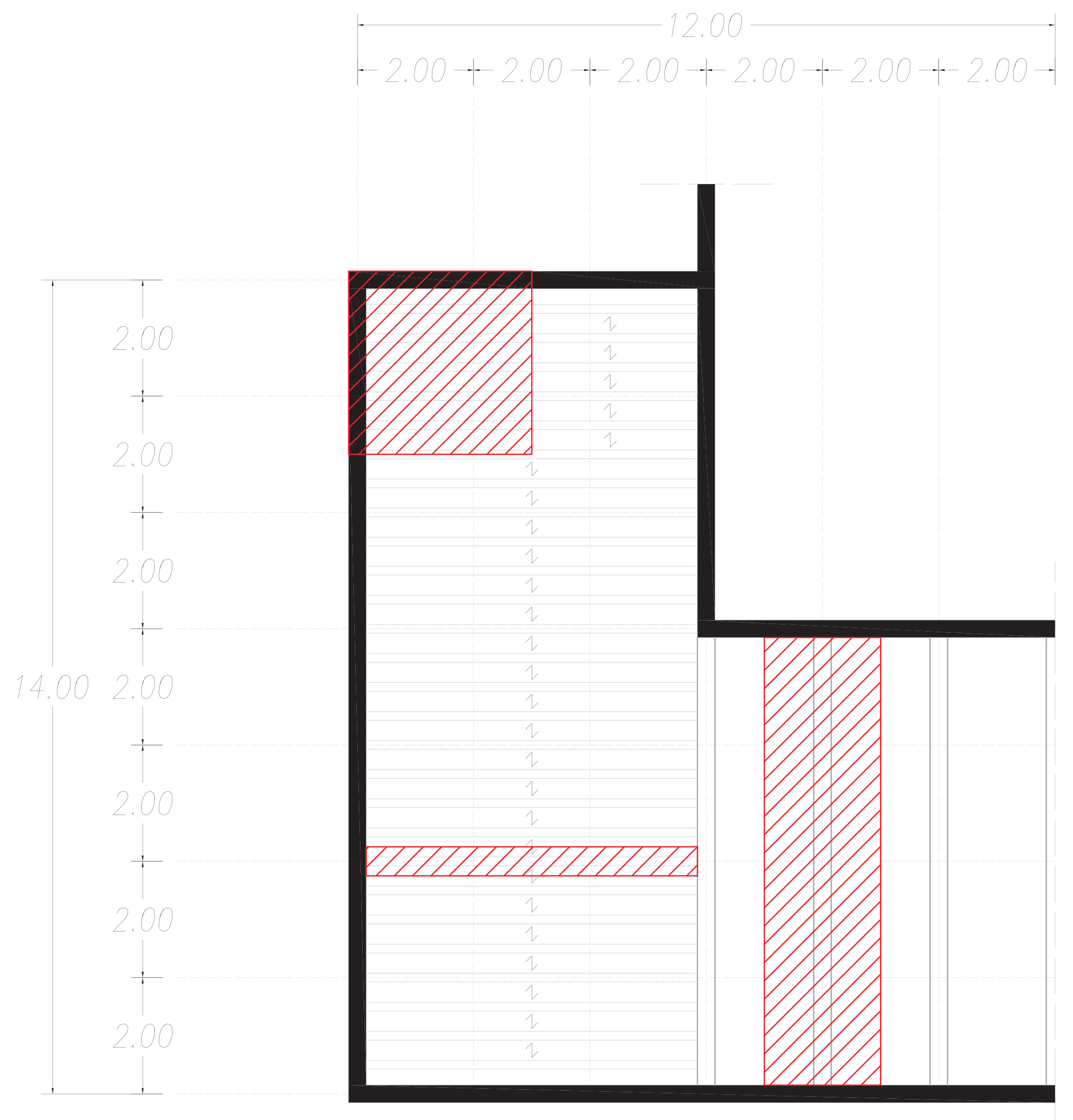
LEVEL -01 STRUCTURAL PLAN 1 : 200



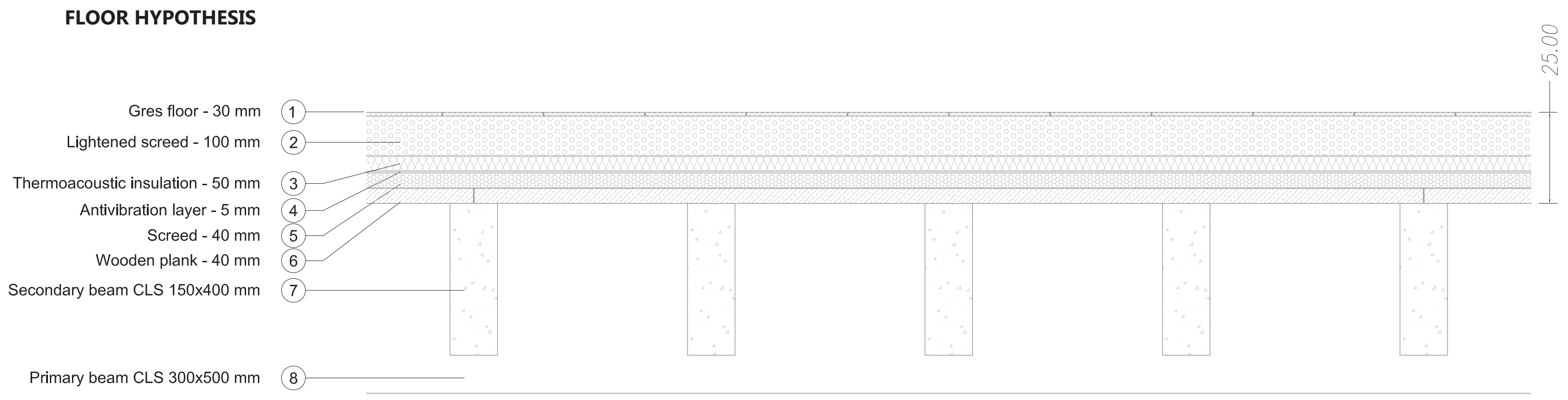
LEVEL 00 STRUCTURAL PLAN 1 : 200

Music Hall Structural Analysis

PLAN AND TRIBUTARY AREA



FLOOR HYPOTHESIS



FLOOR WEIGHT

Material		Weight in Kg/m3	Thickness in mm	Thickness in m	Weight in Kg/m3	TOTAL weight in kN/m2
Gres	1	/	10	0.01	24	4.67
Lightened screed	2	1200	100	0.1	120	
Thermoacoustic insulation	3	250	50	0.05	12.5	**Dead Loads**
Antivibration layer	4	/	5	0.01	6	4.67
Screed	5	2000	40	0.04	80	
Wooden plank	6	750	40	0.04	30	**Live Loads**
Primary beams	7	/	500	0.5		NCT 2018 cat. C2 = 4
Secondary beams	8	/	400	0.4		

COMPUTATIONS - SECONDARY BEAMS

DATA

Beam: IPE 220

Span (L) = $6\,m$

Spacing (l) = $0.5\,m$

Dead Loads (G) = $4.67\,\frac{kN}{m^2}$

Live Loads (Q) = $4\,\frac{kN}{m^2}$

ULS (Ultimate Limit State)

$$q_{ULS} = \gamma_g \times G + \gamma_q \times Q \rightarrow q_{ULS} = 1.35 \times 4.67\,\frac{kN}{m^2} + 1.5 \times 4\,\frac{kN}{m^2} = 12.31\,\frac{kN}{m^2}$$

$$q_{linear} = q_{ULS} \times l \rightarrow q_{linear} = 12.31\,\frac{kN}{m^2} \times 0.5\,m = 6.16\,\frac{kN}{m}$$

$$M_d = \frac{q_{linear} \times L^2}{8} \rightarrow M_d = \frac{6.16\,\frac{kN}{m}(6\,m)^2}{8} = 27.72\,kNm$$

$$V_d = \frac{1}{2} \times q_{linear} \times l \rightarrow V_d = \frac{1}{2} \times 6.16\,\frac{kN}{m} \times 6\,m = 18.48\,kN$$

ULS (Ultimate Limit State)

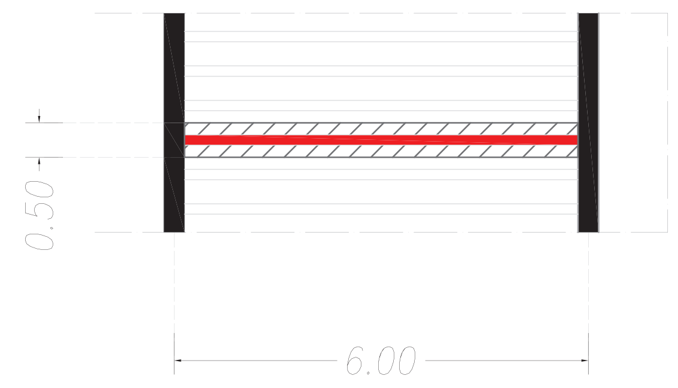
DEFLACTION RESISTANCE CHECK (Total load)

$$q_{SLS} = G + Q \rightarrow q_{SLS} = 4.67\,\frac{kN}{m^2} + 4\,\frac{kN}{m^2} = 8.67\,\frac{kN}{m^2}$$

$$q_{linear} = q_{SLS} \times l \rightarrow q_{linear} = 8.67\,\frac{kN}{m^2} \times 0.5\,m = 4.34\,\frac{kN}{m}$$

$$\eta_d = \frac{5qL^4}{384EI} \rightarrow \eta_d = \frac{5}{384}\,\frac{4.34\frac{kN}{m}\times(6\,m)^4}{210000000\frac{kN}{m^2}\times 0.00002772\text{ m4}} = 0.0126\,m = 1.26\,cm$$

SECONDARY BEAM AND TRIBUTARY AREA



COMPUTATIONS - SECONDARY BEAMS

DATA

Beam: IPE 220

Span (L) = $6\,m$

Spacing (l) = $0.5\,m$

Dead Loads (G) = $4.67\,\frac{kN}{m^2}$

Live Loads (Q) = $4\,\frac{kN}{m^2}$

Safety coefficient – DL (γ_g) = 1.35

Safety coefficient – LL (γ_q) = 1.5

Young's Module (E) = $21000\,\frac{N}{mm^2}$

ULS (Ultimate Limit State)

$$q_{ULS} = \gamma_g \times G + \gamma_q \times Q \rightarrow q_{ULS} = 1.35 \times 4.67\,\frac{kN}{m^2} + 1.5 \times 4\,\frac{kN}{m^2} = 12.31\,\frac{kN}{m^2}$$

$$q_{linear} = q_{ULS} \times l \rightarrow q_{linear} = 12.31\,\frac{kN}{m^2} \times 0.5\,m = 6.16\,\frac{kN}{m}$$

$$M_d = \frac{q_{linear} \times L^2}{8} \rightarrow M_d = \frac{6.16\,\frac{kN}{m}(6\,m)^2}{8} = 27.72\,kNm$$

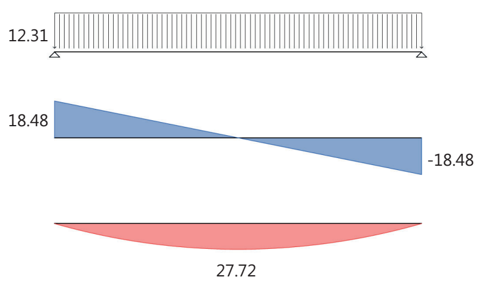
$$V_d = \frac{1}{2} \times q_{linear} \times l \rightarrow V_d = \frac{1}{2} \times 6.16\,\frac{kN}{m} \times 6\,m = 18.48\,kN$$

BENDING MOMENT RESISTANCE CHECK

$$M_r = \frac{W_{pl} \times f_{yk}}{\gamma_m} \rightarrow M_r = \frac{285000\,mm^3 \times 235\frac{N}{mm^2}}{1.05} = 63.79\,kNm$$

$$\frac{M_d}{M_r} \leq 1 = \frac{27.72\,kNm}{63.79\,kNm} = 0.44 \leq 1 \rightarrow verified$$

INTERNAL ACTION DIAGRAM



SHEAR RESISTANCE CHECK

$$V_r = \frac{A_v \times f_{yk}}{\gamma_m \times \sqrt{3}} \rightarrow V_r = \frac{1590\,mm^2 \times 235\frac{N}{mm^2}}{1.05 \times \sqrt{3}} = 205.45\,kN$$

$$\frac{V_d}{V_r} \leq 1 = \frac{18.48\,kN}{205.45\,kN} = 0.09 \leq 1 \rightarrow verified$$

ULS (Ultimate Limit State)

DEFLACTION RESISTANCE CHECK (Total load)

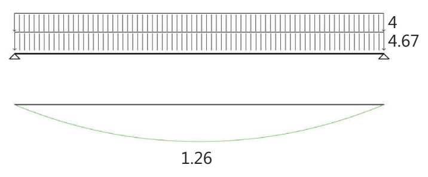
$$q_{SLS} = G + Q \rightarrow q_{SLS} = 4.67\,\frac{kN}{m^2} + 4\,\frac{kN}{m^2} = 8.67\,\frac{kN}{m^2}$$

$$q_{linear} = q_{SLS} \times l \rightarrow q_{linear} = 8.67\,\frac{kN}{m^2} \times 0.5\,m = 4.34\,\frac{kN}{m}$$

$$\eta_d = \frac{5qL^4}{384EI} \rightarrow \eta_d = \frac{5}{384}\,\frac{4.34\frac{kN}{m}\times(6\,m)^4}{210000000\frac{kN}{m^2}\times 0.00002772\text{ m4}} = 0.0126\,m = 1.26\,cm$$

$$\eta_r = \frac{l}{250} \rightarrow \eta_r = \frac{6\,m}{250} = 0.024\,m = 2.4\,cm$$

$$\eta_d \leq \eta_r = 1.26\,cm \leq 2.4\,cm \rightarrow verified$$



DEFLACTION RESISTANCE CHECK (Live load only)

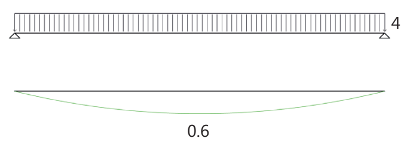
$$q = Q = 2\,\frac{kN}{m^2}$$

$$q_{linear} = Q \times l \rightarrow q_{linear} = 4\,\frac{kN}{m^2} \times 0.5\,m = 2\,\frac{kN}{m}$$

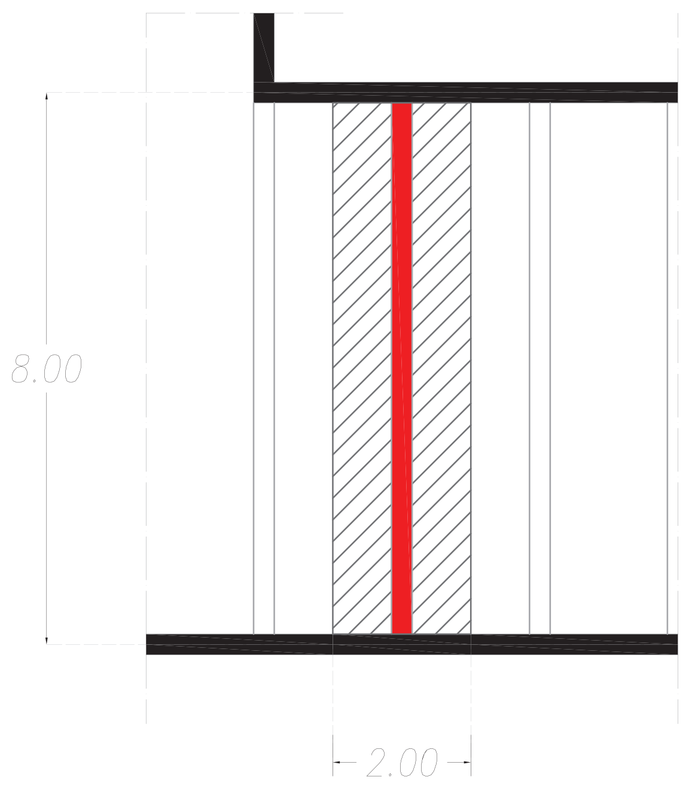
$$\eta_d = \frac{5qL^4}{384EI} \rightarrow \eta_d = \frac{5}{384}\,\frac{2\frac{kN}{m}\times(6\,m)^4}{210000000\frac{kN}{m^2}\times 0.00002772\text{ m4}} = 0.006\,m = 0.6\,cm$$

$$\eta_r = \frac{l}{300} \rightarrow \eta_r = \frac{6\,m}{300} = 0.02\,m = 2\,cm$$

$$\eta_d \leq \eta_r = 0.6\,cm \leq 2\,cm \rightarrow verified$$



PRIMARY BEAM AND TRIBUTARY AREA



COMPUTATIONS - PRIMARY BEAMS

DATA

Beam: IPE 500

Span (L) = $8\,m$

Spacing (l) = $6\,m$

Dead Loads (G) = $4.67\,\frac{kN}{m^2}$

Live Loads (Q) = $4\,\frac{kN}{m^2}$

Safety coefficient – DL (γ_g) = 1.35

Safety coefficient – LL (γ_q) = 1.5

Young's Module (E) = $21000\,\frac{N}{mm^2}$

ULS (Ultimate Limit State)

$$q_{ULS} = \gamma_g \times G + \gamma_q \times Q \rightarrow q_{ULS} = 1.35 \times 4.67\,\frac{kN}{m^2} + 1.5 \times 4\,\frac{kN}{m^2} = 12.31\,\frac{kN}{m^2}$$

$$q_{linear} = q_{ULS} \times l \rightarrow q_{linear} = 12.31\,\frac{kN}{m^2} \times 6\,m = 73.86\,\frac{kN}{m}$$

$$M_d = \frac{q_{linear} \times L^2}{10} \rightarrow M_d = \frac{73.86\,\frac{kN}{m}(8\,m)^2}{10} = 472.04\,kNm$$

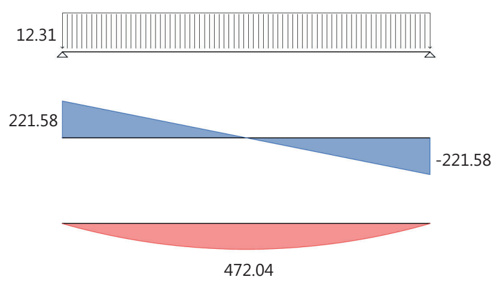
$$V_d = \frac{1}{2} \times q_{linear} \times l \rightarrow V_d = \frac{1}{2} \times 73.86\,\frac{kN}{m} \times 6\,m = 221.58\,kN$$

BENDING MOMENT RESISTANCE CHECK

$$M_r = \frac{W_{pl} \times f_{yk}}{\gamma_m} \rightarrow M_r = \frac{2194000\,mm^3 \times 235\frac{N}{mm^2}}{1.05} = 491.03\,kNm$$

$$\frac{M_d}{M_r} \leq 1 = \frac{472.04\,kNm}{491.03\,kNm} = 0.96 \leq 1 \rightarrow verified$$

INTERNAL ACTION DIAGRAM



SHEAR RESISTANCE CHECK

$$V_r = \frac{A_v \times f_{yk}}{\gamma_m \times \sqrt{3}} \rightarrow V_r = \frac{5090\,mm^2 \times 235\frac{N}{mm^2}}{1.05 \times \sqrt{3}} = 657.71\,kN$$

$$\frac{V_d}{V_r} \leq 1 = \frac{221.58\,kN}{657.71\,kN} = 0.34 \leq 1 \rightarrow verified$$

ULS (Ultimate Limit State)

DEFLACTION RESISTANCE CHECK (Total load)

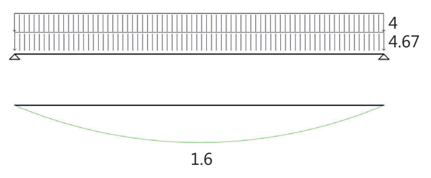
$$q_{SLS} = G + Q \rightarrow q_{SLS} = 4.67\,\frac{kN}{m^2} + 4\,\frac{kN}{m^2} = 8.67\,\frac{kN}{m^2}$$

$$q_{linear} = q_{SLS} \times l \rightarrow q_{linear} = 8.67\,\frac{kN}{m^2} \times 6\,m = 52.02\,\frac{kN}{m}$$

$$\eta_d = \frac{3qL^4}{384EI} \rightarrow \eta_d = \frac{3}{384}\,\frac{52.02\,\frac{kN}{m}\times(8\,m)^4}{210000000\frac{kN}{m^2}\times 0.00048200\,m^4} = 0.016\,m = 1.6\,cm$$

$$\eta_r = \frac{l}{250} \rightarrow \eta_r = \frac{6\,m}{250} = 0.024\,m = 2.4\,cm$$

$$\eta_d \leq \eta_r = 0.016\,m \leq 0.024\,m \rightarrow verified$$



DEFLACTION RESISTANCE CHECK (Live load only)

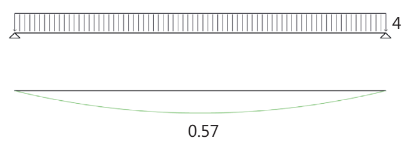
$$q = Q = 4\,\frac{kN}{m^2}$$

$$q_{linear} = Q \times l \rightarrow q_{linear} = 4\,\frac{kN}{m^2} \times 6\,m = 18\,\frac{kN}{m}$$

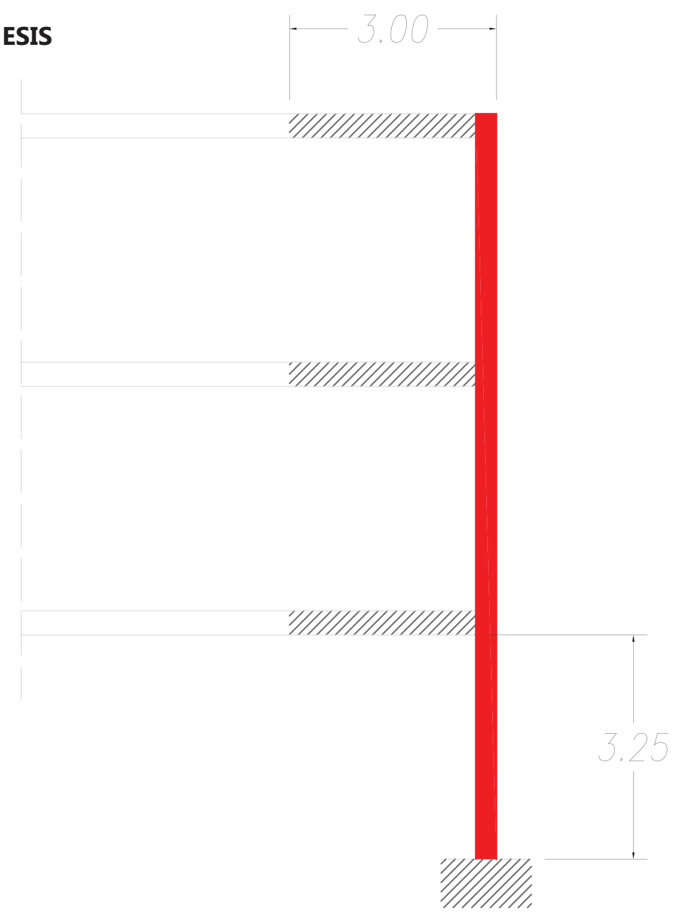
$$\eta_d = \frac{3qL^4}{384EI} \rightarrow \eta_d = \frac{3}{384}\,\frac{18\,\frac{kN}{m}\times(8\,m)^4}{210000000\,\frac{kN}{m^2}\times 0.00048200\,m^4} = 0.0057\,m = 0.57\,cm$$

$$\eta_r = \frac{l}{300} \rightarrow \eta_r = \frac{6\,m}{300} = 0.02\,m = 2\,cm$$

$$\eta_d \leq \eta_r = 0.57\,cm \leq 2\,cm \rightarrow verified$$



COLUMN HYPOTHESIS



COLUMN HYPOTHESIS

$$q_{ULS} = \gamma_g\ x\ G + \gamma_q\ x\ Q \rightarrow q_{ULS} = 1.3\ x\ 7.73\,\frac{kN}{m^2} + 1.5\ x\ 4\,\frac{kN}{m^2} = 16.05\,\frac{kN}{m^2}$$

Overall axial load acting on the column $N_{sd} = q_{ULS} * A \rightarrow N_{sd} = 16.05\,\frac{kN}{m^2}\ x\ 9\,m^2 = 144.45\,kN$

Chosen concrete → $C\ 40/50$

Pillar height (H) = $30\,cm = 0.3\,m$

Pillar base (B) = $30\,cm = 0.3\,m$

Pillar Area (A) = $b\ x\ h = (0.3\,m)x(0.3\,m) = 0.09\,m^2$

Pillar total height (h) = $3.25\,m$

Inertia radius $i = \frac{h}{\sqrt{12}}$ for rectangular section

Effective slenderness $\lambda_{eff} = \frac{l_0}{i} = \frac{l_0}{\frac{h}{\sqrt{12}}} = \frac{\sqrt{12} * l_0}{h} = \frac{\sqrt{12} * 325}{50} = 22.51$

Limit slenderness $\lambda_{limit} = \frac{20}{n} = \frac{20}{\frac{N_d}{A * fcd}} = \frac{20}{\frac{103765\,daN}{50^2 * 22.67}} = 41.64$

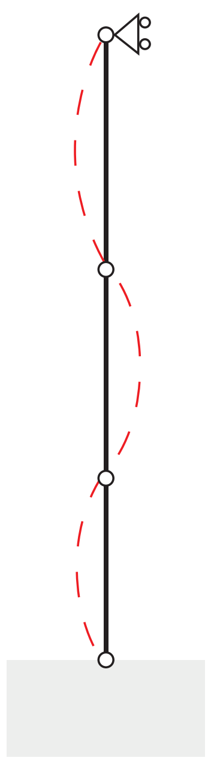
$\lambda_{eff} \leq \lambda_{limit} \rightarrow \omega = 1{,}0$

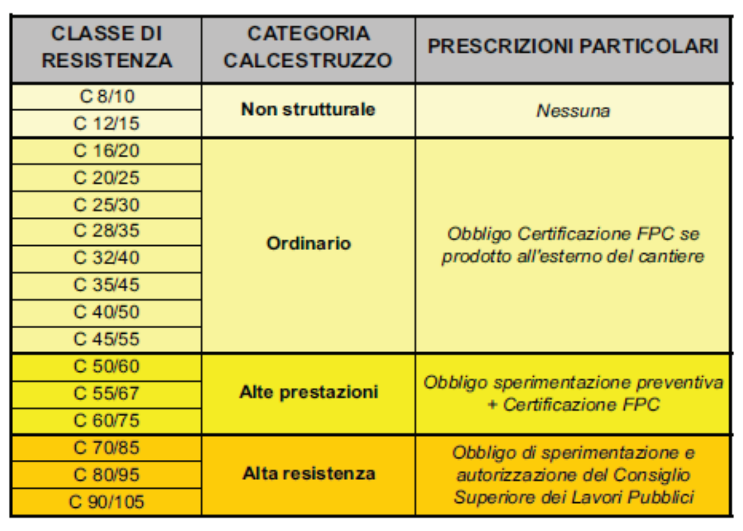
Acting Stress $\sigma = \frac{N}{\omega * A} = \frac{144.45\ x\ 100\,daN}{1\ x\ 50^2 cm^2} = 5.78\,\frac{daN}{cm^2}$

$R_{ck} = 300\,\frac{daN}{cm^2}$

Design stress $\sigma_{amm} = 0{,}7 * \left(60 + \frac{Rck - 150}{4}\right) = 0{,}7 * \left(60 + \frac{300 - 150}{4}\right) = 68.25\,\frac{daN}{cm^2}$

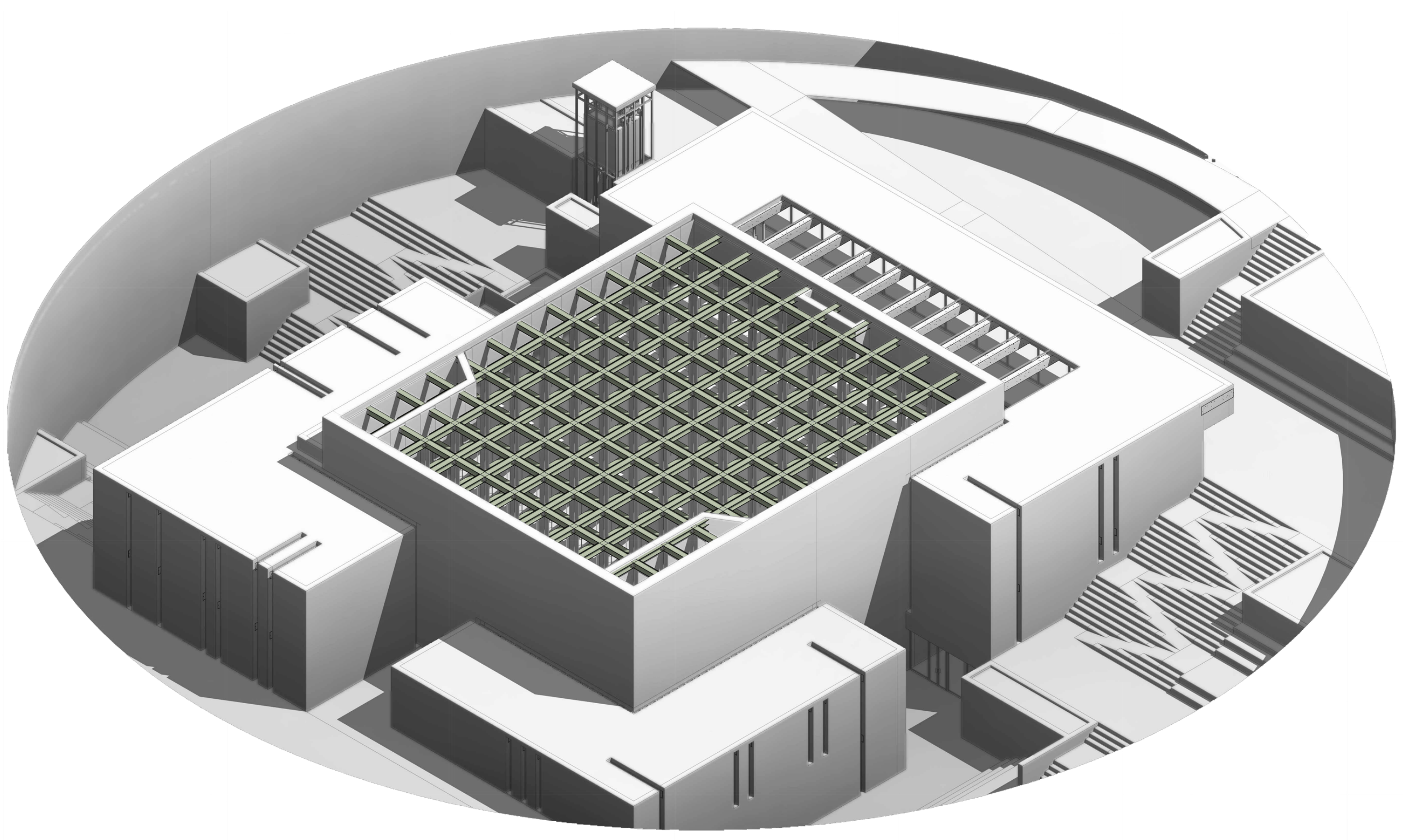
$\sigma \leq \sigma_{amm} \rightarrow 5.78\,\frac{daN}{cm^2} \leq 68.25\,\frac{daN}{cm^2} \rightarrow verified$





CLASSE DI RESISTENZA	CATEGORIA CALCESTRUZZO	PRESCRIZIONI PARTICOLARI
C 8/10	**Non strutturale**	*Nessuna*
C 12/15		
C 16/20	**Ordinario**	*Obbligo Certificazione FPC se prodotto all'esterno del cantiere*
C 20/25		
C 25/30		
C 28/35		
C 32/40		
C 35/45		
C 40/50		
C 45/55		
C 50/60	**Alte prestazioni**	*Obbligo sperimentazione preventiva + Certificazione FPC*
C 55/67		
C 60/75		
C 70/85	**Alta resistenza**	*Obbligo di sperimentazione e autorizzazione del Consiglio Superiore dei Lavori Pubblici*
C 80/95		
C 90/105		

Music Hall Structural Analysis



Structural Validation Through FEM Analysis

A finite element structural analysis of the theatre roof trusses was conducted in MIDAS Gen to evaluate the performance of the proposed steel grid under realistic loading conditions. The study assessed global deformation, stress distribution, and code compliance at both Serviceability (SLS) and Ultimate Limit States (ULS).

To evaluate material efficiency and structural performance of the auditorium roof structure, three separate analyses were performed under identical geometry, loading conditions, and boundary constraints while varying the steel beam profiles.

-HEB 300: Very low stress ratios and minimal deflection, structurally safe but significantly oversized and materially inefficient.

-IPE 160: High stress ratios approaching 1.0 at ULS and excessive deflection at SLS, structurally critical and insufficient.

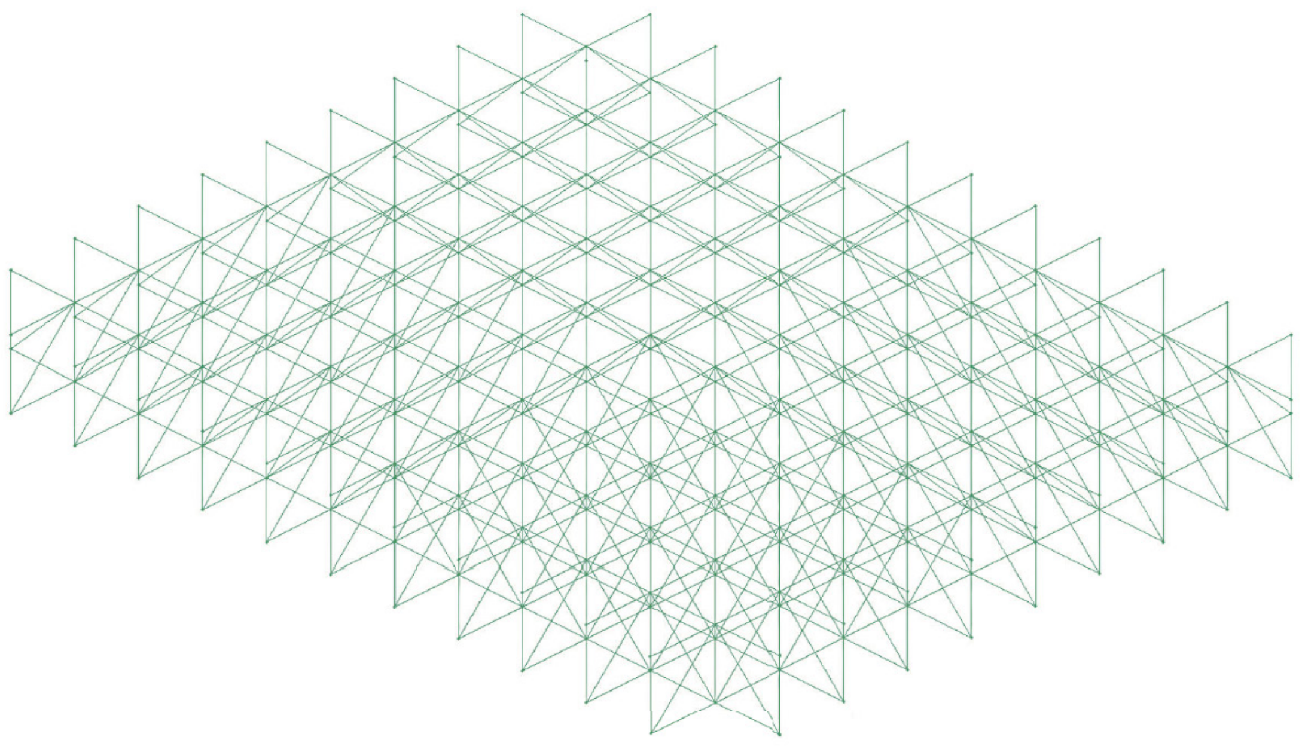
-HEA 160: Best beam option with balanced performance with acceptable SLS deflections and safe ULS stress utilization.

The HEA 160 profile was therefore selected as the optimal compromise between structural safety and material efficiency.

Modeling Process

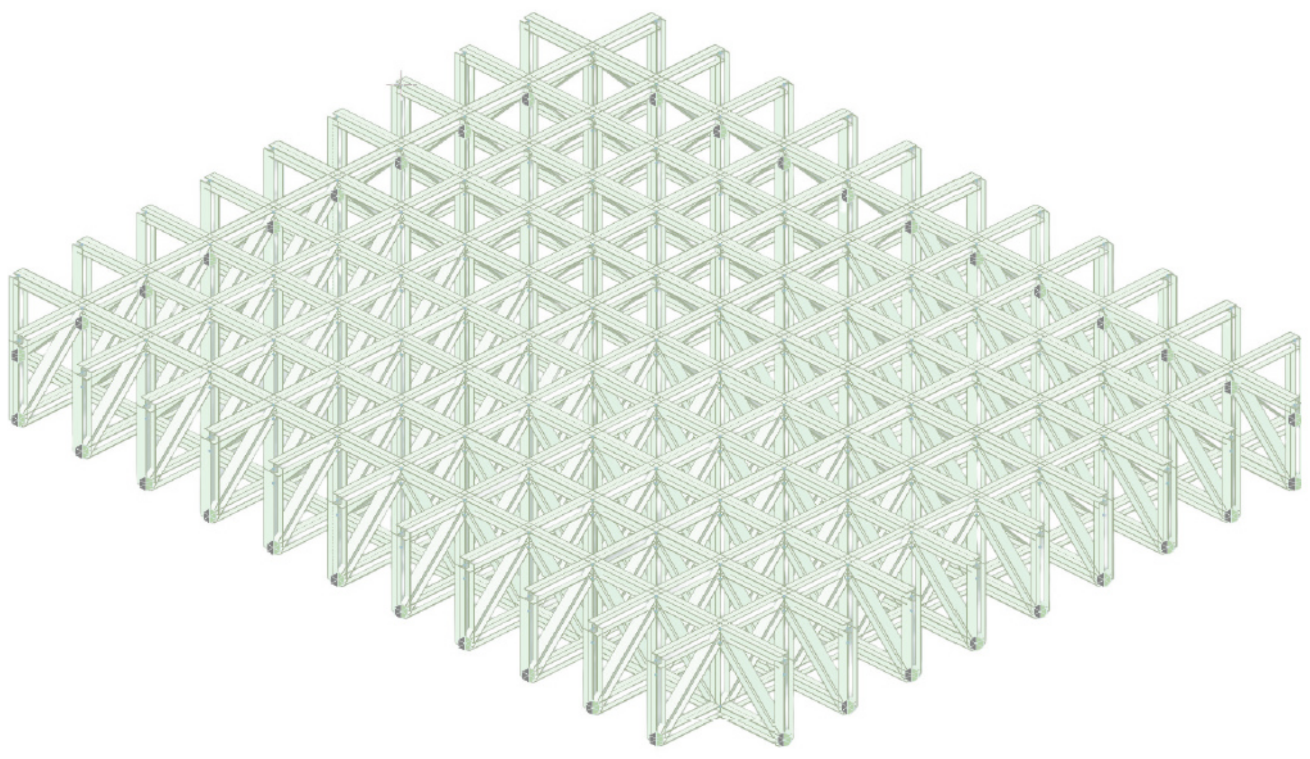
Importing Elements Into MIDAS

The structural geometry was exported as a DXF from Revit and simplified into beam centerlines before import to ensure the analytical model accurately matched the design geometry, with continuous nodes and no element discontinuities.



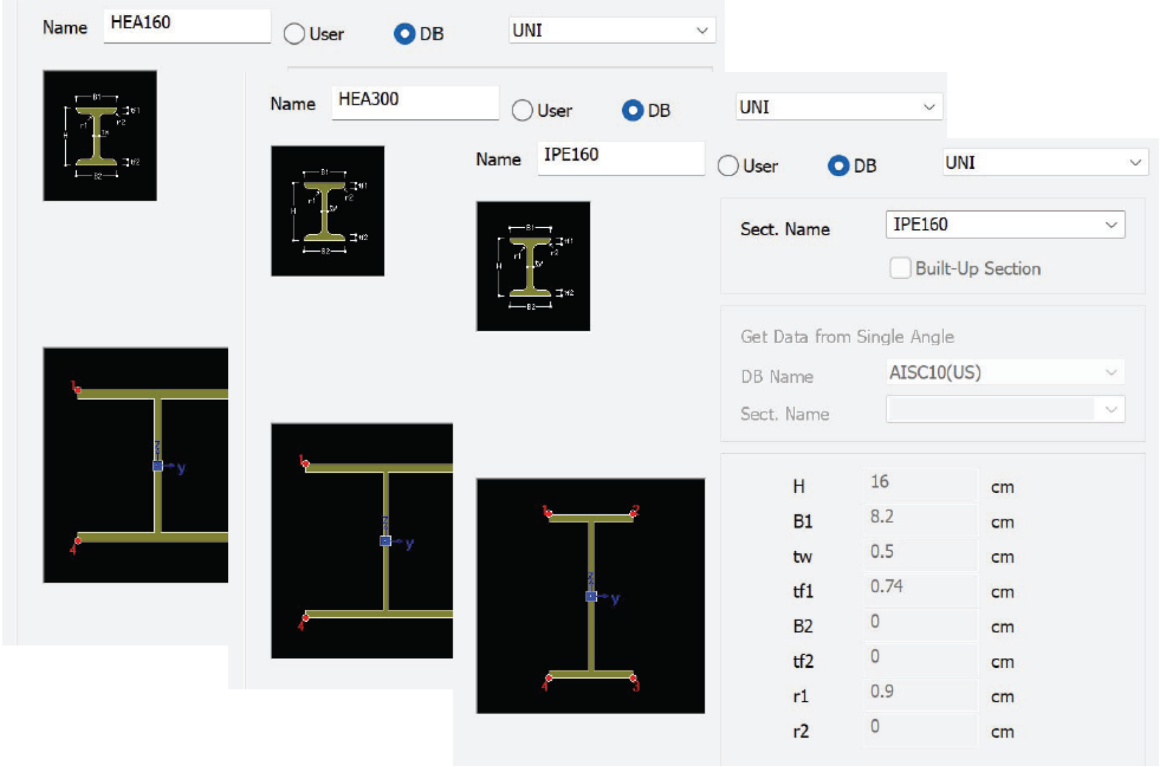
Selecting Boundary Conditions

The structural geometry was exported as a DXF from Revit and simplified into beam centerlines before import to ensure the analytical model accurately matched the design geometry, with continuous nodes and no element discontinuities.



Defining Materials And Sections

*S275 structural steel was assigned to the model and three beam profiles (**HEB 300, IPE 160,** and **HEA 160**) were tested to compare the structural behavior of different cross-sections and dimensions under identical loading and boundary conditions.*



Name: HEA160 ○ User ● DB UNI

Name: HEA300 ○ User ● DB UNI

Name: IPE160 ○ User ● DB UNI

Sect. Name: IPE160

☐ Built-Up Section

Get Data from Single Angle

DB Name: AISC10(US)

Sect. Name:

H	16	cm
B1	8.2	cm
tw	0.5	cm
tf1	0.74	cm
B2	0	cm
tf2	0	cm
r1	0.9	cm
r2	0	cm

Defining Loads In MIDAS

Dead loads (self-weight of structural elements) and live loads (imposed loads from auditorium use) were defined and applied, with self-weight activated, to accurately represent permanent and variable actions and enable correct generation of SLS and ULS load combinations.

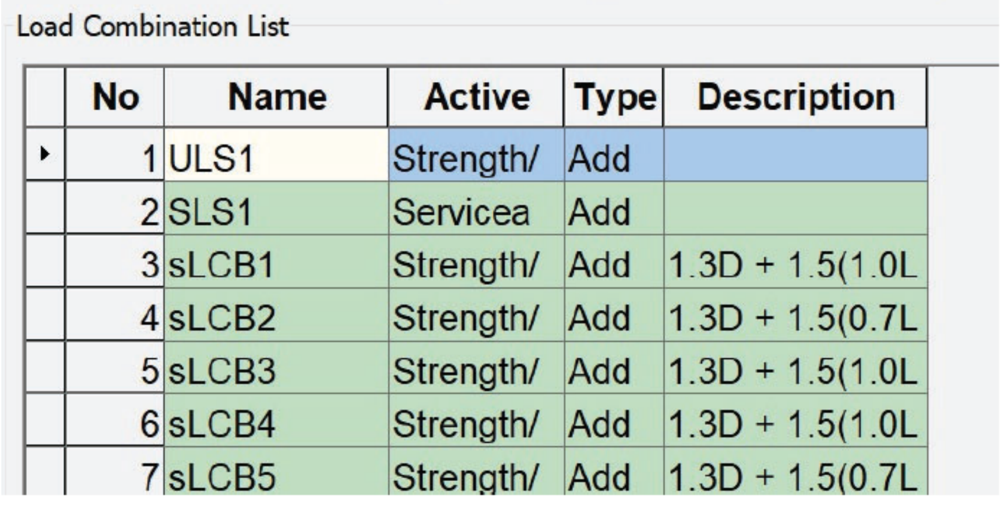
Layer	Spessore	Densità (kg/m³)	γ (kN/m³)	Carico q (kN/m²)
Gravel	0,020 m	2000	19,62	0,392
Asphalt	0,010 m	2400	23,54	0,235
thermal layer	0,040 m	30	0,294	0,012
Substrate concrete/sabbia	0,030 m	2500	25	0,75
Pannelli fonoassorbenti	x			0,196
Impianti / luci (allowance)	x			0,5
			DLtotale	2,085

Carichi nodali su maglia 2,00 × 2,00 m
DEAD LOADS
Nodo interno (area trib. = 4,0 m²)
F interno=−4.0×2,085=−8,34 kN
Nodo bordo (area trib. = 2,0 m²)
F bordo=−2.0×2,085=−4,17 kN

LIVE LOADS
LL1-manutenzione- q=0.50 kN/m²
F interno=−4.0×0,50=−2,00 kN
F bordo=−2.0×0,50=−1,00 kN
LL2-carico temporaneo pesante - q=1.50 kN/m²
F interno=−4.0×1,50=−6,00 kN
F bordo=−2.0×1,50=−3,00 kN

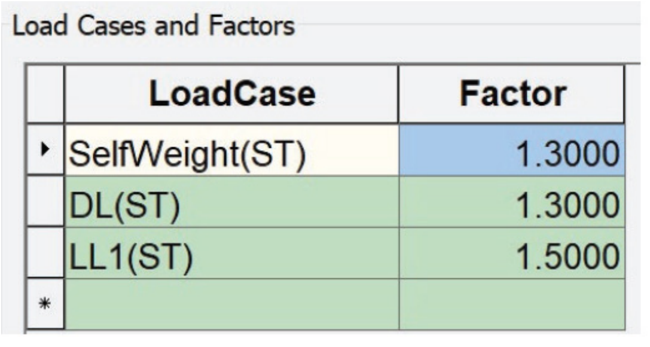
Defining Load Combinations

Serviceability (SLS) and Ultimate (ULS) load combinations were defined to evaluate both displacement and strength performance, with SLS calculated as DL + LL using unit load factors to verify deflections, and ULS calculated as 1.3·DL + 1.5·LL to verify structural capacity and overall safety.



Load Combination List

No	Name	Active	Type	Description
1	ULS1	Strength/	Add	
2	SLS1	Servicea	Add	
3	sLCB1	Strength/	Add	1.3D + 1.5(1.0L
4	sLCB2	Strength/	Add	1.3D + 1.5(0.7L
5	sLCB3	Strength/	Add	1.3D + 1.5(1.0L
6	sLCB4	Strength/	Add	1.3D + 1.5(1.0L
7	sLCB5	Strength/	Add	1.3D + 1.5(0.7L



Load Cases and Factors

LoadCase	Factor
SelfWeight(ST)	1.3000
DL(ST)	1.3000
LL1(ST)	1.5000
*	

Results

FEM calculations were carried out to evaluate global displacements, deformed shape, and overall structural behavior under Serviceability Limit State (SLS) conditions, confirming realistic deformation patterns and proper performance of the hinged support assumptions. A steel code compliance verification was subsequently conducted at Ultimate Limit State (ULS), comparing the three beam scenarios. The HEB 300 exhibited very low stress ratios, indicating significant oversizing and unnecessary material use, while the IPE 160 approached unity stress ratios and excessive deflection, proving structurally insufficient

.

The HEA 160 demonstrated balanced stress utilization and acceptable displacement behavior, satisfying both serviceability and ultimate safety requirements without excess material. It therefore emerged as the optimal structural solution, achieving the best compromise between safety, stiffness, and material efficiency.

All results were compiled and systematically compared to document the analytical process and provide a transparent, evidence-based justification for the final section selection.

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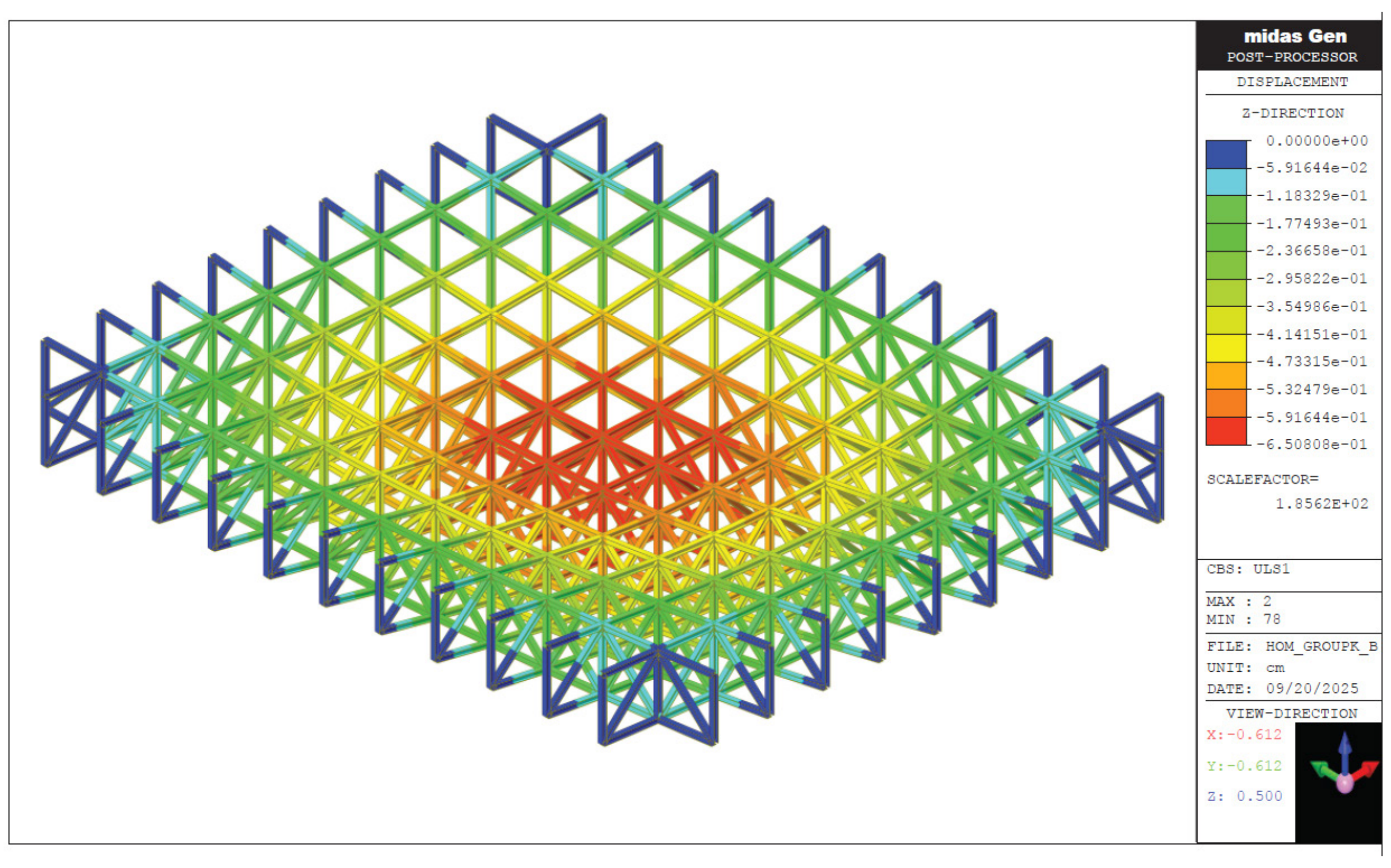
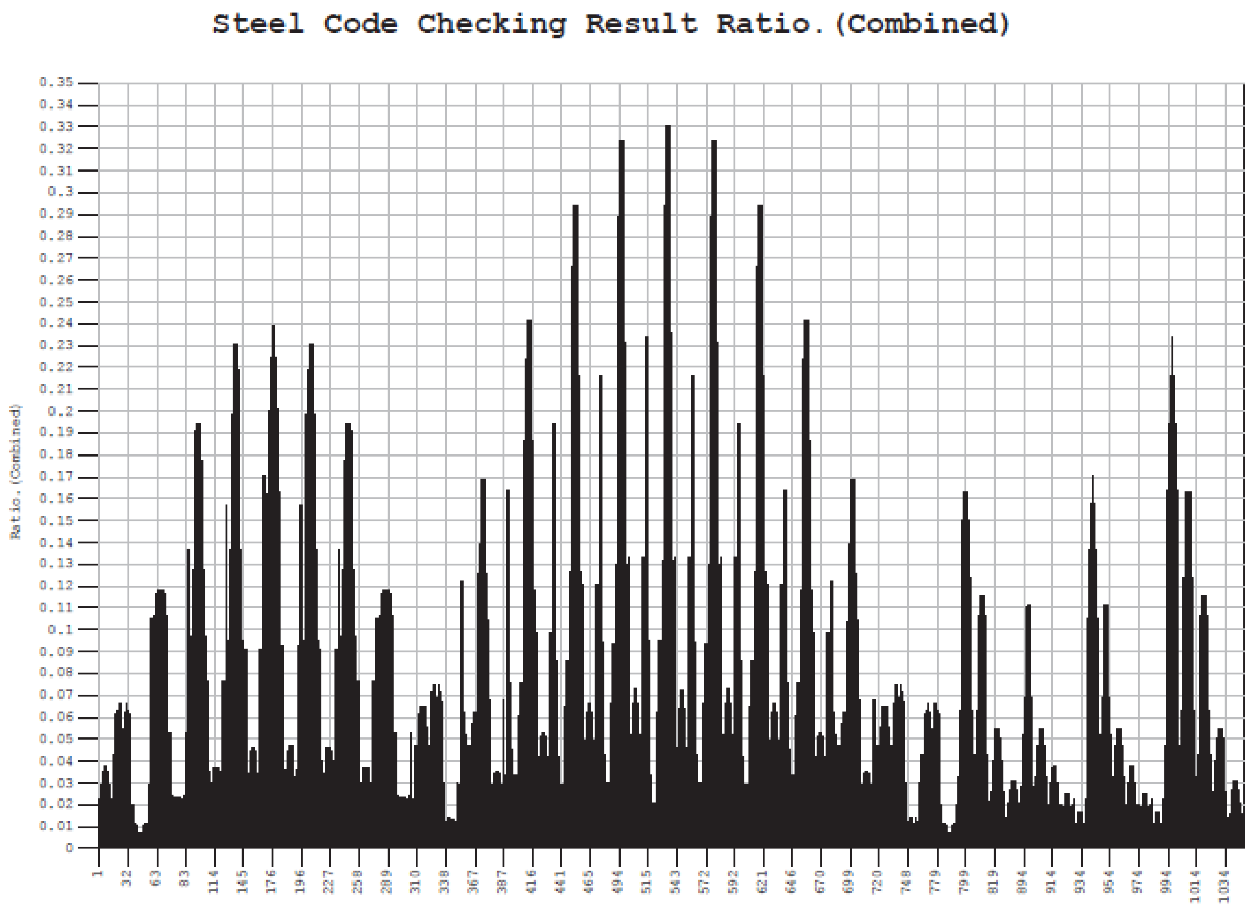




SECTION	HEIGHT	TOTAL WEIGHT (kN)	MAX DISPLACEMENT SLS(mm)	STRESS RATIO (ULS)	EFFICIENCY	ASSESSMENT
HEB300	300	1536,6	3,5	0,137	VERY LOW	OVERSIZED
HEA160	160	992,4	6,5	0,33	BALANCED	OPTIMAL
IPE160	160	273,4	10,5	0,99	CRITICAL	UNSAFE

Music Hall Mechanical System

Based on rule-of-thumb sizing, the main supply and return ductwork requires 6 m² of total area. This is provided by four underground ducts (two supply, two return), each measuring 1.0 m × 2.0 m, operating at an air velocity of approximately 12.0 m/s. While this velocity is relatively high, placing the ducts underground allows for improved acoustic insulation and limits noise transmission into the performance spaces. The branch supply and return system accounts for an additional 10 m² of duct area. Air is distributed through approximately 100 smaller ducts measuring 40 cm × 20 cm, operating at a reduced velocity of 6.0 m/s to maintain acoustic comfort within occupied areas. The total mechanical space amounts to 468 m², slightly exceeding rule-of-thumb estimates, reflecting allowances for acoustic performance and spatial integration.

Air distribution in the main performance hall uses a displacement ventilation strategy, supplying conditioned air through under-seat diffusers and extracting warm air at ceiling level. Heat and contaminants generated by occupants rise naturally and are removed through concealed high-level returns, supporting thermal comfort, acoustic control, and minimal visual impact.

Benefits of the System:

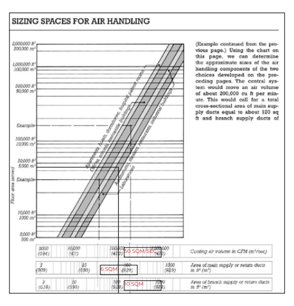
1. Temperature control:
In audience seating areas as air is directly supplied under the seats. With this design, drafts and under-seat cold air are eliminated, and the warmer air layers are allowed to rise above head level.

2. Energy saving:
Heating and cooling are only provided to the lower occupied zone instead of the entire hall volume, which lowers the operational energy use by the system.

3. Acoustic comfort:
The performance of the hall and the system are not compromised by air movement as low-velocity delivery minimizes movement noise and maintains the cabin quiet.

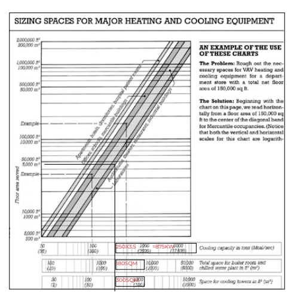
4. Discreet integration:
All seating and ceiling orthogonal surfaces incorporate the system, thus preserving Architectural Expression and Sightline Intactness.

5. Improved air quality:
Audience-related contaminants and heat are removed and discharged at the ceiling level, preserving air quality and comfort during extended bouts.



SIZING SPACES FOR AIR HANDLING

(Example continued from the previous page.) Using the chart on this page, we can determine the approximate sizes of the air handling components of the two choices developed on the preceding pages. The central system would move an air volume of about 200,000 cu ft per minute. This would call for a total cross-sectional area of main supply ducts equal to about 120 sq ft and branch supply ducts of

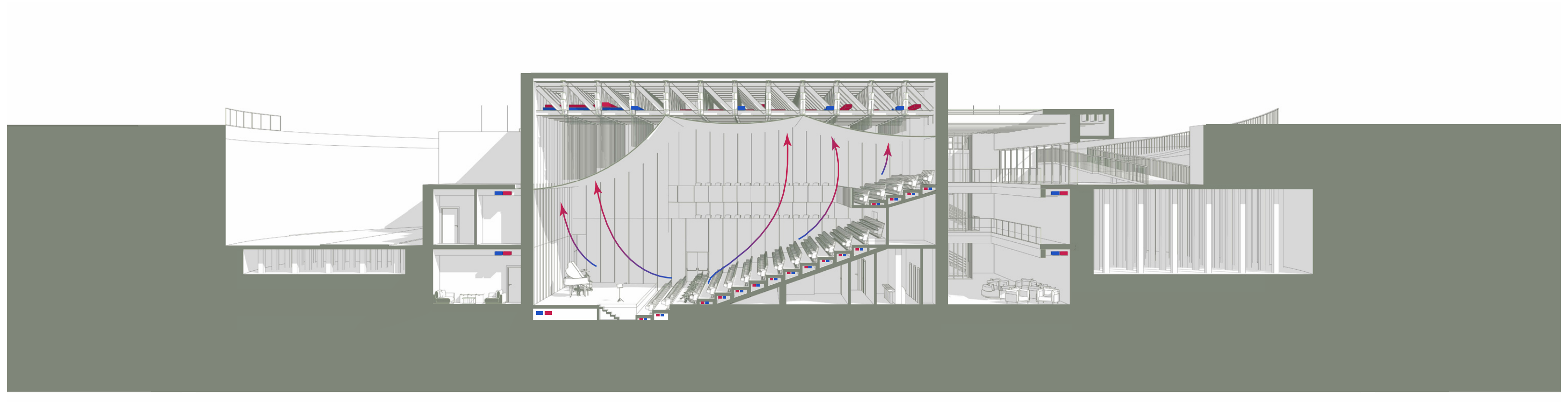


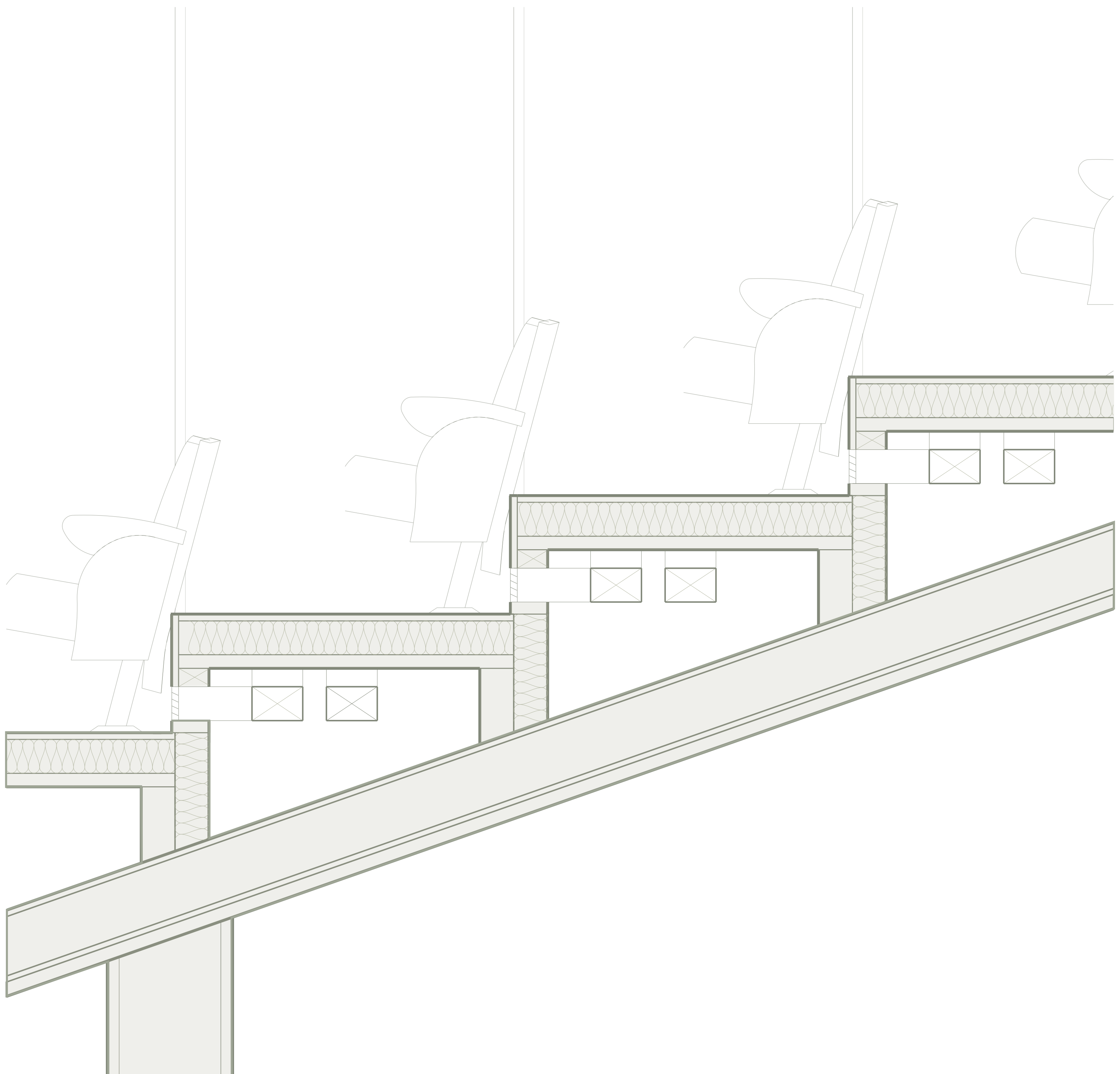
SIZING SPACES FOR MAJOR HEATING AND COOLING EQUIPMENT

AN EXAMPLE OF THE USE OF THESE CHARTS

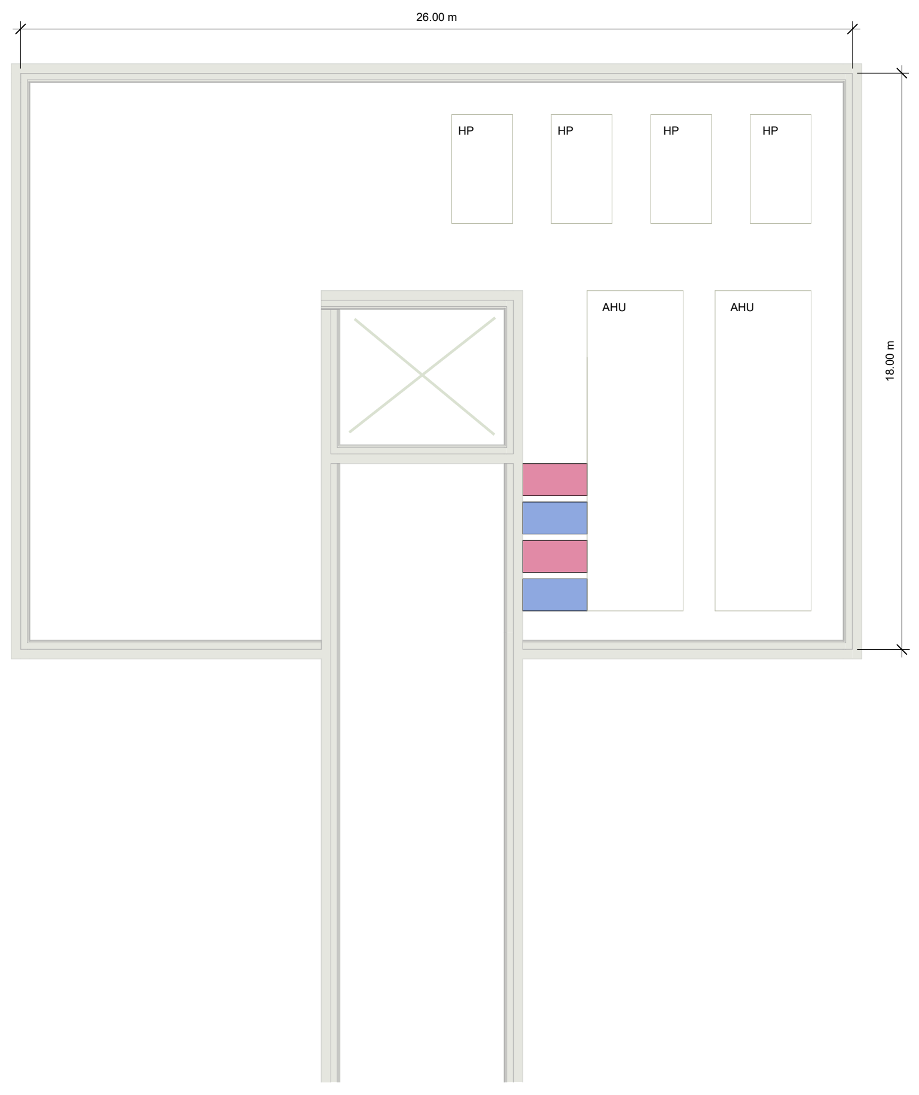
The Problem: Rough out the necessary spaces for VAV heating and cooling equipment for a department store with a total net floor area of 150,000 sq ft.

The Solution: Beginning with the chart on this page, we read horizontally from a floor area of 150,000 sq ft to the center of the diagonal band for Mercantile occupancies. (Notice that both the vertical and horizontal scales for this chart are logarith-





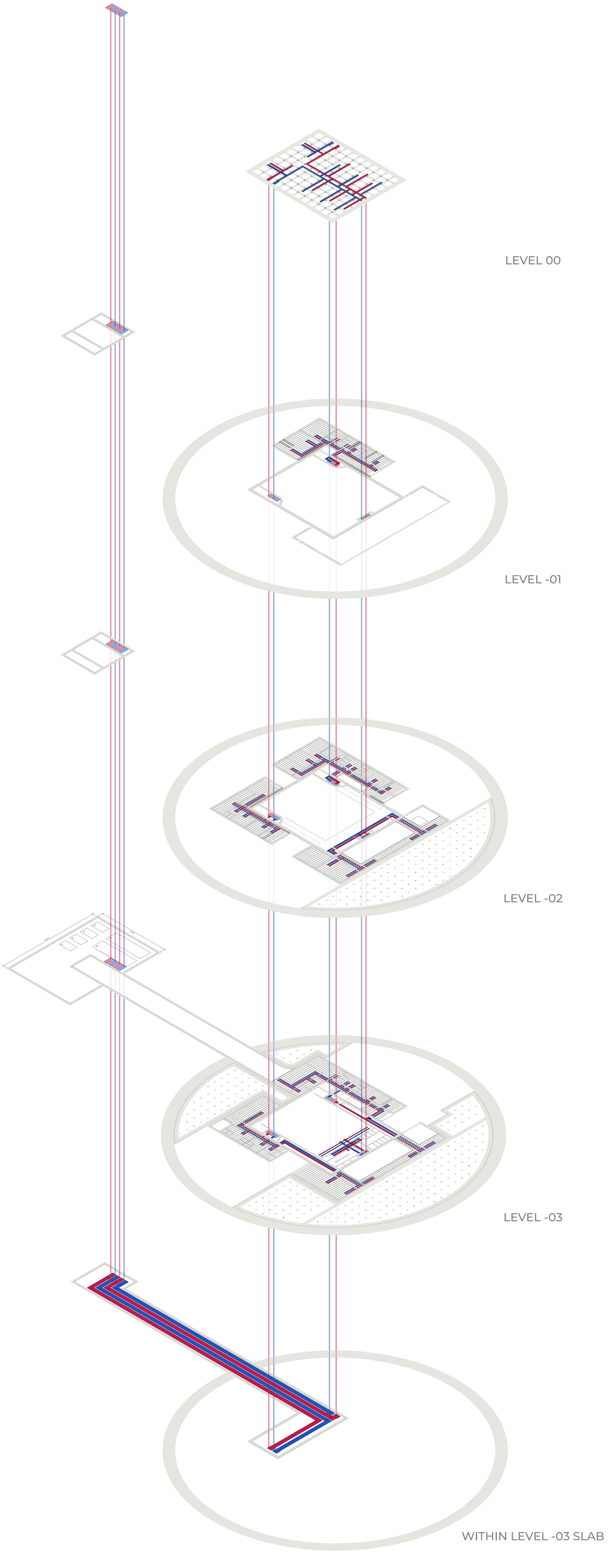
THEATER SEATING 1:15



The total mech. space amounts to 468 m², slightly exceeding rule-of-thumb estimates, reflecting allowances for acoustic performance and spatial integration. It includes 2 air handling units and 4 heat pumps.

Model	Cooling Capacity	Length (mm)	Width (mm)	Height (mm)	Approx. Weight
NXP 0175	~175 kW	2,120	1,250	1,976	~1,000 kg
NXP 0400	~400 kW	2,120	1,250	1,976	~1,100 kg
NXP 0500	~500 kW	2,600	1,250	2,000	~2,000 kg

Parameter	Per AHU	Two AHUs Total
Airflow capacity	25 m³/s	50 m³/s
Footprint (Length × Width)	10 m × 3 m (30 m²)	60 m² (without clearance)
Clearance for maintenance	1 m all sides	2 m length & width total

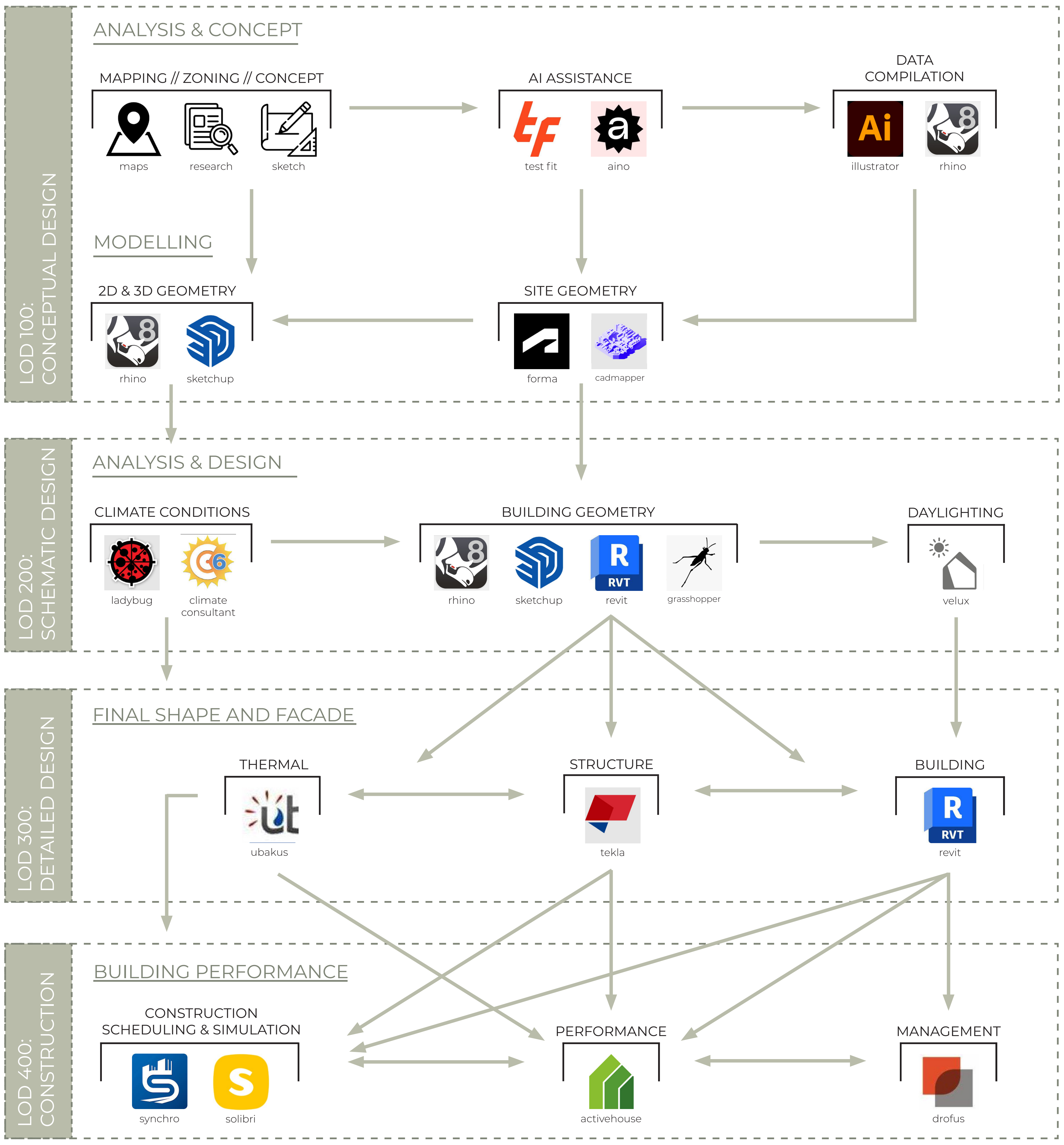


BIM Workflow and Applications

There are a plethora of BIM software options available that can be utilized during the planning, design, construction, and management stages of a project. These software tools range from those used for initial conceptual design to those focused on detailed architectural modeling, structural analysis, and MEP system integration. Additionally, there are tools for construction scheduling, cost estimation, and facility management.

Throughout the development of this thesis, we utilized BIM programs to create a comprehensive and connected design. The workflow below illustrates the interconnectedness of these various applications, demonstrating how each one supports a smooth and coordinated design process. For example, architectural design software can integrate seamlessly with structural and MEP design tools, allowing for real-time collaboration and clash detection. Construction planning software can pull data directly from design models to create accurate schedules and cost estimates. During the construction phase, on-site teams can access updated models to ensure precise implementation and track progress. Finally, facility management tools can use the as-built BIM models to maintain and operate the building efficiently.

This interconnected approach ensures that all stakeholders, from architects and engineers to contractors and facility managers, have access to accurate and up-to-date information, enhancing collaboration, reducing errors, and ultimately leading to a more efficient and successful project outcome. Moreover, the continuous feedback loop between the stages facilitates ongoing improvements and adaptations throughout the building's lifecycle.



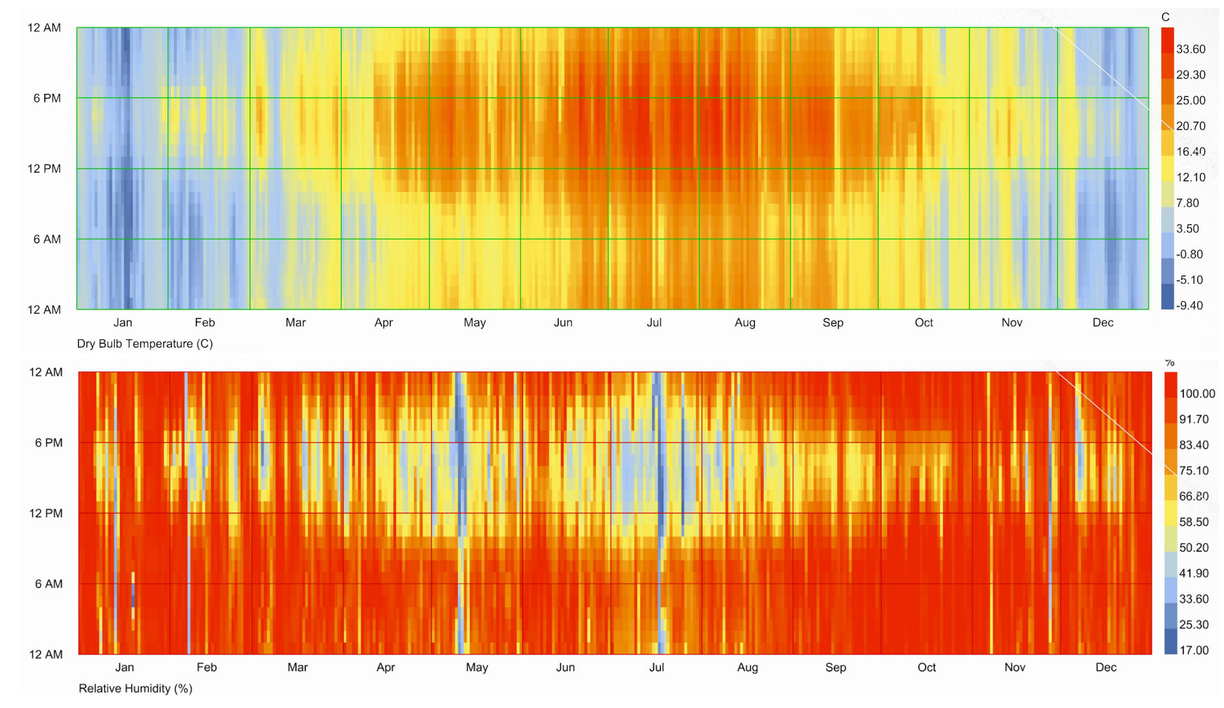
CATEGORY I: GENERAL

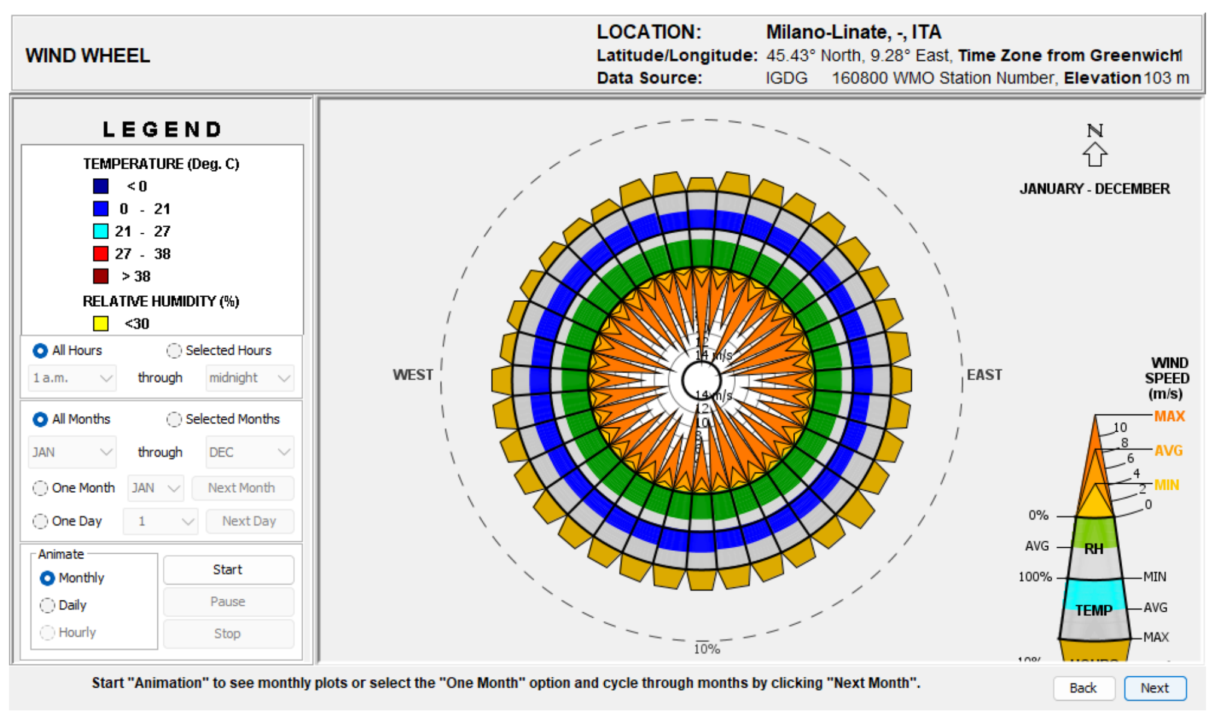
1120	Facade Systems Modelling | Glazing/Cladding/Curtain Systems Modelling
1190	HVAC Systems Modelling | Heating/Ventilation/Air-conditioning Modelling
1310	Parametric Modelling

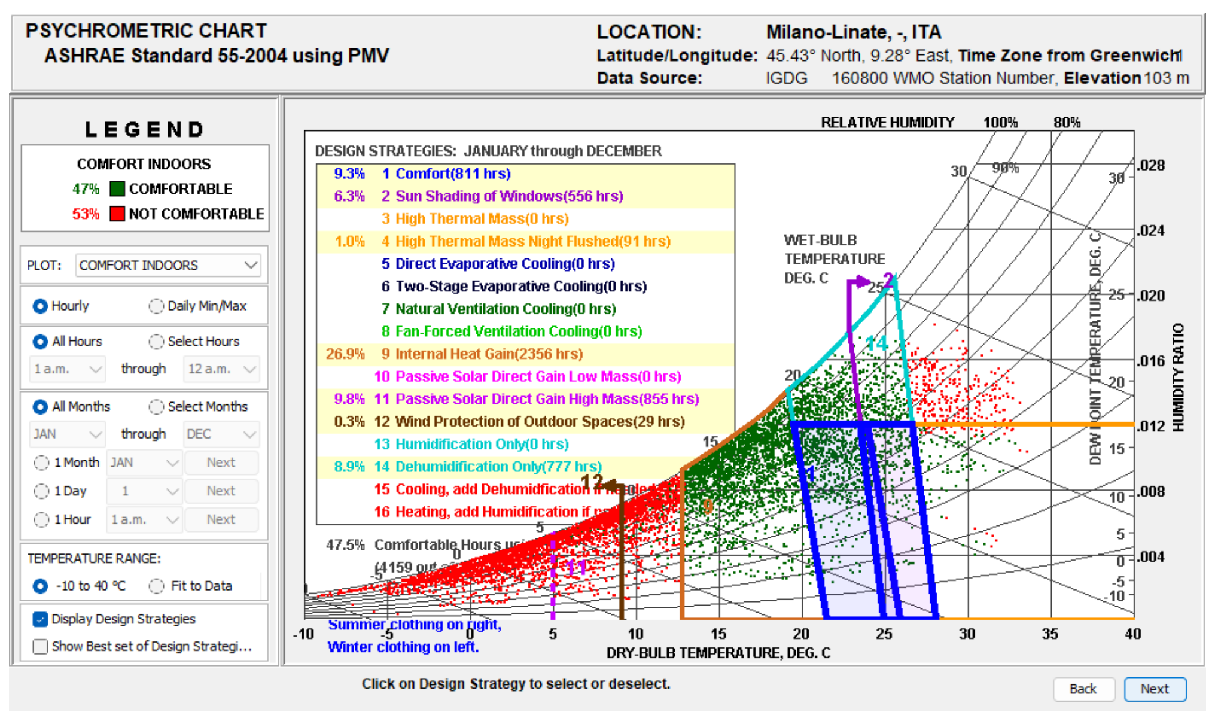
CATEGORY II: DOMAIN

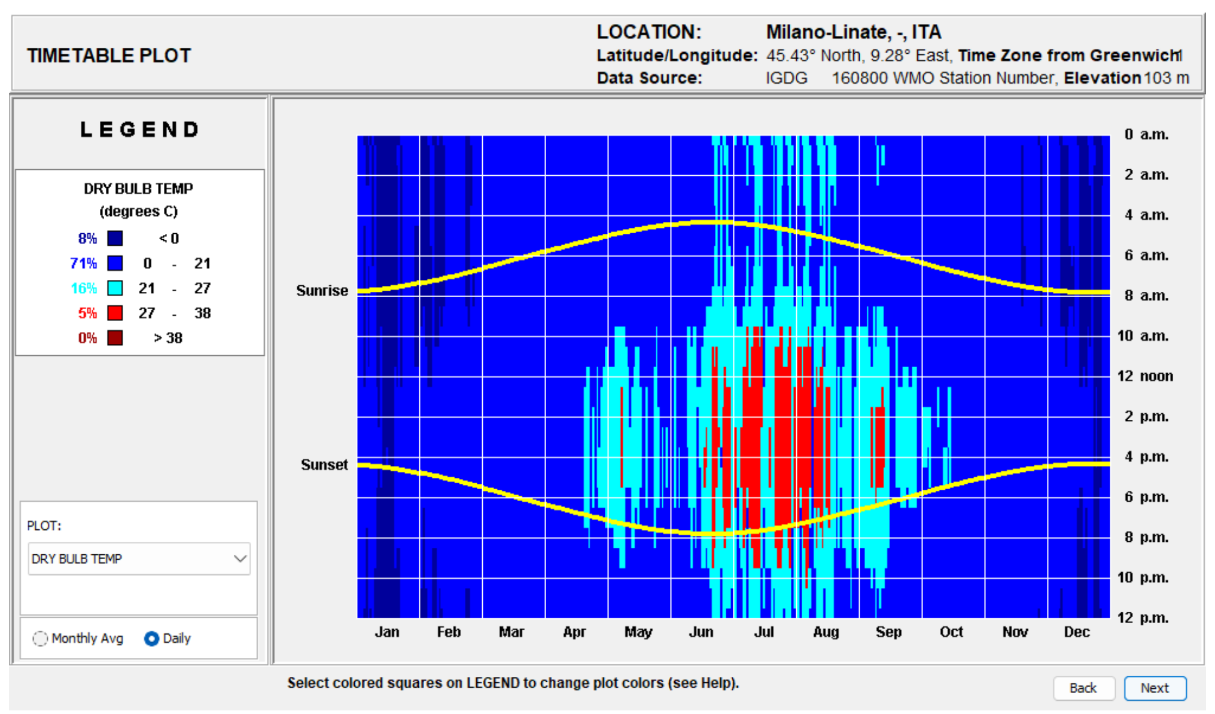
Capturing & Representing	
2010	2D Documentation
Planning and Designing	
3010	Conceptualization
3110	Urban Planning
Simulating & Quantifying	
4020	Acoustic Analysis
4120	Lighting Analysis
4180	Site Analysis
4190	Solar Analysis
4200	Spatial Analysis
4210	Structural Analysis
4220	Sustainability Analysis
4230	Thermal Analysis
4260	Wind Studies

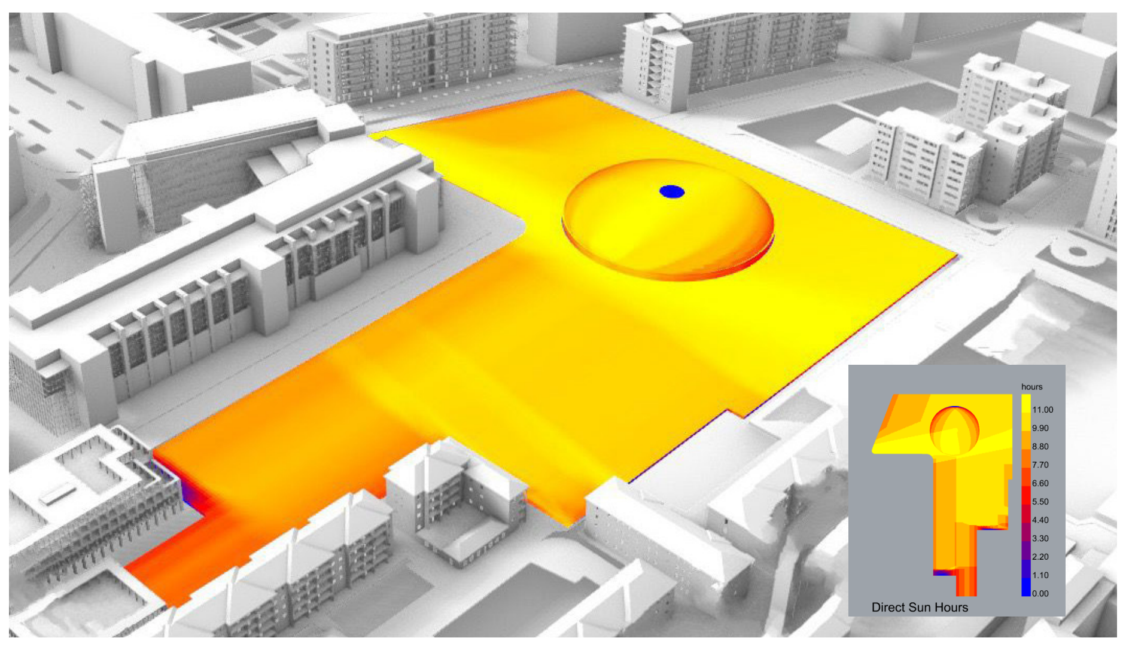
Climate Analysis





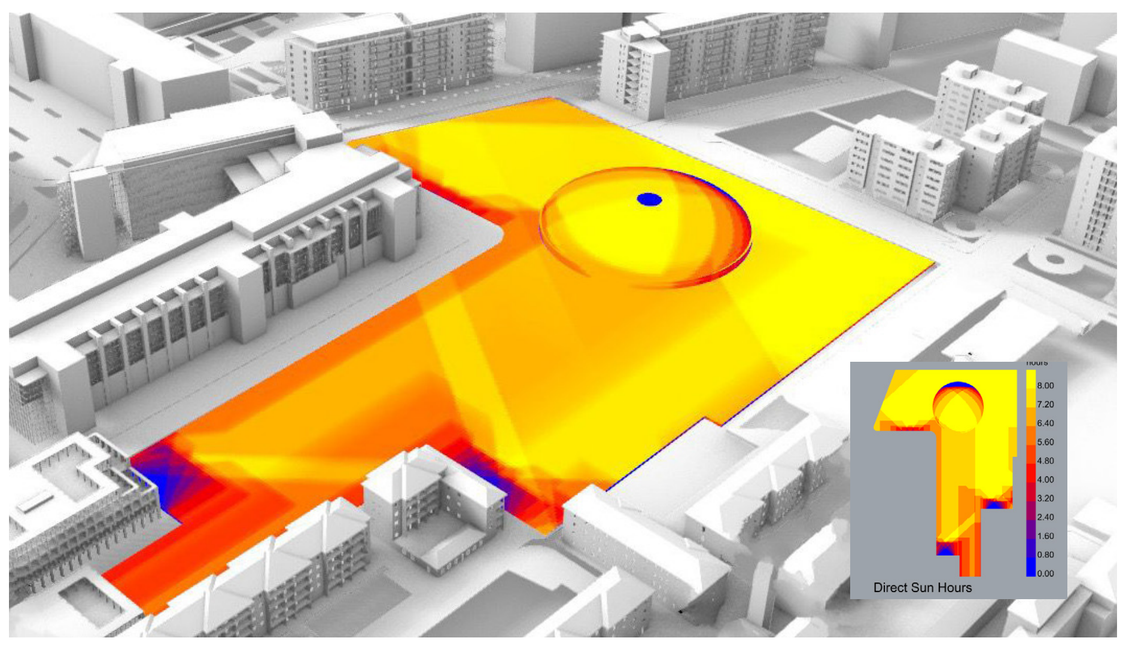






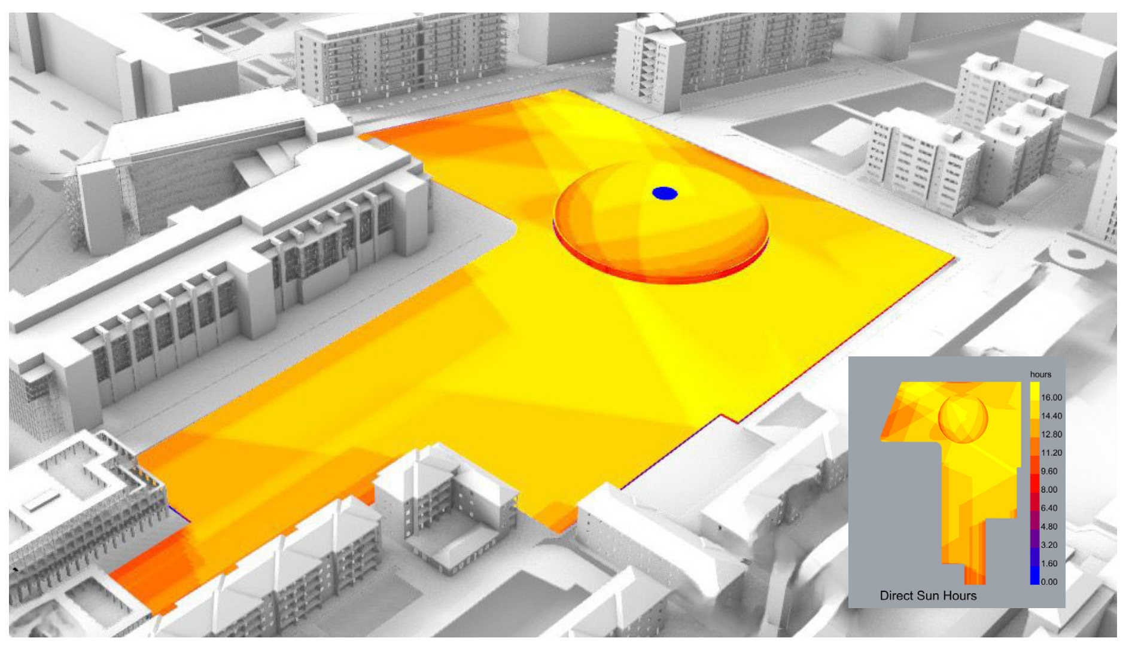
SPRING/FALL EQUINOX

During the spring and the autumn, the canopy gets exposed to a good amount of sunlight guaranteeing that the spaces underneath have enough light.



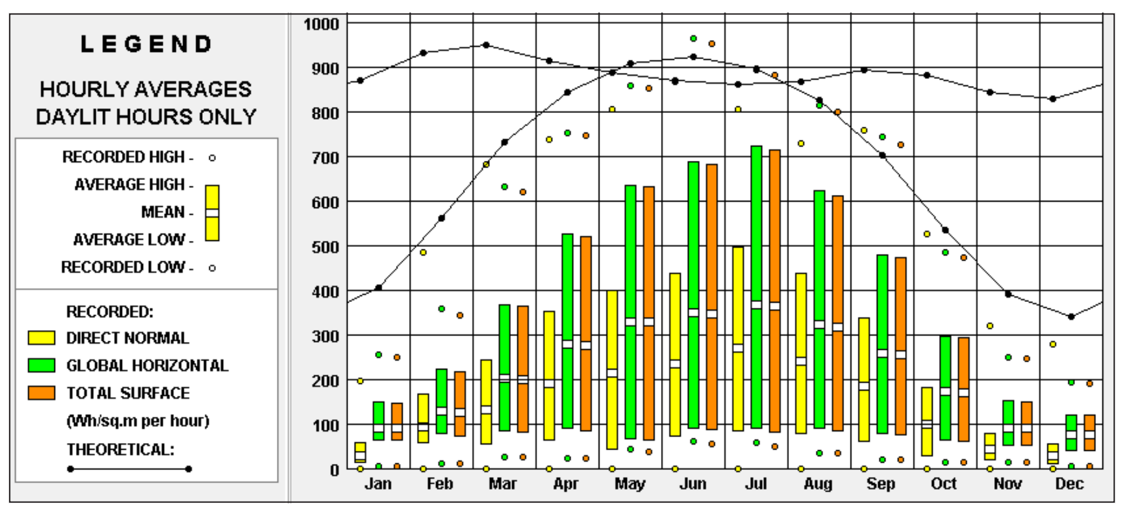
WINTER SOLSTICE

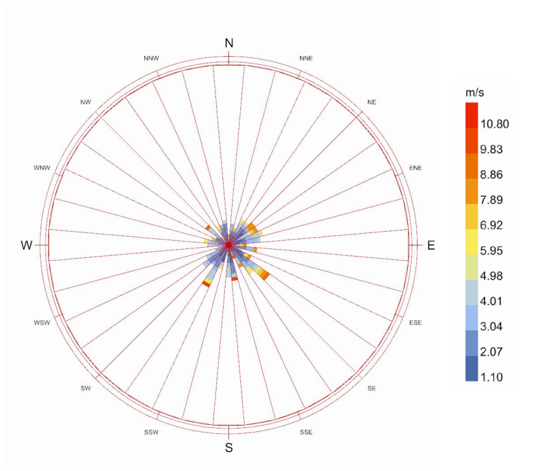
The N facade receives very little direct sunlight, but the southern facade and most of the park still have the potential to receive 7-8 hours. The south facing part of the canopy still recieves lots of light in the winter which is good news for the space inside



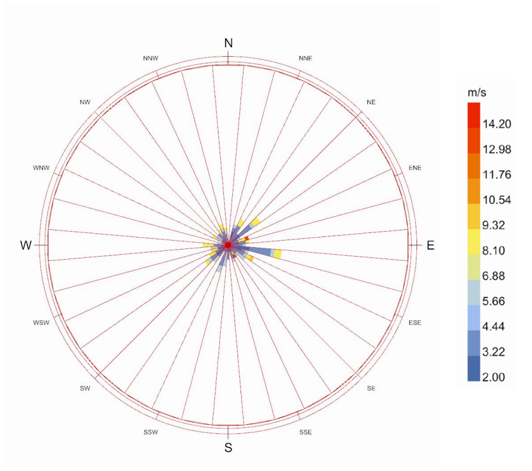
SUMMER SOLSTICE

The entire building is exposed to 8-16 hours of direct sunlight a day proving that during the summer months the canopy is needed to recude the heat level and provide relief.



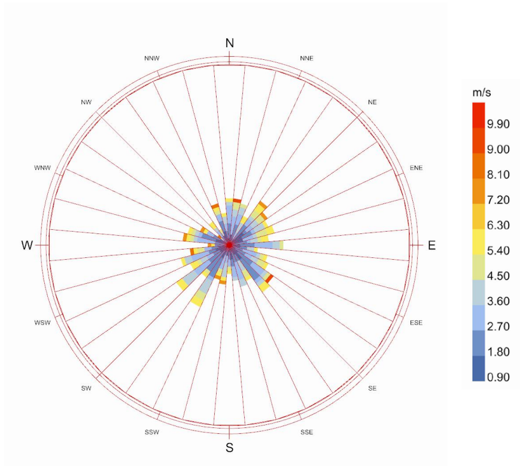


JANUARY



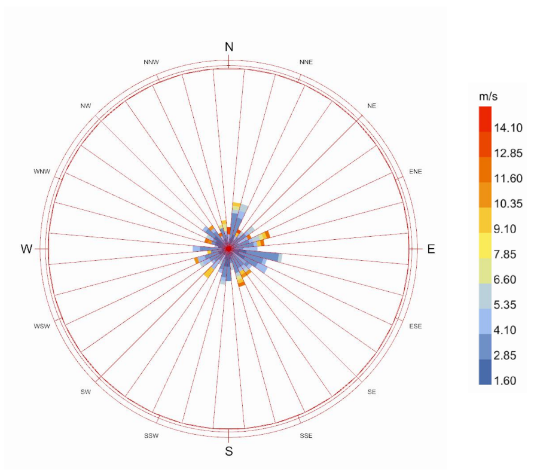
FEBRUARY

Strong gusts of wind

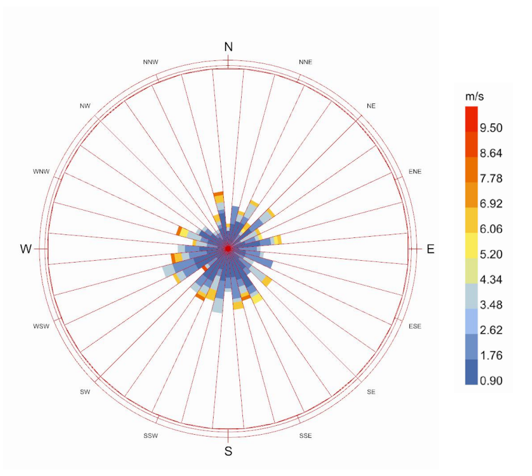


MARCH

Windy month from all directions

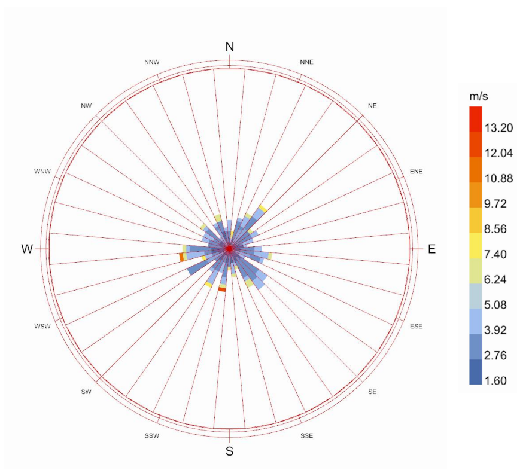


APRIL

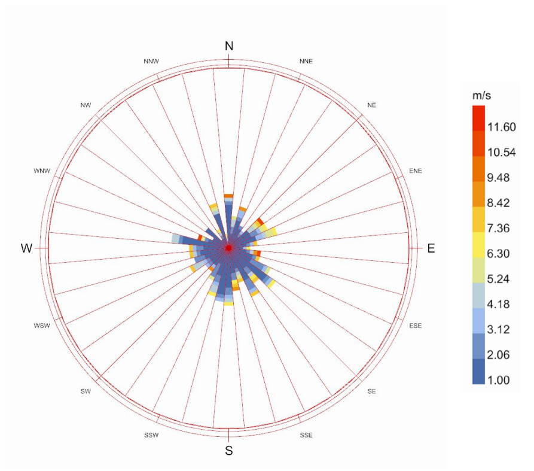


MAY

Nice breeze throughout this month

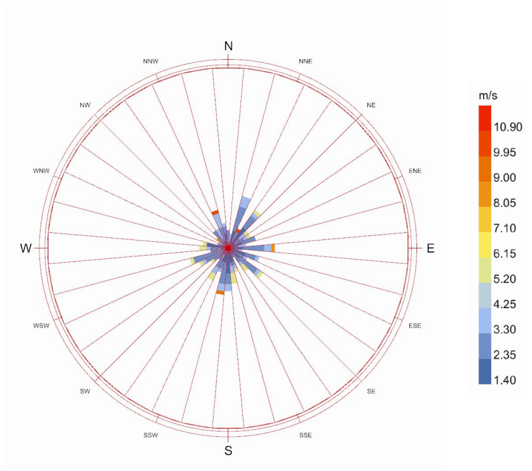


JUNE

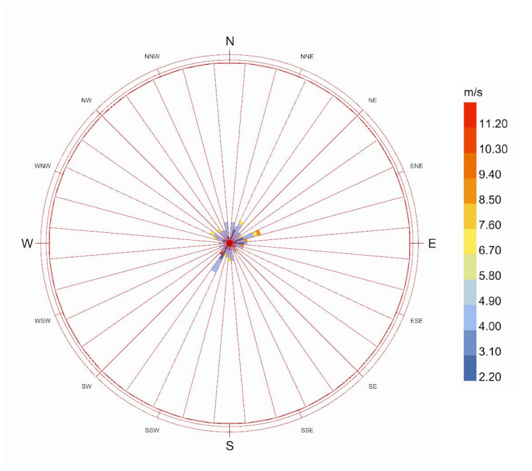


JULY

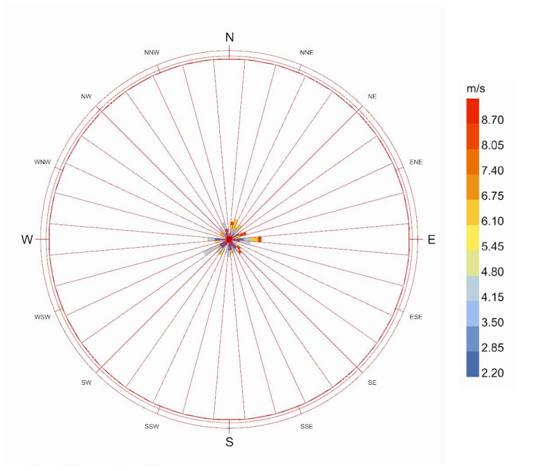
Nice breeze throughout this month



AUGUST

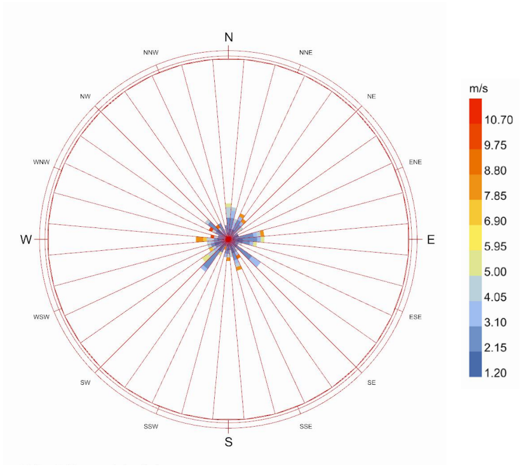


SEPTEMBER

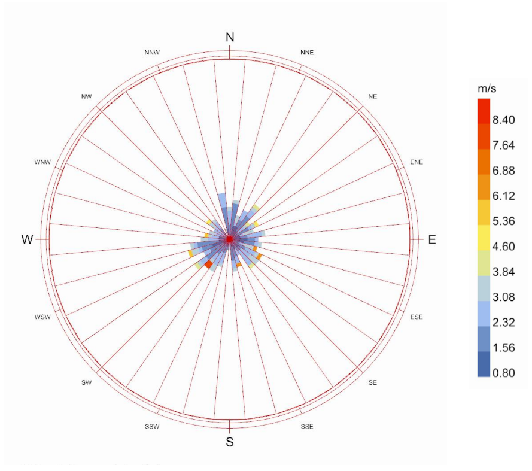


OCTOBER

Least windy month



NOVEMBER



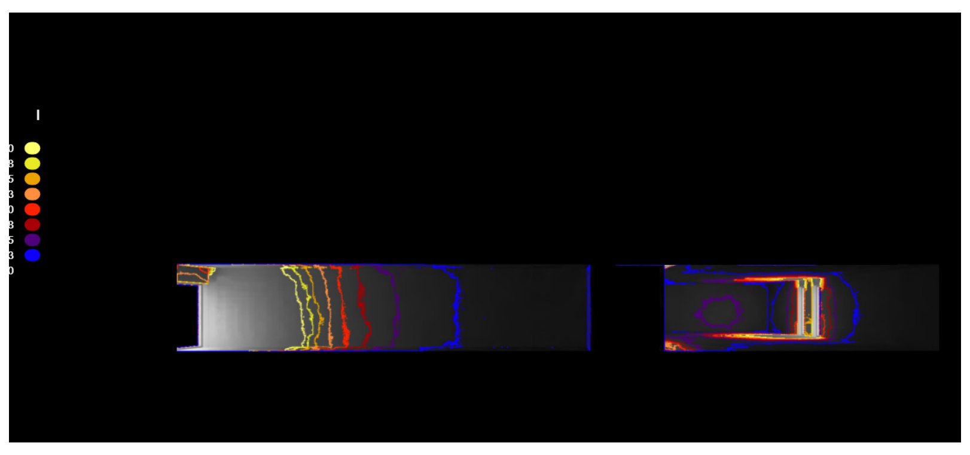
DECEMBER

The wind analysis shows stronger and more variable winds in winter and early spring, particularly in February and March, while summer months experience milder, more consistent breezes. October emerges as the least windy period of the year. These results informed a design that remains permeable during warmer months to encourage natural ventilation and comfort along paths and open spaces, while building massing and landscape elements provide shelter from stronger winter winds. This balance supports a wild, open park character without compromising usability or safety.

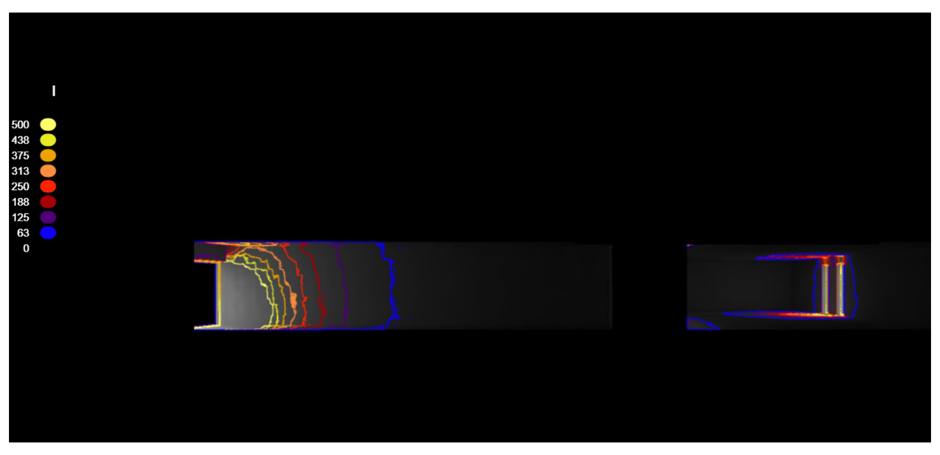
Daylighting

Natural daylighting analysis in a building offers numerous benefits that enhance both the environment and occupant well-being. By optimizing the use of natural light, energy consumption is significantly reduced, leading to lower electricity bills and a smaller carbon footprint. Proper daylighting can reduce the need for artificial lighting, minimizing glare and improving visual comfort. For our Music Hall, we know that lighting will be an issue because not only is it carved out of the ground and recessed levels, it is also covered by a canopy. There is a deep heavyness to the walls so balancing this out with lighting is very important. It is assumed that we will have to use artifical lighting due to the conditions we are working with, but first we wanted to see what (if any) daylighting is available.

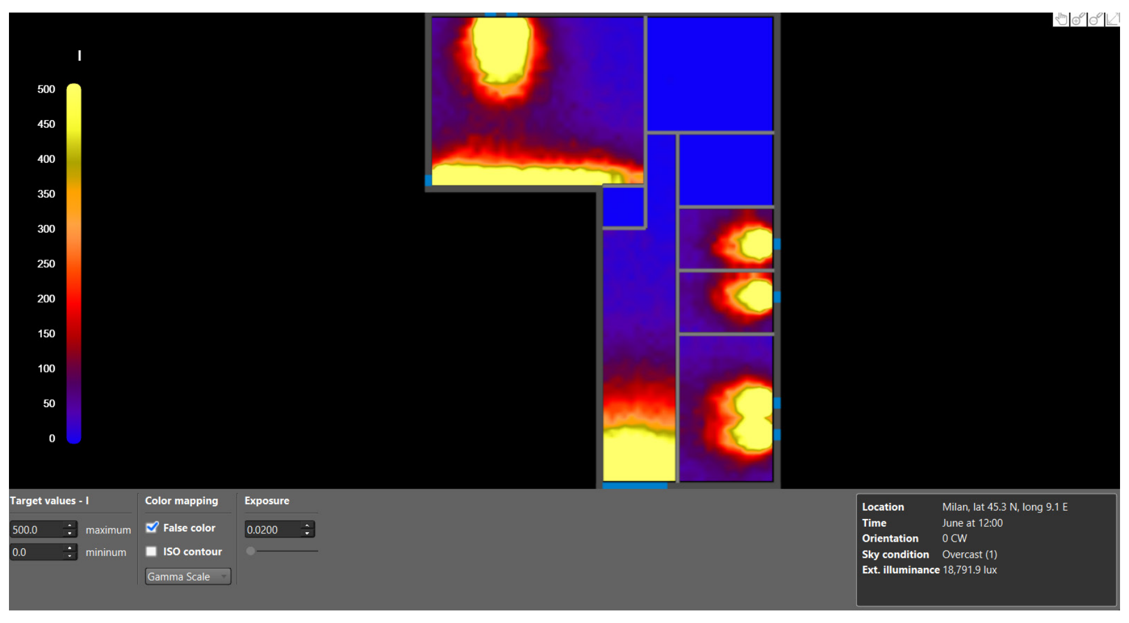
For this study, we have decided to study the lighting and subsequent comfort in the highest level of classroom spaces. We will always use the assumption of overcast skys for the analysis due to the recessed level and canopy cover. This study found that in summer and winter the skylights and glazing does illuminate the space significantly more than we assumed. However these are not adequate results. We will need to make intentional decisions for artifical ligting in these spaces.Additionally, the skylights ended up playing a large role because we did a study without them and there is a noticable difference.



Illuminance study with skylights - summer

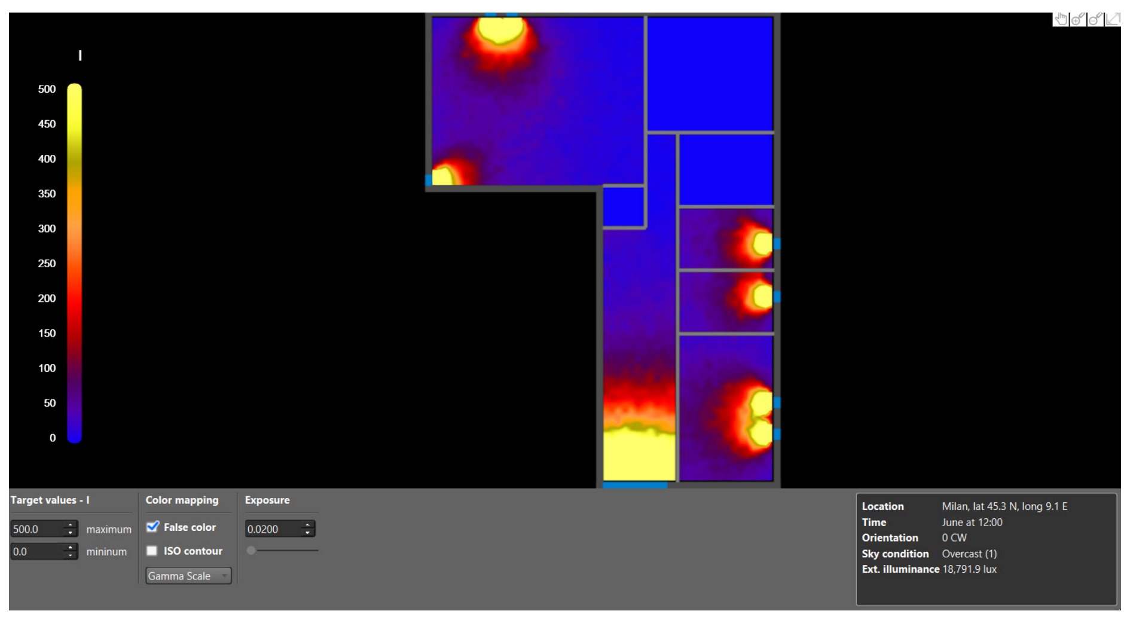


Illuminance study with skylights - winter

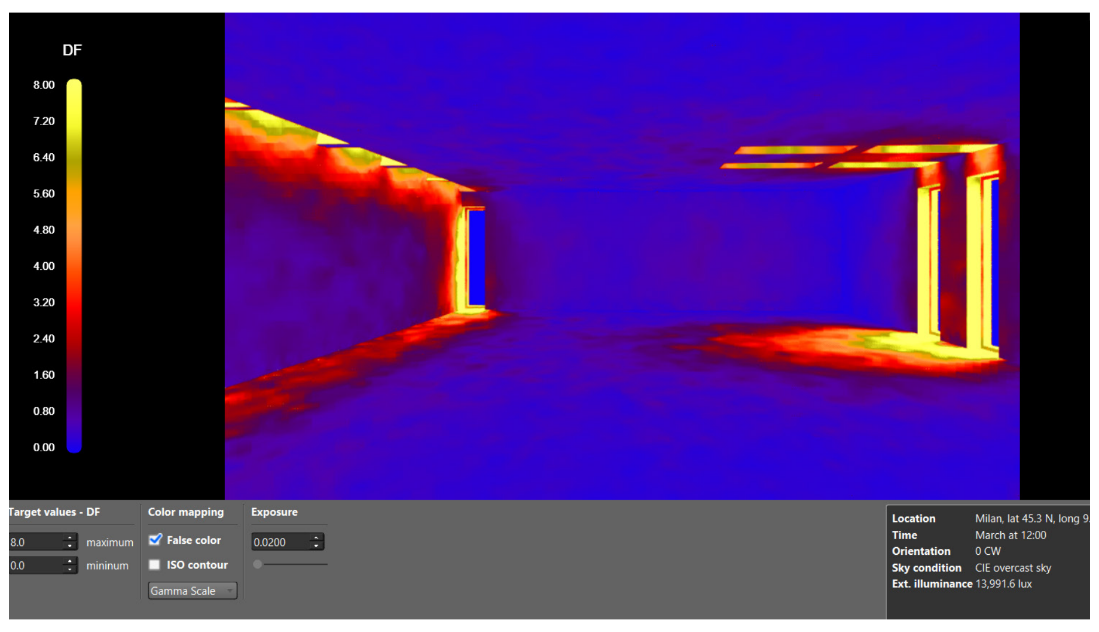


Illuminance study with skylights - summer

VS



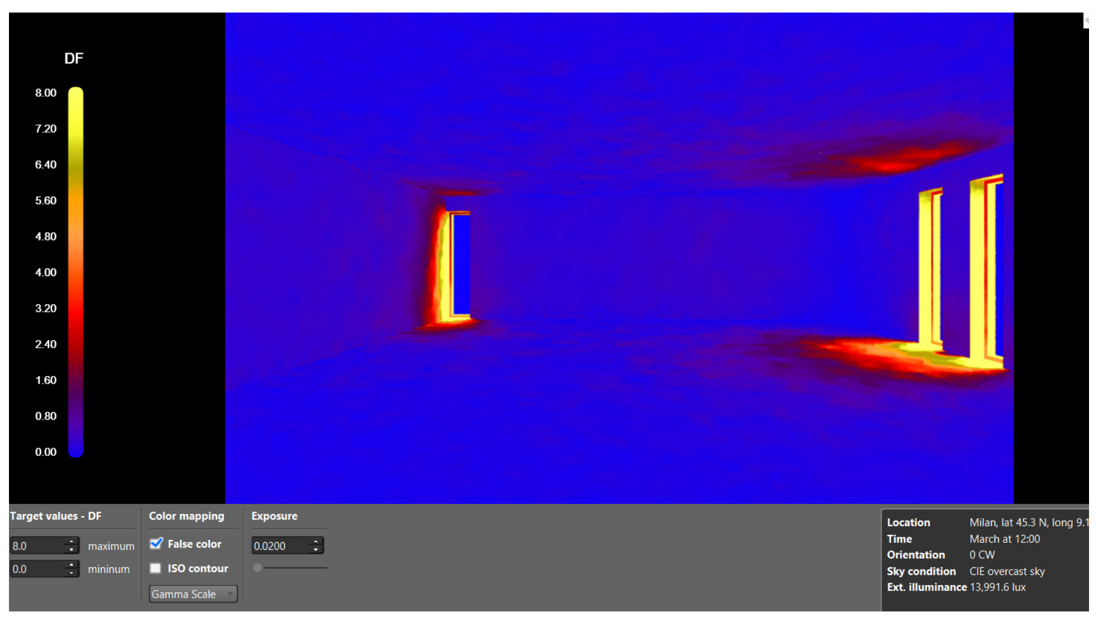
Illuminance study without skylights - summer



Target values - DF: 8.0 maximum, 0.0 mininum
Color mapping: ☑ False color ☐ ISO contour, Gamma Scale
Exposure: 0.0200
Location: Milan, lat 45.3 N, long 9.
Time: March at 12:00
Orientation: 0 CW
Sky condition: CIE overcast sky
Ext. illuminance: 13,991.6 lux

Daylighting study with skylights - the skylights increase the amount of natural lighting in the space which reduces the need for artifical lighting and the subsequent engergy usage that brings.

VS



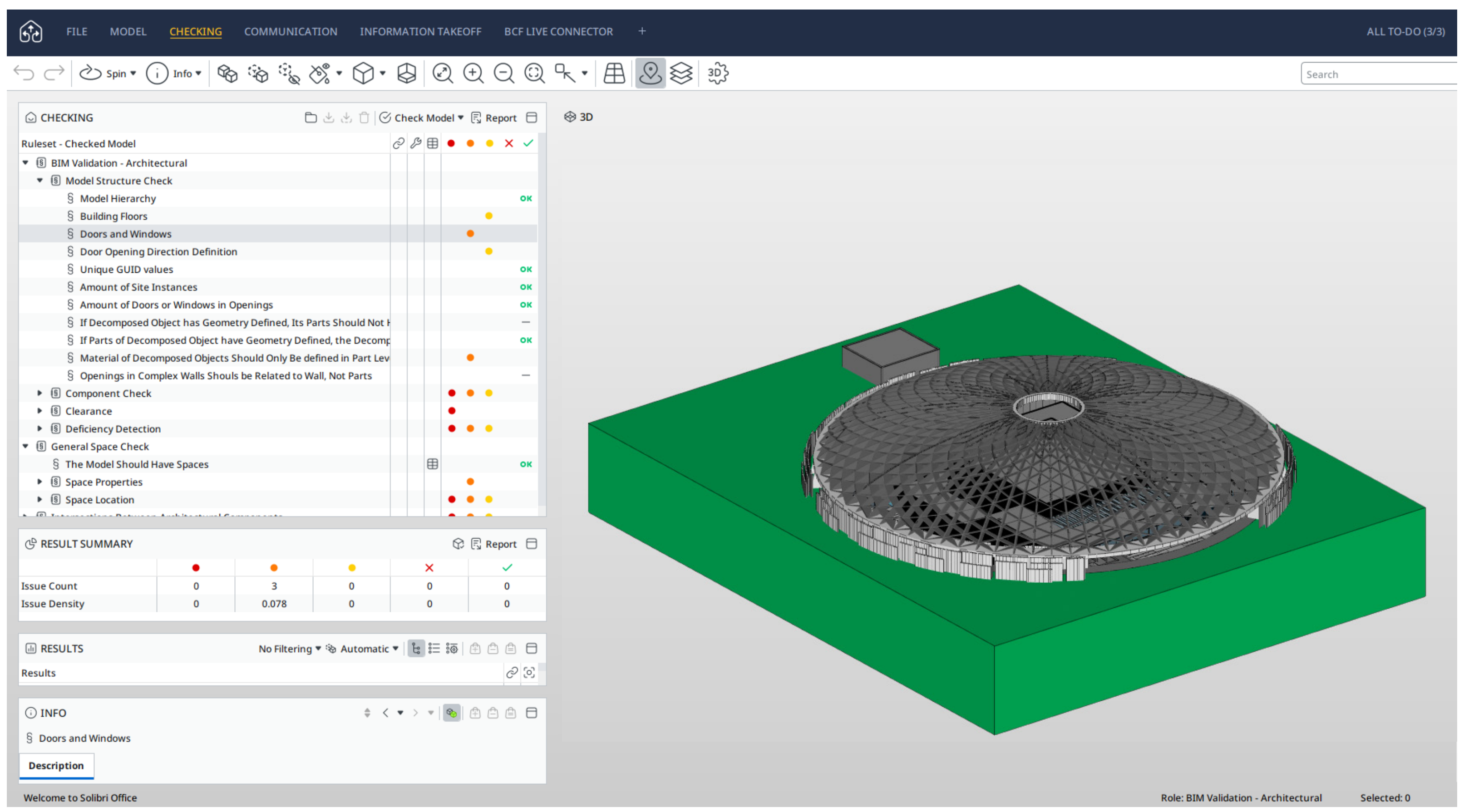
Target values - DF: 8.0 maximum, 0.0 mininum
Color mapping: ☑ False color ☐ ISO contour, Gamma Scale
Exposure: 0.0200
Location: Milan, lat 45.3 N, long 9.1
Time: March at 12:00
Orientation: 0 CW
Sky condition: CIE overcast sky
Ext. illuminance: 13,991.6 lux

Daylighting study without skylights - this study specifically shows the significant lack of daylighting without the skylights. This is a major problem for the classroom spaces on the level below this without skylights. We need to find a way to address this by specifying an excellent artificial lighting scheme.

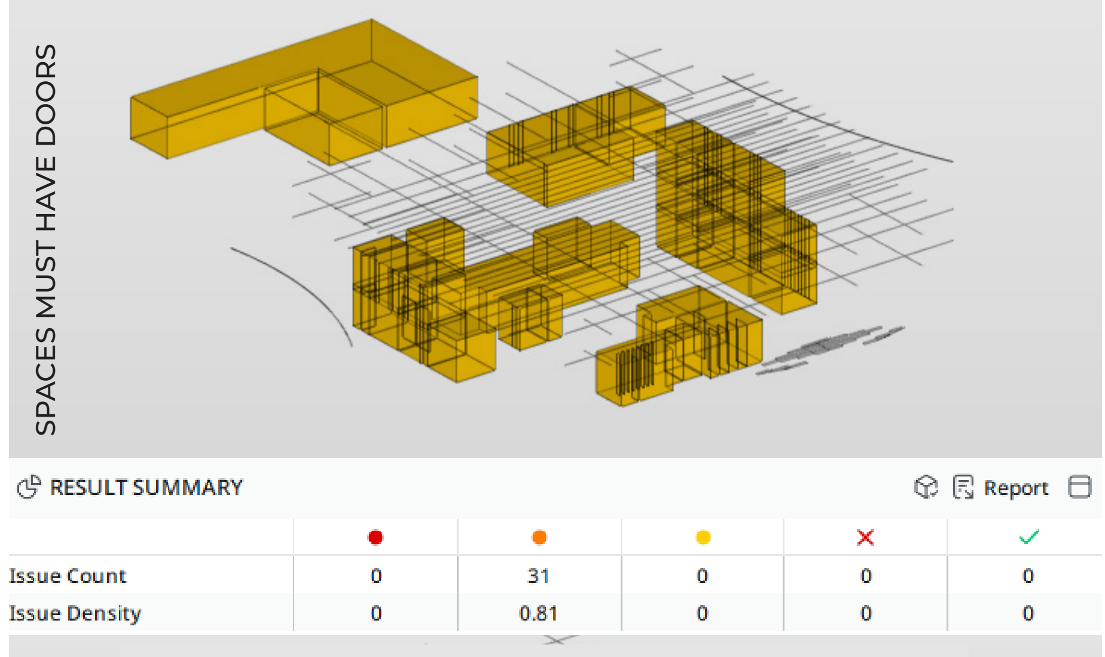
Model Checking

Solibri is a software tool used in the architecture, engineering, and construction (AEC) industries for building information modeling (BIM) validation and quality assurance. It provides comprehensive model checking, coordination, and clash detection to ensure that BIM projects meet industry standards and design requirements.

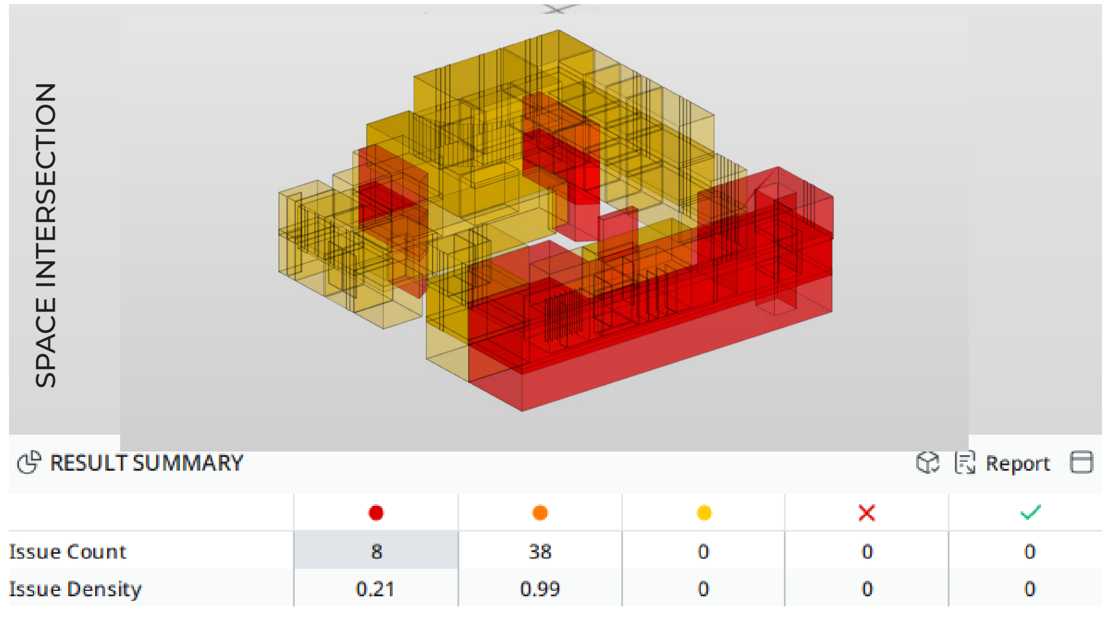
Solibri helps users identify & resolve issues early in the design process, improving collaboration, reducing errors, and enhancing the overall efficiency and quality of construction projects.



Checking Spaces: We discovered we have two main issues: space intersection and spaces without doors. A couse for these could be double height spaces that we modeled incorrectly or shafts.

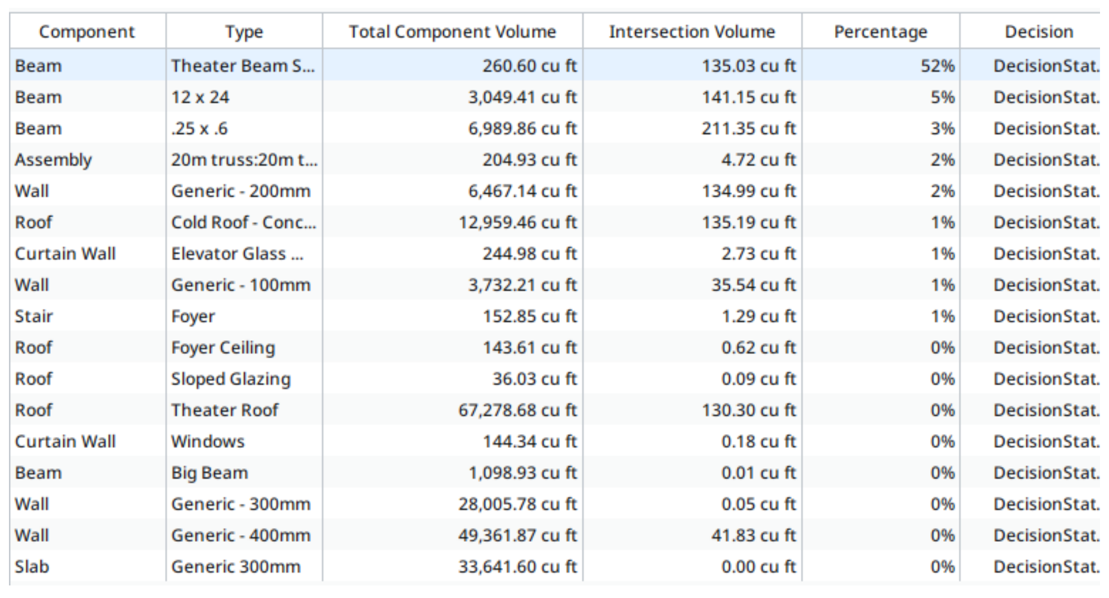


	🔴	🟠	🟡	✕	✓
Issue Count	0	31	0	0	0
Issue Density	0	0.81	0	0	0

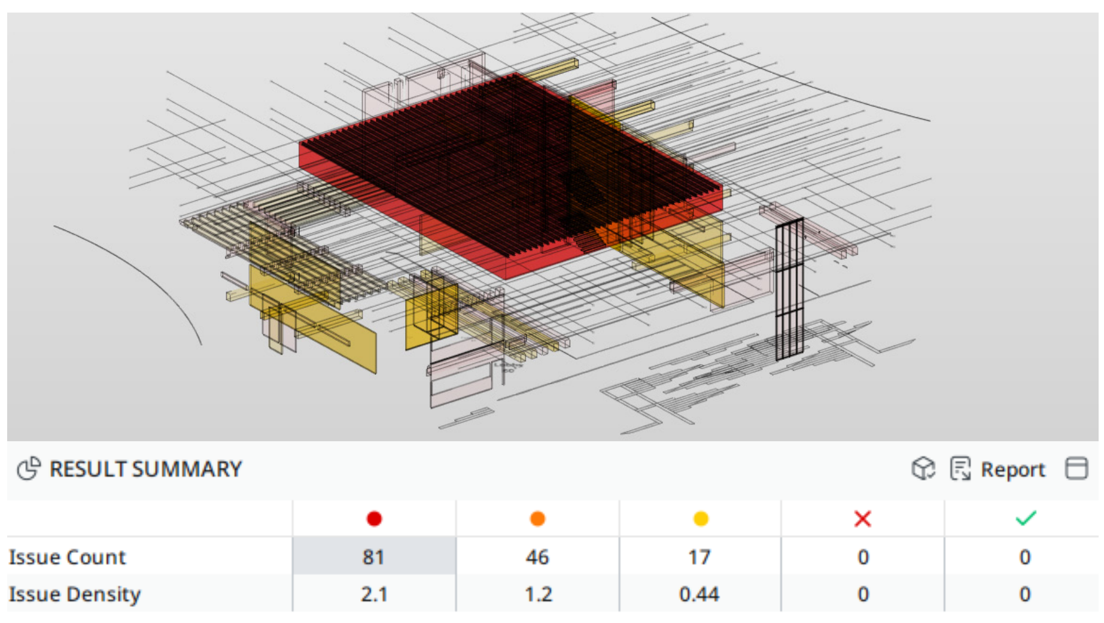


	🔴	🟠	🟡	✕	✓
Issue Count	8	38	0	0	0
Issue Density	0.21	0.99	0	0	0

Checking Beam Intersection: Since we have only shear walls and beams in our model we decided to check to see if there were any beam intersections showing us not only where we modeled incorrectly, but in what areas we need connections.



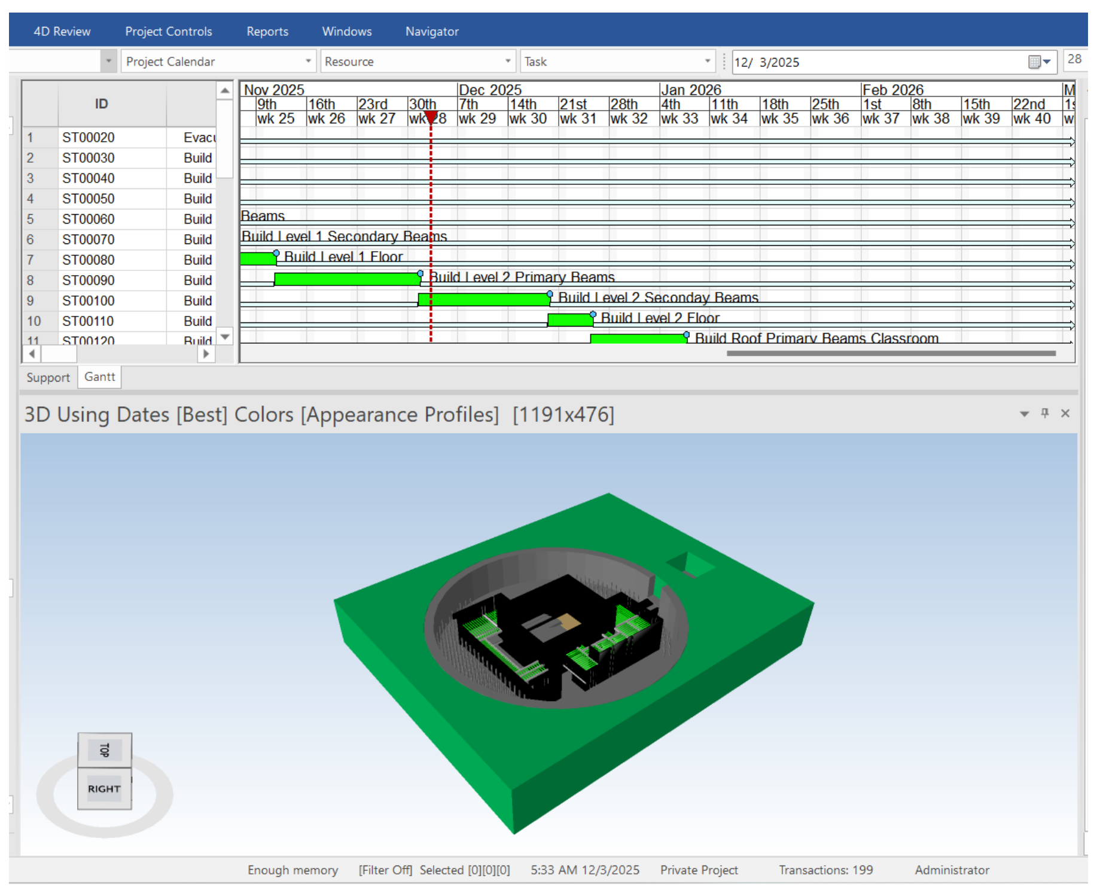
Component	Type	Total Component Volume	Intersection Volume	Percentage	Decision
Beam	Theater Beam S...	260.60 cu ft	135.03 cu ft	52%	DecisionStat.
Beam	12 x 24	3,049.41 cu ft	141.15 cu ft	5%	DecisionStat.
Beam	.25 x .6	6,989.86 cu ft	211.35 cu ft	3%	DecisionStat.
Assembly	20m truss:20m t...	204.93 cu ft	4.72 cu ft	2%	DecisionStat.
Wall	Generic - 200mm	6,467.14 cu ft	134.99 cu ft	2%	DecisionStat.
Roof	Cold Roof - Conc...	12,959.46 cu ft	135.19 cu ft	1%	DecisionStat.
Curtain Wall	Elevator Glass ...	244.98 cu ft	2.73 cu ft	1%	DecisionStat.
Wall	Generic - 100mm	3,732.21 cu ft	35.54 cu ft	1%	DecisionStat.
Stair	Foyer	152.85 cu ft	1.29 cu ft	1%	DecisionStat.
Roof	Foyer Ceiling	143.61 cu ft	0.62 cu ft	0%	DecisionStat.
Roof	Sloped Glazing	36.03 cu ft	0.09 cu ft	0%	DecisionStat.
Roof	Theater Roof	67,278.68 cu ft	130.30 cu ft	0%	DecisionStat.
Curtain Wall	Windows	144.34 cu ft	0.18 cu ft	0%	DecisionStat.
Beam	Big Beam	1,098.93 cu ft	0.01 cu ft	0%	DecisionStat.
Wall	Generic - 300mm	28,005.78 cu ft	0.05 cu ft	0%	DecisionStat.
Wall	Generic - 400mm	49,361.87 cu ft	41.83 cu ft	0%	DecisionStat.
Slab	Generic 300mm	33,641.60 cu ft	0.00 cu ft	0%	DecisionStat.



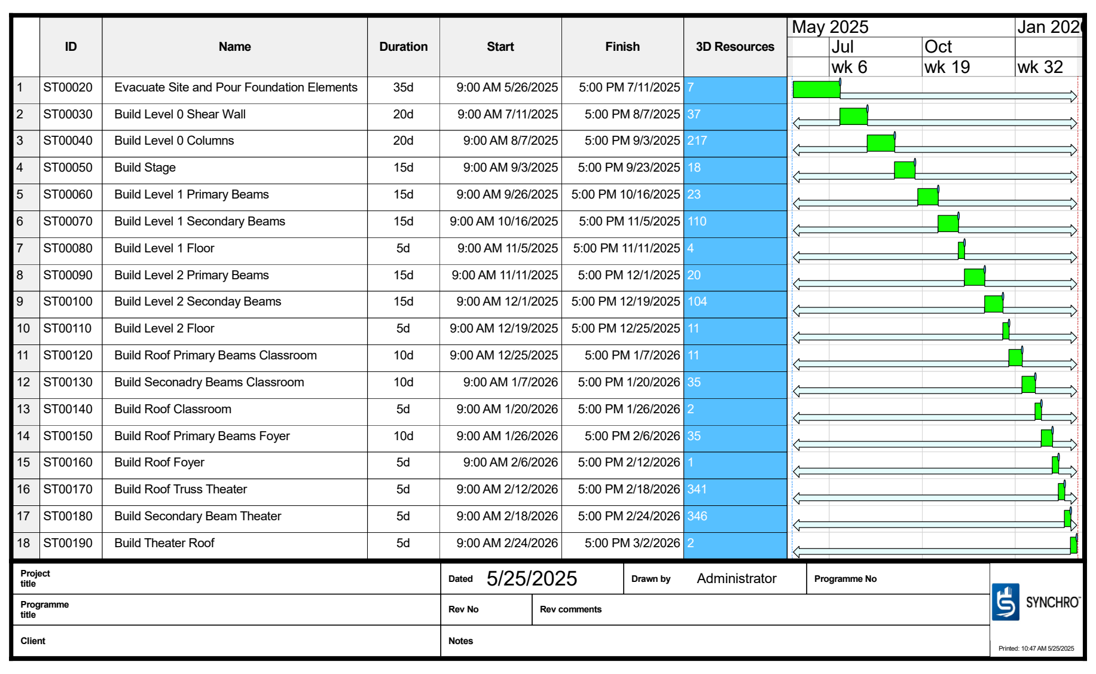
	🔴	🟠	🟡	✕	✓
Issue Count	81	46	17	0	0
Issue Density	2.1	1.2	0.44	0	0

Construction Planning

Project schedule for the construction of a Music Hall built in an evacuated space. The timeline outlines the sequential tasks for constructing various foundational and structural components of the tower, spanning from June 2025 to March 2026. Each task is listed with a specific start and finish date, along with the duration in days. The tasks include laying the foundation, building multiple floors separated with primary and secondary beams. The logic network is established based on the dependency of the different tasks to be performed. Task durations are determined based on several factors: varying skill levels, efficiency of workers' time, mistakes and misunderstandings, and material properties (e.g., concrete setting time). To accommodate these factors, some task dependencies are facilitated by the use of lag times to ensure proper completion of previous tasks.

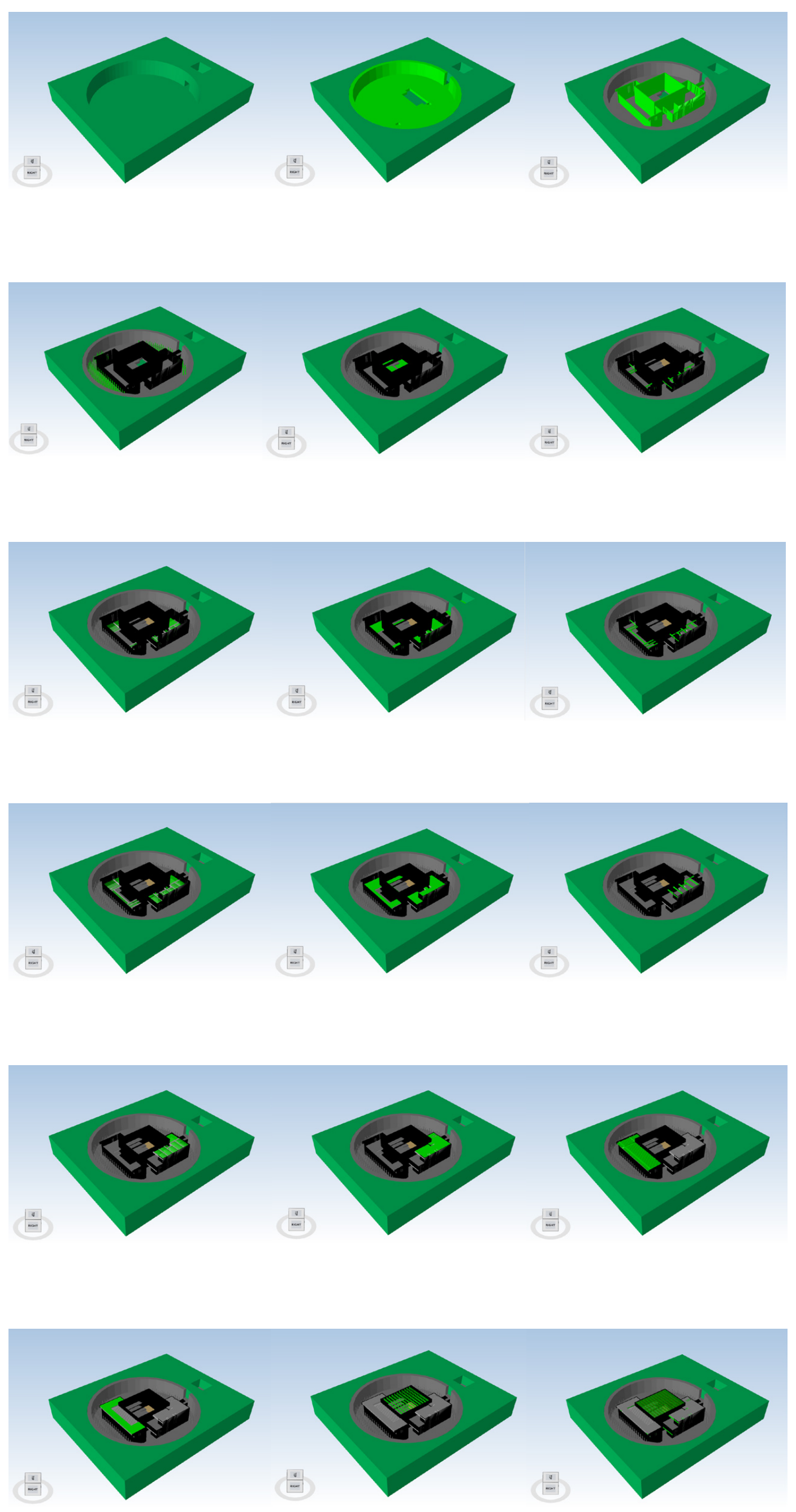


Enough memory [Filter Off] Selected [0][0][0] 5:33 AM 12/3/2025 Private Project Transactions: 199



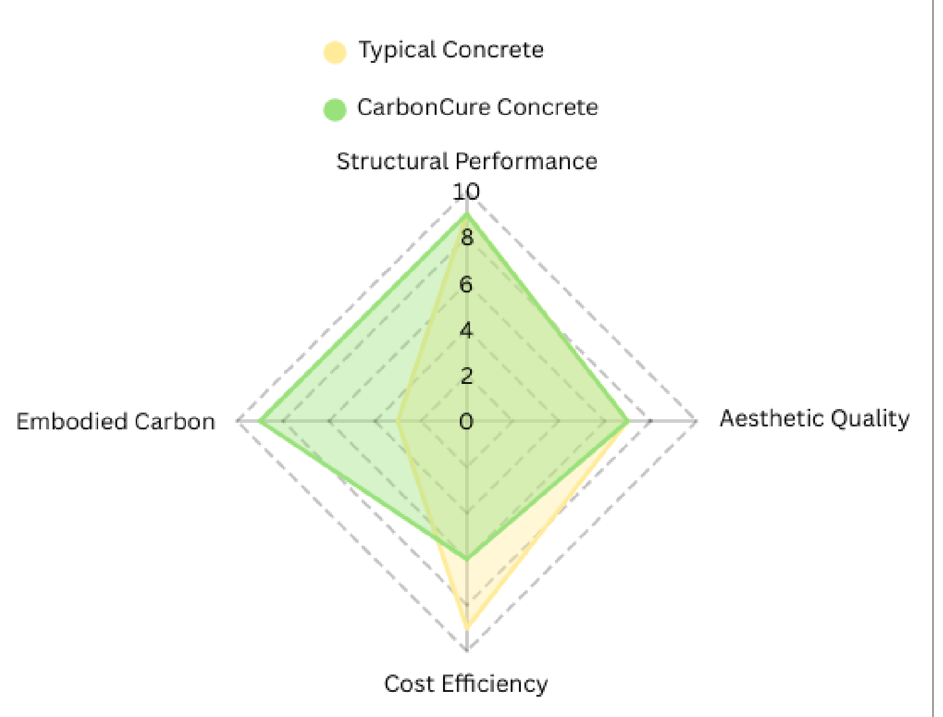
	ID	Name	Duration	Start	Finish	3D Resources
1	ST00020	Evacuate Site and Pour Foundation Elements	35d	9:00 AM 5/26/2025	5:00 PM 7/11/2025	7
2	ST00030	Build Level 0 Shear Wall	20d	9:00 AM 7/11/2025	5:00 PM 8/7/2025	37
3	ST00040	Build Level 0 Columns	20d	9:00 AM 8/7/2025	5:00 PM 9/3/2025	217
4	ST00050	Build Stage	15d	9:00 AM 9/3/2025	5:00 PM 9/23/2025	18
5	ST00060	Build Level 1 Primary Beams	15d	9:00 AM 9/26/2025	5:00 PM 10/16/2025	23
6	ST00070	Build Level 1 Secondary Beams	15d	9:00 AM 10/16/2025	5:00 PM 11/5/2025	110
7	ST00080	Build Level 1 Floor	5d	9:00 AM 11/5/2025	5:00 PM 11/11/2025	4
8	ST00090	Build Level 2 Primary Beams	15d	9:00 AM 11/11/2025	5:00 PM 12/1/2025	20
9	ST00100	Build Level 2 Seconday Beams	15d	9:00 AM 12/1/2025	5:00 PM 12/19/2025	104
10	ST00110	Build Level 2 Floor	5d	9:00 AM 12/19/2025	5:00 PM 12/25/2025	11
11	ST00120	Build Roof Primary Beams Classroom	10d	9:00 AM 12/25/2025	5:00 PM 1/7/2026	11
12	ST00130	Build Seconadry Beams Classroom	10d	9:00 AM 1/7/2026	5:00 PM 1/20/2026	35
13	ST00140	Build Roof Classroom	5d	9:00 AM 1/20/2026	5:00 PM 1/26/2026	2
14	ST00150	Build Roof Primary Beams Foyer	10d	9:00 AM 1/26/2026	5:00 PM 2/6/2026	35
15	ST00160	Build Roof Foyer	5d	9:00 AM 2/6/2026	5:00 PM 2/12/2026	1
16	ST00170	Build Roof Truss Theater	5d	9:00 AM 2/12/2026	5:00 PM 2/18/2026	341
17	ST00180	Build Secondary Beam Theater	5d	9:00 AM 2/18/2026	5:00 PM 2/24/2026	346
18	ST00190	Build Theater Roof	5d	9:00 AM 2/24/2026	5:00 PM 3/2/2026	2

Project title
Dated 5/25/2025
Drawn by Administrator
Programme No
Programme title
Rev No
Rev comments
Client
Notes
SYNCHRO



Economic Strategy

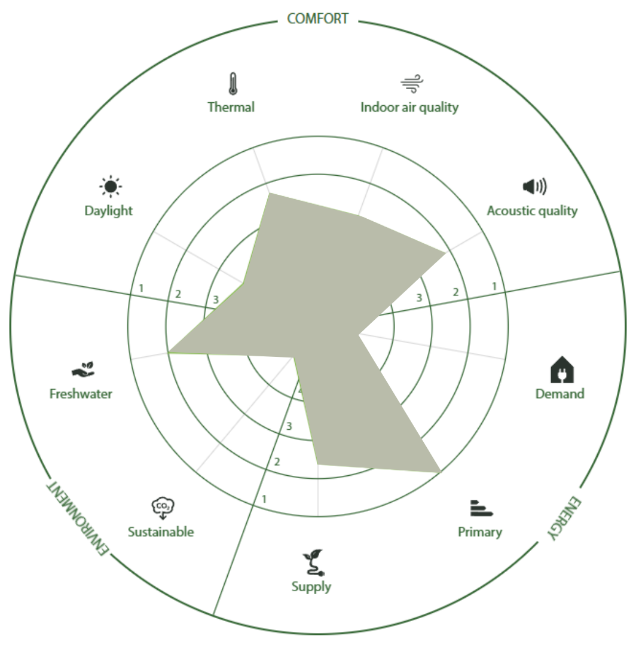
The section evaluates the economic and environmental impact of using CarbonCure concrete instead of typical reinforced concrete for a structural wall over a 30 year period. Technically and aesthetically, CarbonCure performs equivalently, maintaining durability, lifespan, and finish quality while preserving architectural intent. Its key advantage is embodied carbon reduction, saving roughly 8.5 tons of CO_2 across the full wall area, with no expected replacement during the study period. Economically, CarbonCure carries a modest upfront premium (about €15,000 total), but lifecycle costs remain comparable, making the added investment predictable and relatively minor within the overall project budget. A multi-criteria assessment balancing performance, aesthetics, cost, and sustainability shows that CarbonCure offers the best trade-off, achieving meaningful carbon reductions without compromising design or constructability, and representing a low-risk, long-term sustainability strategy aligned with architectural and structural goals.



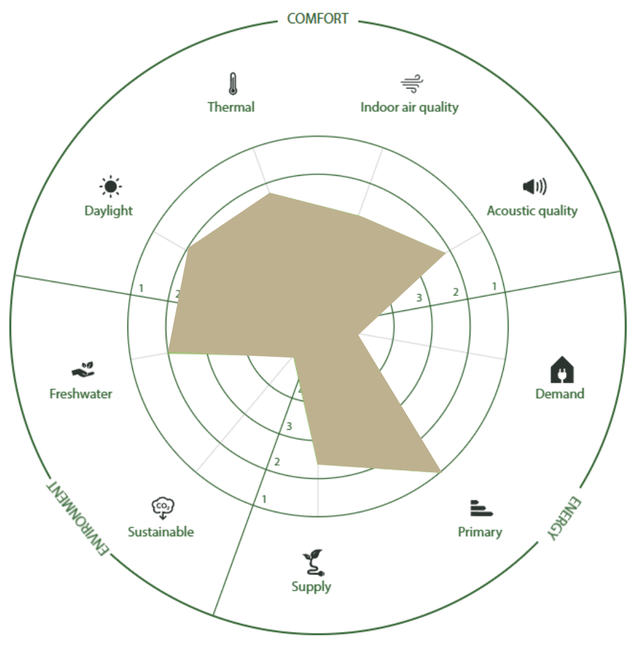
Activehouse

Active House is a tool that evaluates how a building balances comfort, health, and energy, scoring projects from 1-4 (lower is better).

Our main comparison focused on the project with and also without skylights. We kept all of the other values nuetral. The version without skylights performs much worse in daylight & shows higher energy demand due to increased reliance on artificial lighting. In contrast, the skylight version improves daylight conditions & overall environmental quality, showing how impactful this single architectural move is.



ACTIVEHOUSE RADAR CHART WITHOUT SKYLIGHTS



ACTIVEHOUSE RADAR CHART WITH SKYLIGHTS