SEUNGMOK LEE

Rehabilitation of an existing industrial steel-framed structure
: a case study in Kaldnes Vest, Tønsberg

A thesis for the degree of Master of Science

Trondheim, May 2022

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ABSTRACT

Reusing steel could save 96% of environmental impact compared to the primary production of new steel. Despite the benefit, existing steel materials are not reused often due to a lack of incentives for reuse and technical barriers(Sansom & Avery, 2014). Recycling steel is currently dominant which still creates a lot of emissions when scrap steel is melted down in an arc furnace.

This rehabilitation project aims to transform one of the old steel frame industrial structures out of three buildings into an Olympic-sized pool combined with a nursing home by reusing steel materials on the site. Additional steel materials are reused from other industrial halls nearby in Kaldnes Vest, Tønsberg. Kaldnes Vest is located at the end of the canal axis on its west side which was previously a ship yard established in 1899. Kaldnes Vest has a great regional potential to accommodate a variety of activities and extend the currently closed promenade by the end of the canal starting from the city. The combination of the swimming hall and the nursing home could bring a high level of social mix. Furthermore, by connecting the activities of the indoor pool and the outdoor sea bath, it can provide unique experiences to users.

The analysis of daylighting, energy and lifecycle assessment was carried out. Due to the need to provide appropriate thermal comfort conditions of indoor swimming pools, its energy demand is up to 276.79 kWh/m2 yearly. In total, 411.3 kWh/m2/year is required to cover the demand from both the swimming hall and the nursing home. Photovoltaic modules installed on the south roof generate 499 819kWh yearly and it can cover the electrical energy in summer entirely. The steel joist slab system was proposed by assembling approximately 1 000 tons of steel materials from other structures thereby it could save 1469.9 tons of steel in total. 10307.9 ton of concrete is also saved by reusing most of its previous structure. Thanks to reusing massive concrete and steel elements and on-site energy generation, the project saved 4.67 kgCO2e/m2/y and 5.41 kgCO2e/m2/y respectively out of total 13.32 kgCO2e/m2/y

SAMMENDRAG

Gjenbruk av stål kan spare 96 % av miljøbelastningen sammenlignet med primærproduksjon av nytt stål. Til tross for fordelen, gjenbrukes ikke eksisterende stålmaterialer ofte på grunn av mangel på insentiver for gjenbruk og tekniske barrierer (Sansom & Avery, 2014). Gjenvinning av stål er dog dominerende i dagens samfunn, noe som skaper mye utslipp når skrapstål smeltes ned i en lysbueovn.

Dette rehabiliteringsprosjektet tar sikte på å transformere en av de tre gamle industrikonstruksjonene av stålramme om til et basseng i olympisk størrelse kombinert med et sykehjem, ved å gjenbruke stålmaterialer på stedet Ytterligere stålmaterialer gjenbrukes fra andre industrihaller i nærheten i Kaldnes Vest, Tønsberg. Kaldnes Vest ligger i enden av kanalaksen på sin vestside som tidligere var et verft etablert i 1899. Kaldnes Vest har et stort regionalt potensiale for å romme en rekke aktiviteter og forlenge den nå stengte promenaden ved enden av kanal, som starter fra byen. Kombinasjonen av svømmehallen og sykehjemmet vil kunne gi høy sosial miks. Ved å koble sammen aktivitetene til innendørsbassenget og det utendørs sjøbadet kan dette dessuten gi unike opplevelser til brukerne.

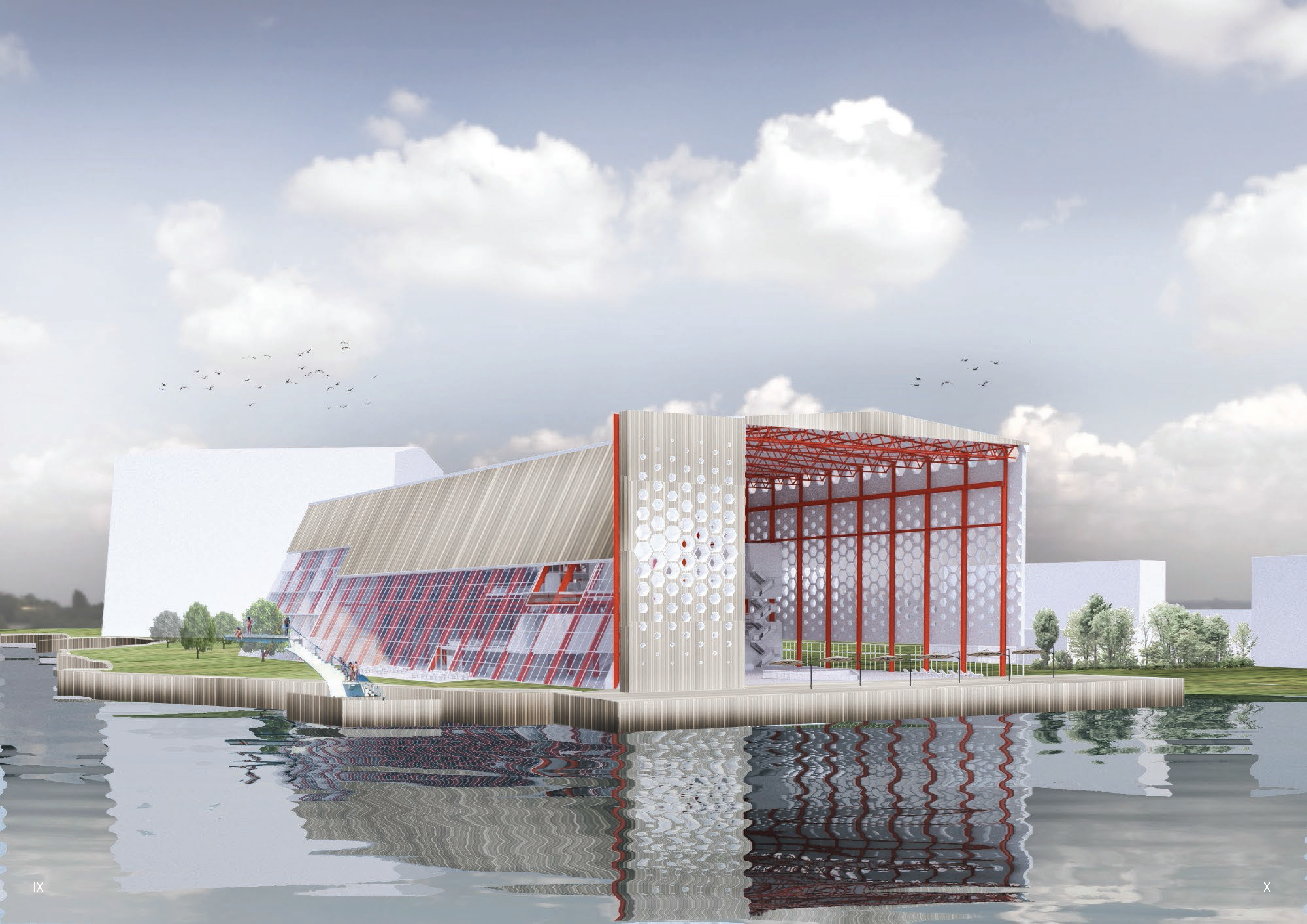
Analysen av dagslys, energi og livsløpsvurdering har blitt utført. På grunn av behovet for å sørge for passende termiske komfortforhold for innendørs svømmebassenger, er energibehovet opp til 276,79 kWh/m2 årlig. Totalt kreves det 411,3 kWh/m2/år for å dekke etterspørselen fra både svømmehallen og sykehjemmet. Solcellemoduler installert på sørtaket genererer 499 819 kWh årlig, og de kan alene dekke den elektriske energien som kreves om sommeren. Stålbjelkeplatesystemet ble foreslått ved å sette sammen ca. 1 000 tonn stålmaterialer fra andre strukturer, slik at det kunne spare 1469,9 tonn stål totalt. 10307,9 tonn betong spares også ved å gjenbruke det meste av sin tidligere struktur. Takket være gjenbruk av massive betong- og stålelementer, samt energiproduksjonen på stedet, sparte prosjektet henholdsvis 4,67 kgCO2e/m2/år og 5,41 kgCO2e/m2/år av totalt 13,32 kgCO2e/m2/år.

ACKNOWLEDGEMENT

I would like to express my special thanks of gratitude to my supervisor Michael Gruner for his supervision. I was able to finish my master's thesis thanks to his invaluable help and inspirations. Secondly, I also want to thank Bunji Izumi for his sincere advice on the structural stability of the project. Last but not least, thank you Sigurdur Gunnarsson from Asplan Viak for sharing his knowledge of Tønsberg and great feedbacks on the work.

Norwegian University of Science and Technology, May 2022.

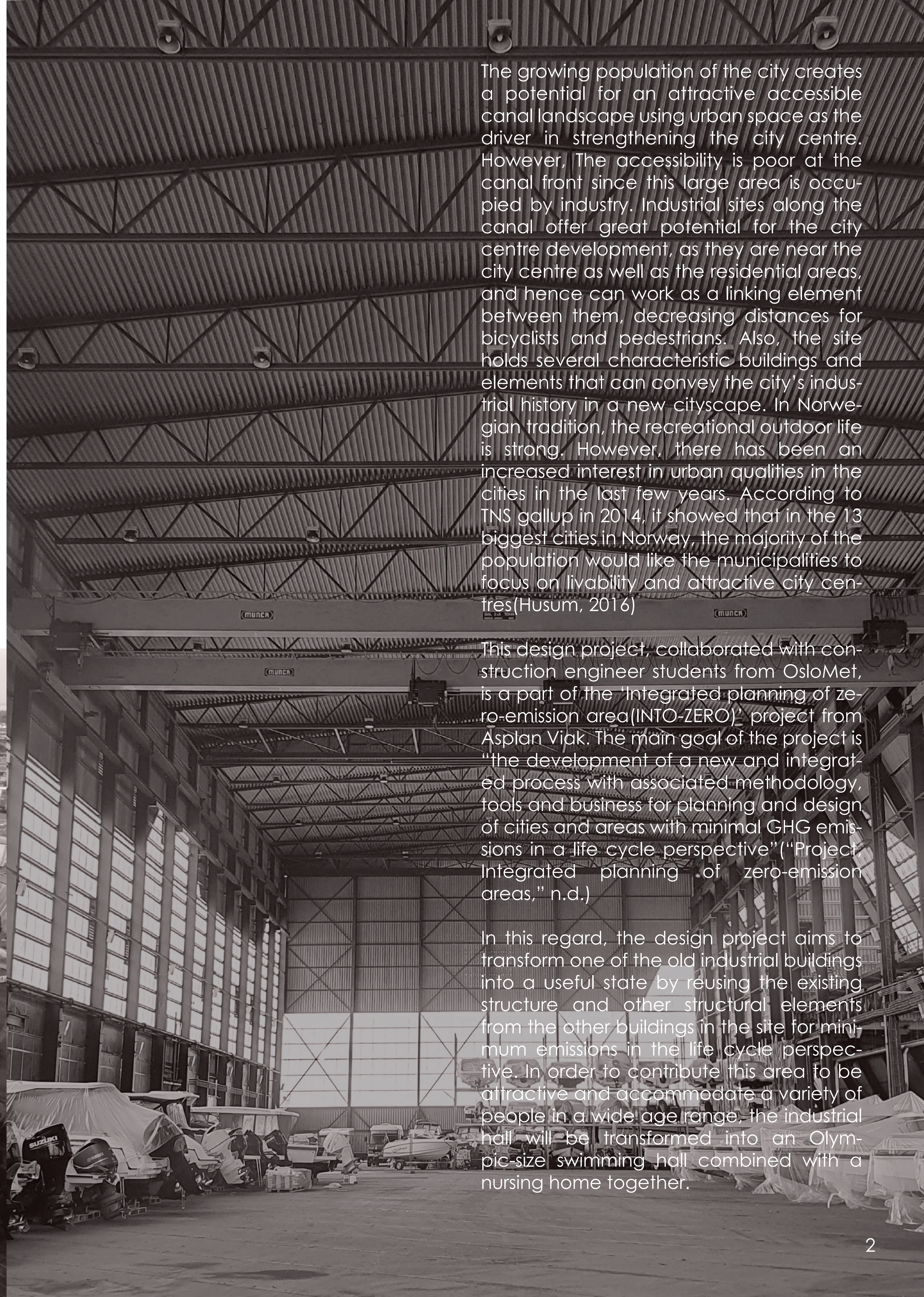
TABLE OF CONTENTS



INTRODUCTION

Tønsberg is a middle-sized city in southern Norway, located in the inner Oslo fjord. In the center of the municipality, Kaldnes Vest is located at the end of the canal axis on its west side which was previously a ship yard established in 1899. The yard focused on shipbuilding and have had produced large and complicated vessels constantly with several companies which have gone in and out through several decades. Due to a gradual reduction of the area-intensive industry in the North Sea, opportunities open up for modern urban development with a high concentration of jobs. Currently, the building has provided a temporary boat storage space for the small boats on trailers(“Takes the Kaldnes name back,” n.d.).

Source: https://storymaps.arcgis.com/stories/6d5e55e6e495453f8ce82548b02a1eab



The growing population of the city creates a potential for an attractive accessible canal landscape using urban space as the driver in strengthening the city centre. However, The accessibility is poor at the canal front since this large area is occupied by industry. Industrial sites along the canal offer great potential for the city centre development, as they are near the city centre as well as the residential areas, and hence can work as a linking element between them, decreasing distances for bicyclists and pedestrians. Also, the site holds several characteristic buildings and elements that can convey the city’s industrial history in a new cityscape. In Norwegian tradition, the recreational outdoor life is strong. However, there has been an increased interest in urban qualities in the cities in the last few years. According to TNS gallup in 2014, it showed that in the 13 biggest cities in Norway, the majority of the population would like the municipalities to focus on livability and attractive city centres(Husum, 2016)

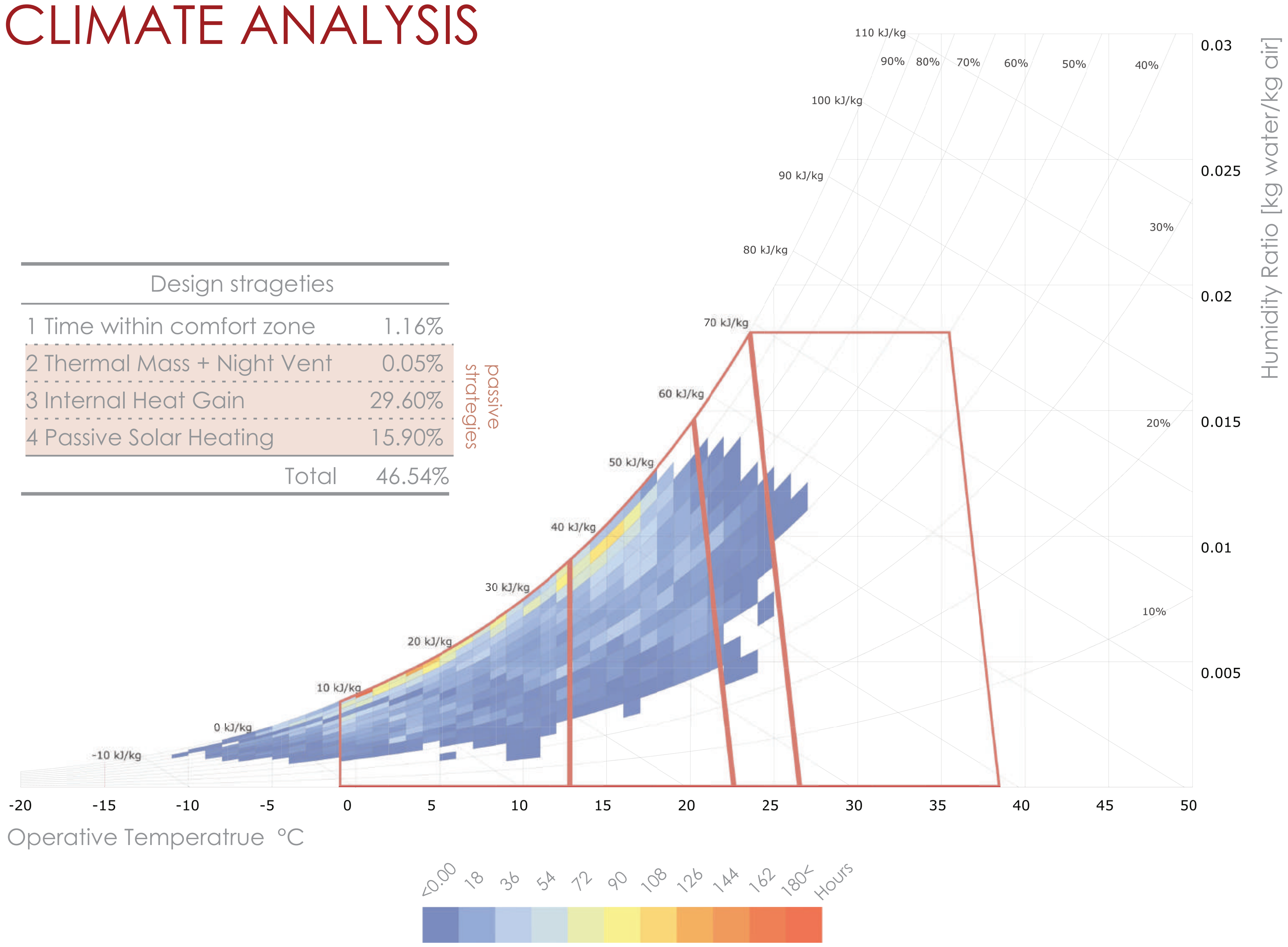
This design project, collaborated with construction engineer students from OsloMet, is a part of the ‘Integrated planning of zero-emission area(INTO-ZERO)’ project from Asplan Viak. The main goal of the project is “the development of a new and integrated process with associated methodology, tools and business for planning and design of cities and areas with minimal GHG emissions in a life cycle perspective”(“Project, Integrated planning of zero-emission areas,” n.d.)

In this regard, the design project aims to transform one of the old industrial buildings into a useful state by reusing the existing structure and other structural elements from the other buildings in the site for minimum emissions in the life cycle perspective. In order to contribute this area to be attractive and accommodate a variety of people in a wide age range, the industrial hall will be transformed into an Olympic-size swimming hall combined with a nursing home together.

CLIMATE ANALYSIS

Design stragegies	
1 Time within comfort zone	1.16%
2 Thermal Mass + Night Vent	0.05%
3 Internal Heat Gain	29.60%
4 Passive Solar Heating	15.90%
Total	46.54%

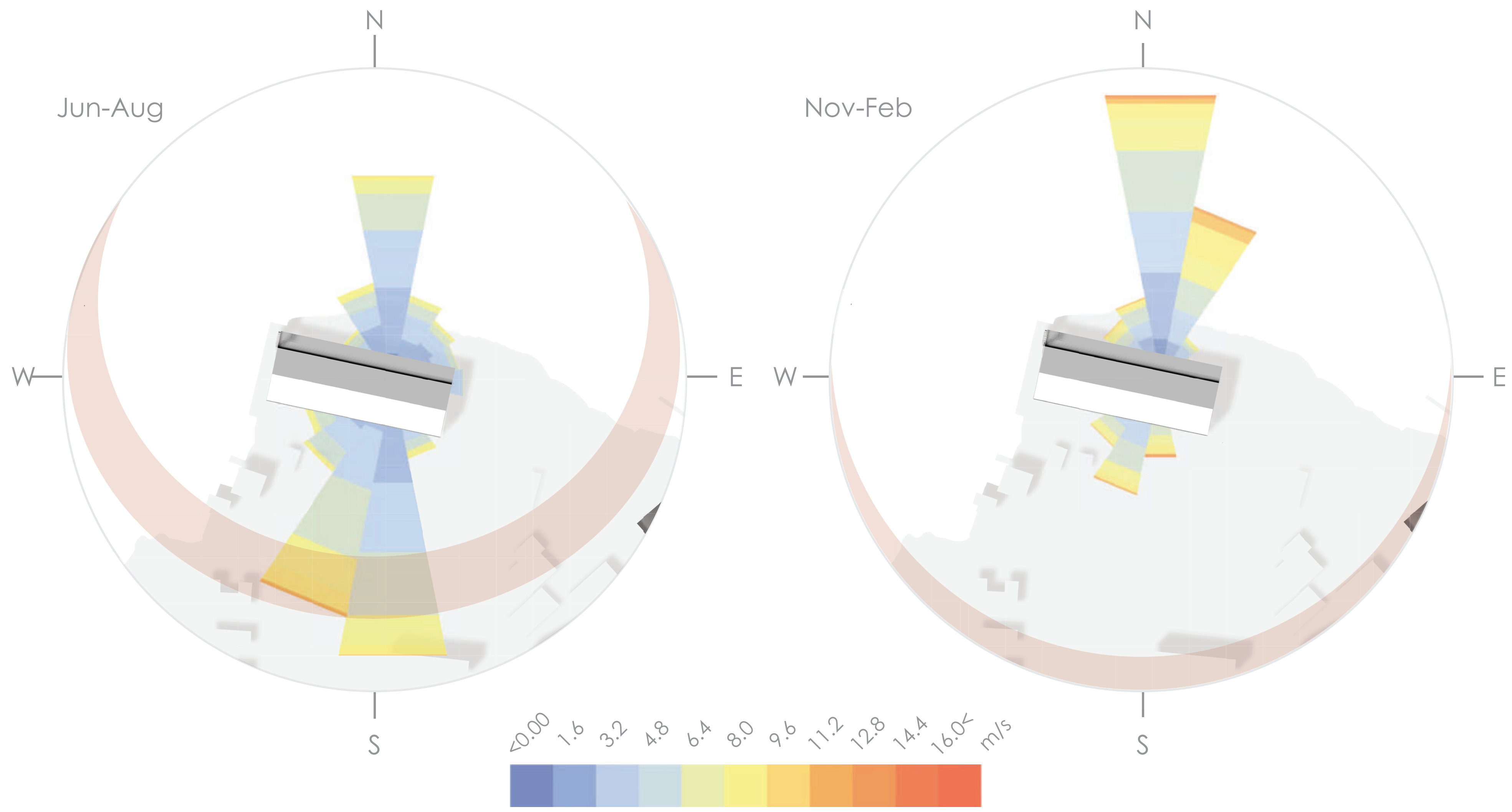
passive strategies



< Psychrometric Chart _ Sandefjord AP-Torp >

The climate of Tønsberg is mild, and generally warm and temperate. There is a lot of rain even in the driest month. According to Köppen and Geiger, this climate is classified as Cfb. The average temperature in Tønsberg is 7.4 °C. About 1046mm of precipitation falls annually. Precipitation is the lowest in April, with an average of 57mm and the greatest amount of precipitation occurs in October, with an average of 122mm("-Climate Tønsberg(NORWAY)," n.d.).

According to the psychrometric chart, the climate conditions of the site represent a comfort zone of 1.16 % during the year. The most effective passive strategy is keeping internal heat gains using low U-value constructions that are adding 29.6 %. In addition, to cover the coldest and driest periods below 13 °C, it needs the use of a the heating system combined with solar heating gain through the windows oriented to the south which provides an extra 15.9 % of comfort time. There is a short warm period of 0.05 % of the year that is covered by natural ventilation



SUMMER

Radiation comes mostly from the south and can go up to 436 kWh/m2 during the summer solstice. The wind blows from most of the direction but the most prevailing wind direction during summer is from the south and the north. The wind velocity reaches a maximum of 11.2 m/s in the south and 9.6 m/s in the north

WINTER

During the winter, the velocity of the winds is higher than in the summer in most directions. The prevailing wind is coming from the north side and it reaches to a maximum of 14.4 m/s.

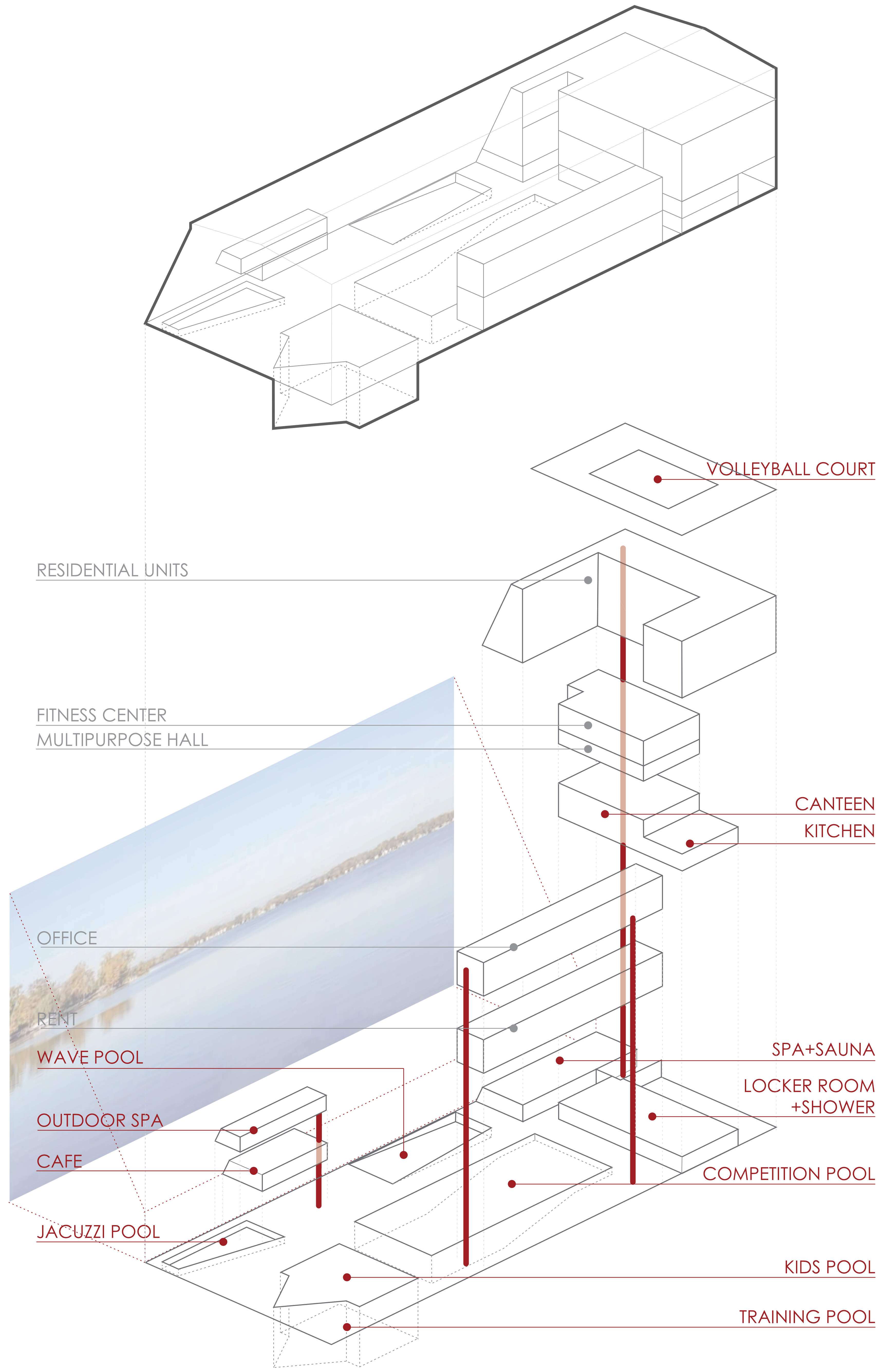
HALL A
PROJECT SITE
200m
400m
600m
800m
1000m
1200m
HALL B
165 000 m2
HALL A

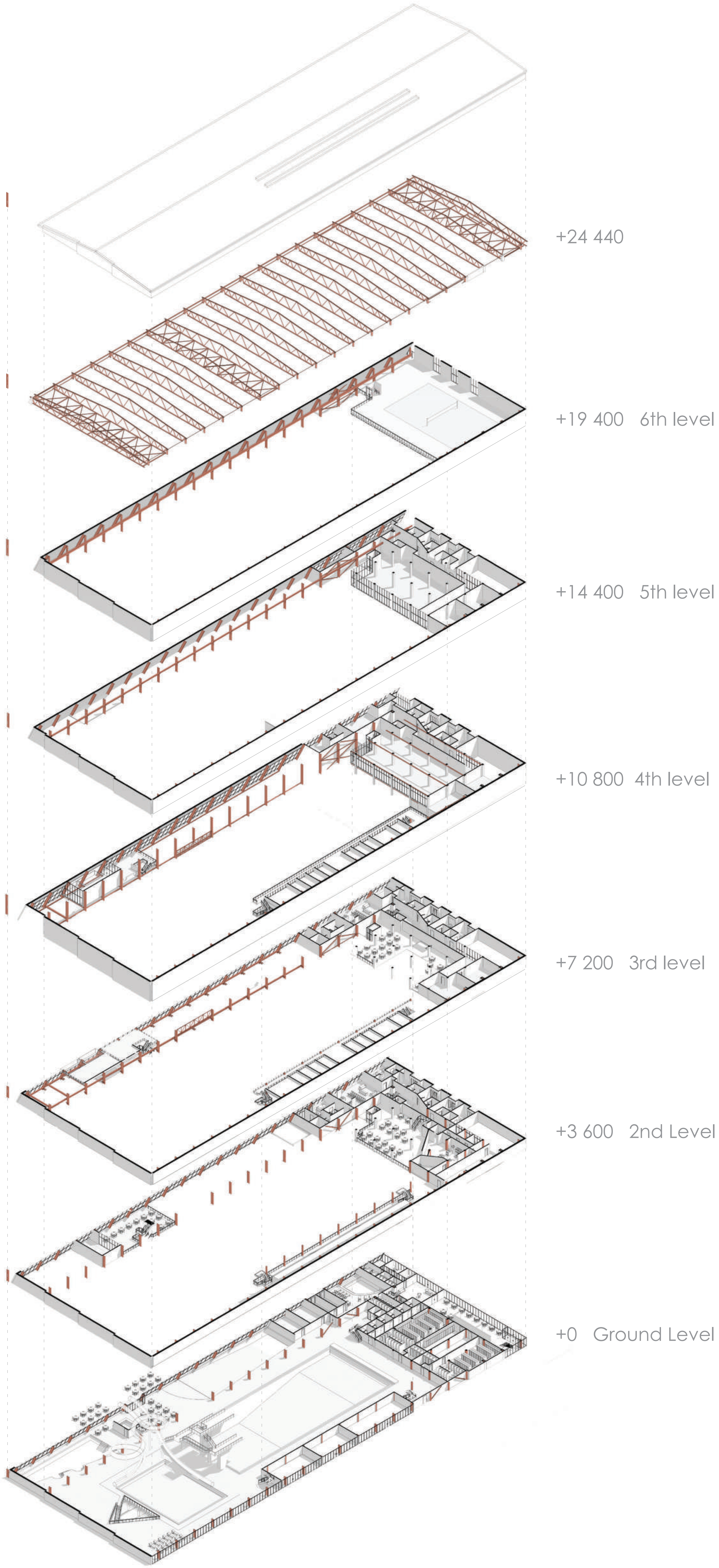
PROGRAMS

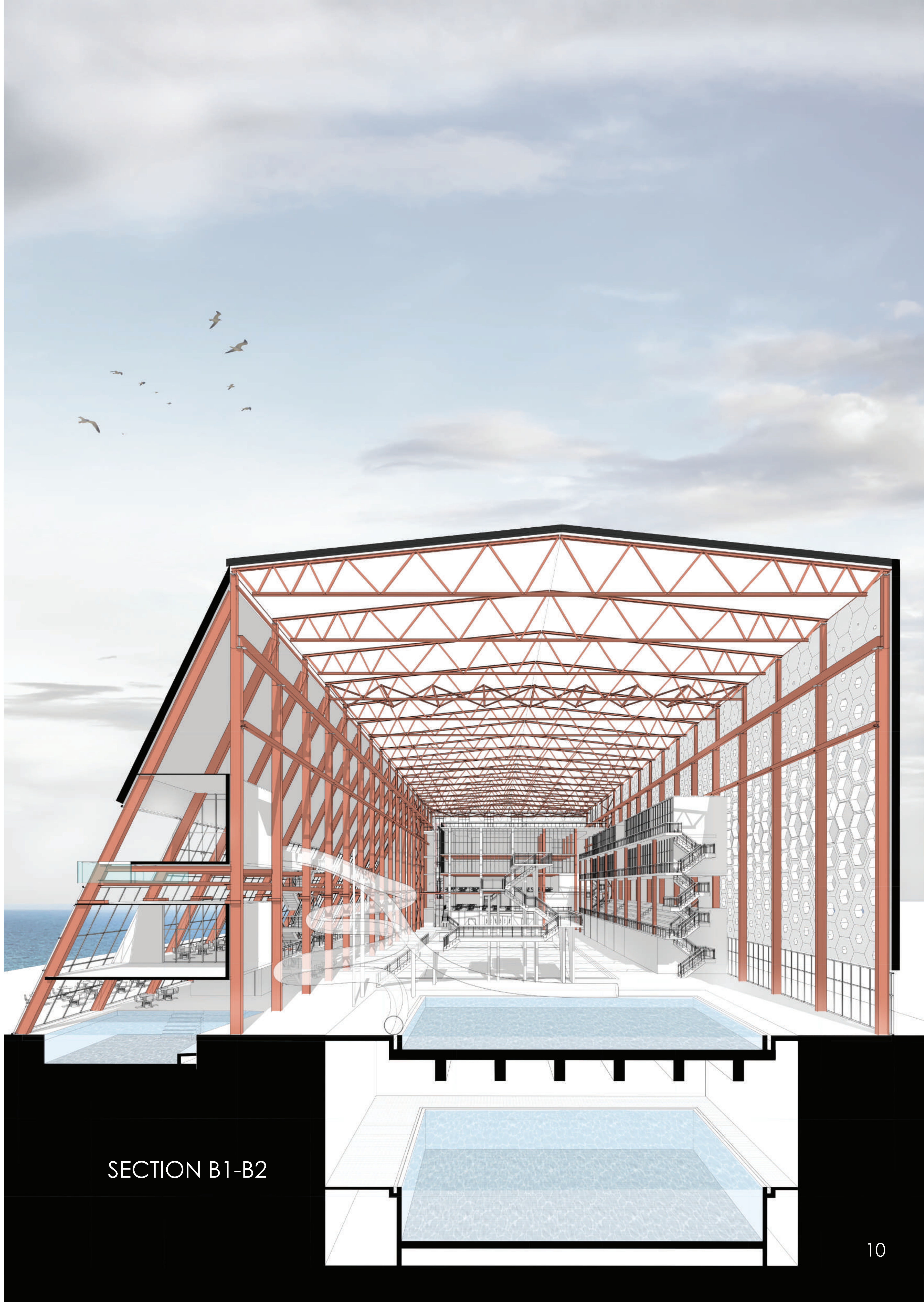
Deploying programs in the project mainly derived from the idea of taking advantage of the existing structural benefit. The construction had two big cranes on the top that have a capacity of 64 tons and 400 tons respectively. One of them was disassembled previously and there is still the structure of the vertical bracing system around the disassembled crane which could bear the load of 400 tons. Furthermore, the building has huge frames on both east and west façades for the full height sliding doors.

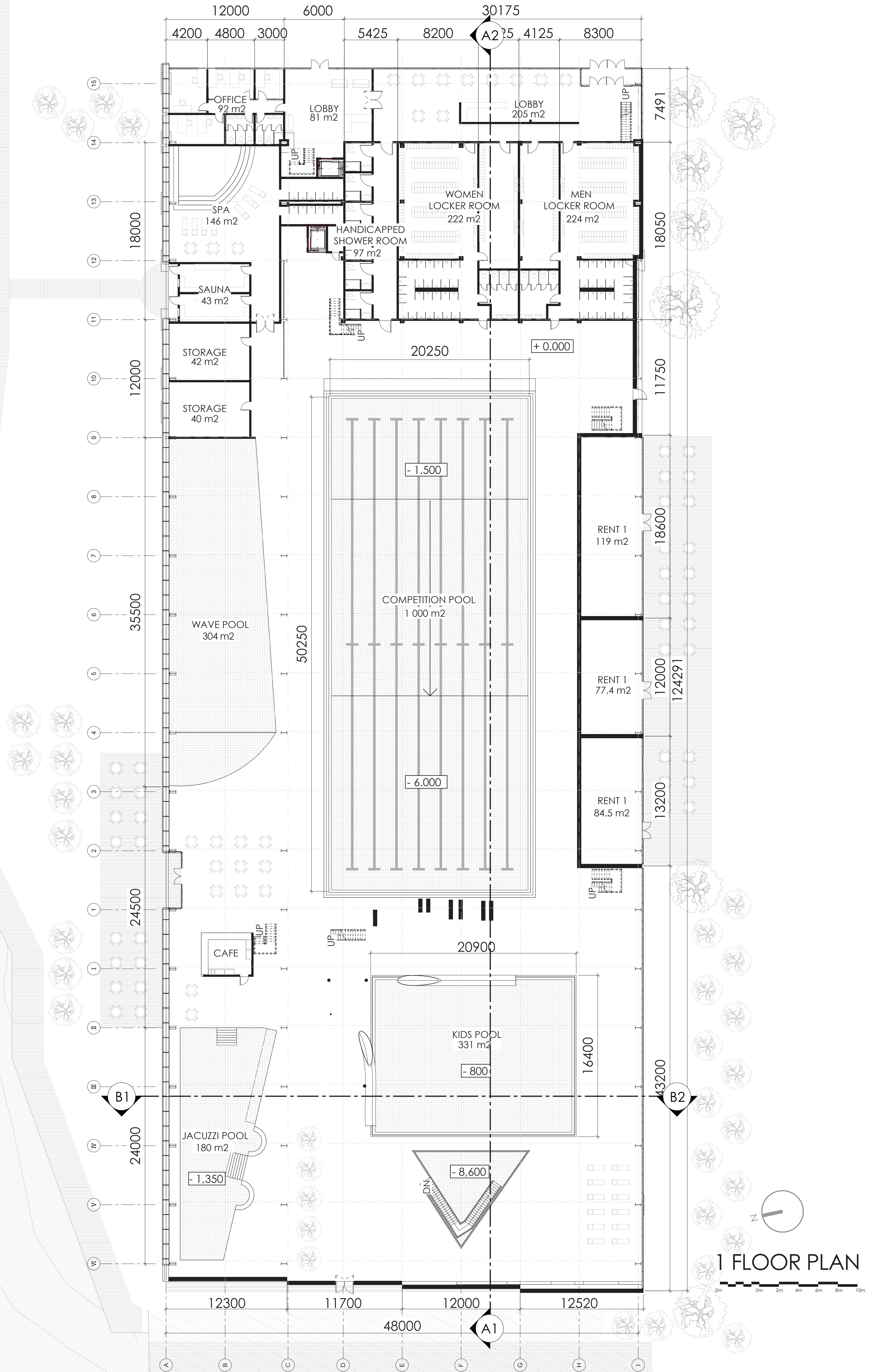
The site has a strong potential to extend the promenade up to the end of the canal that is closed currently. On the west side of the project it could accommodate various activities connecting indoor places to outdoor shoreline.

Due to its structural strength and potential to create unique activities on the site, additional floor slabs are gathered on this plot mostly and it could make open space on the west side facing the sea.

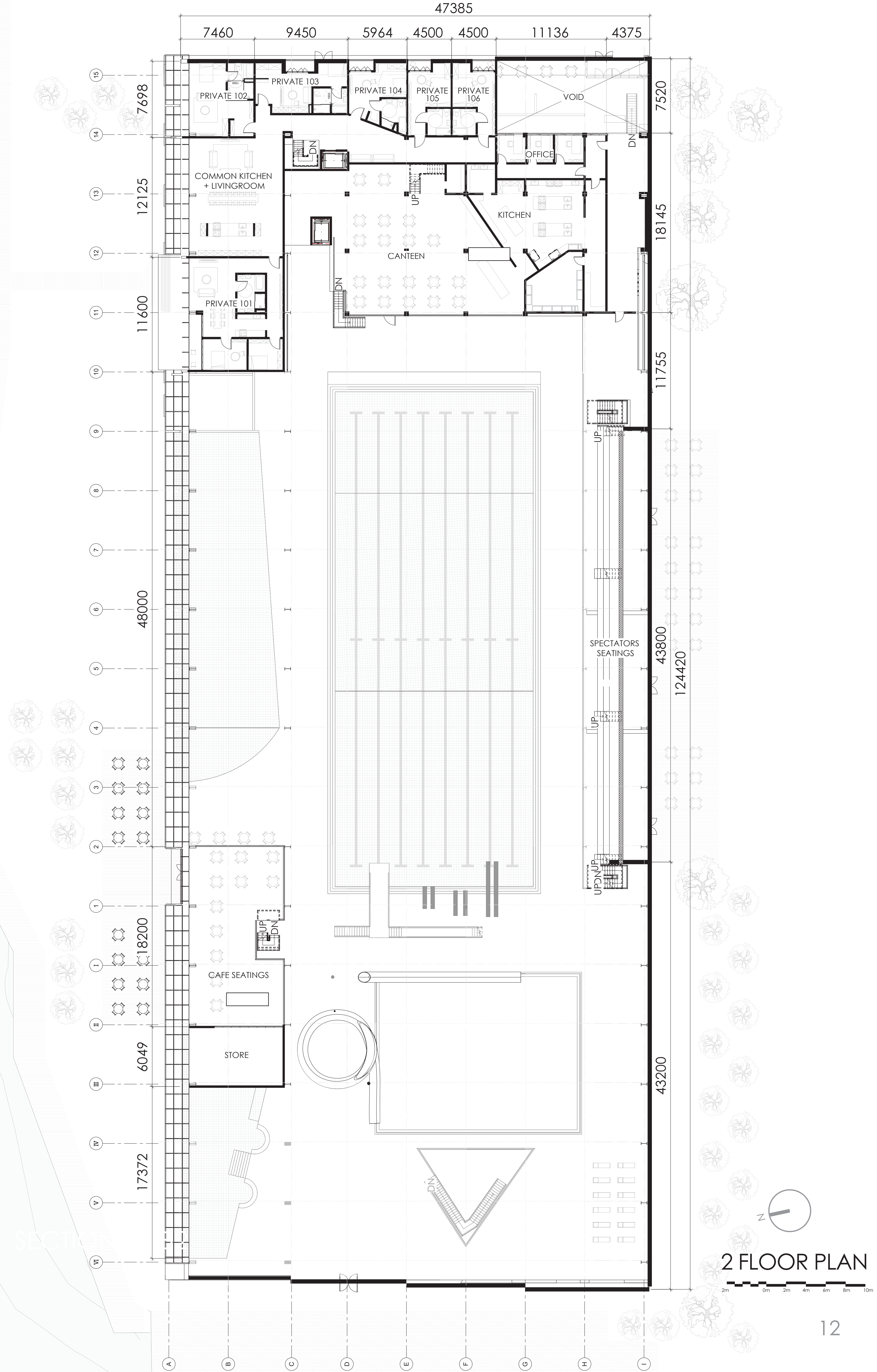



+24 440
+19 400 6th level
+14 400 5th level
+10 800 4th level
+7 200 3rd level
+3 600 2nd Level
+0 Ground Level

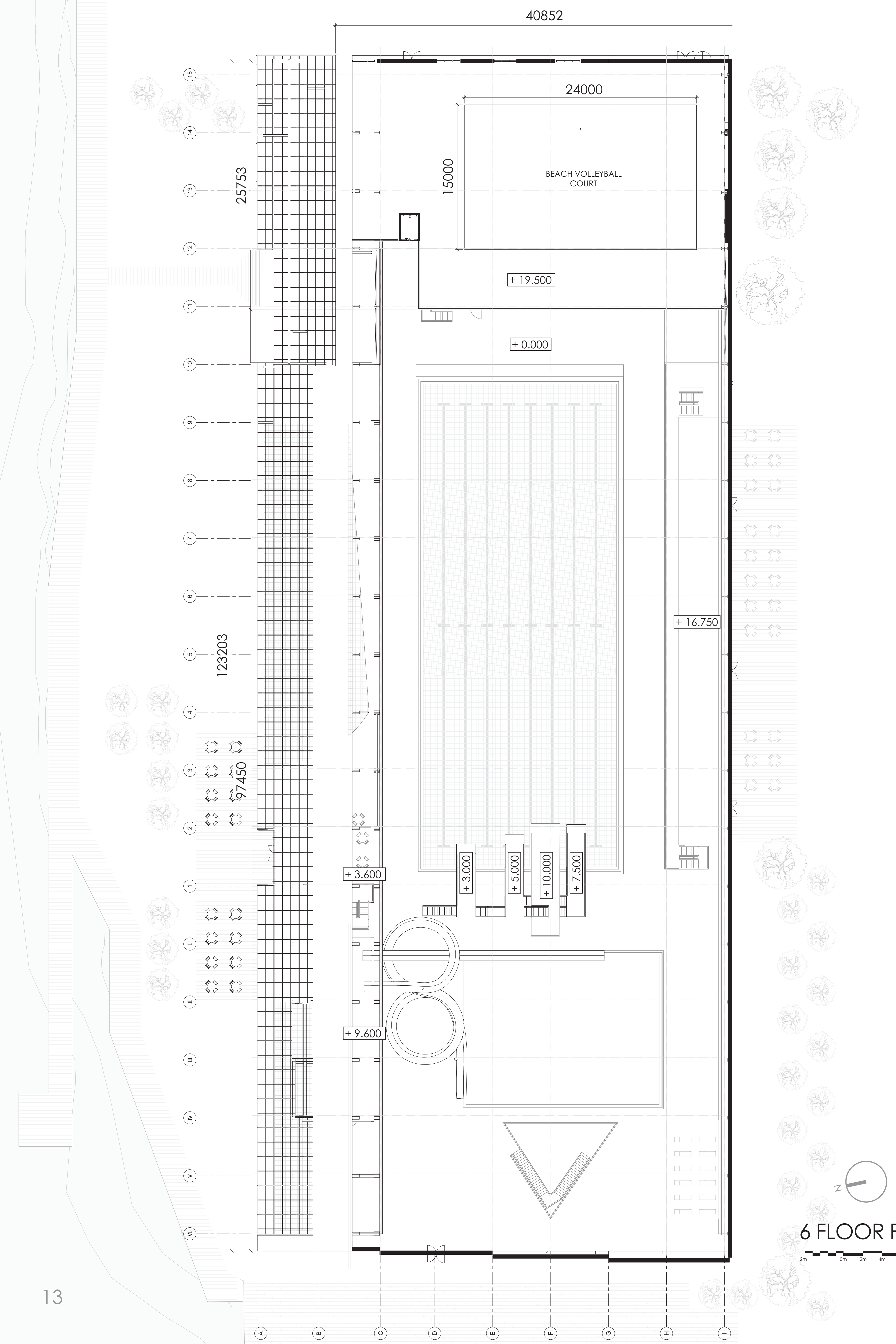

SECTION B1-B2



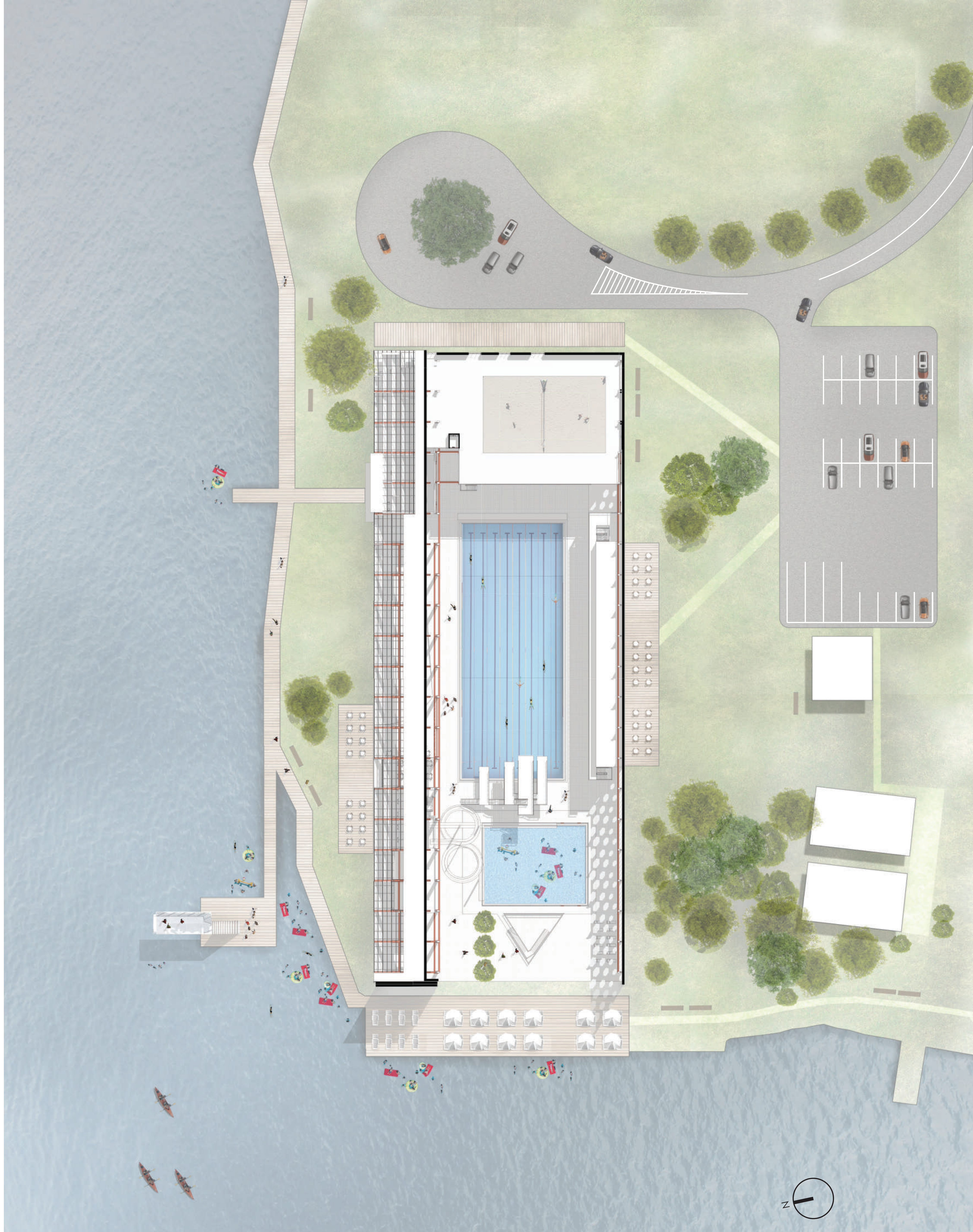
1 FLOOR PLAN



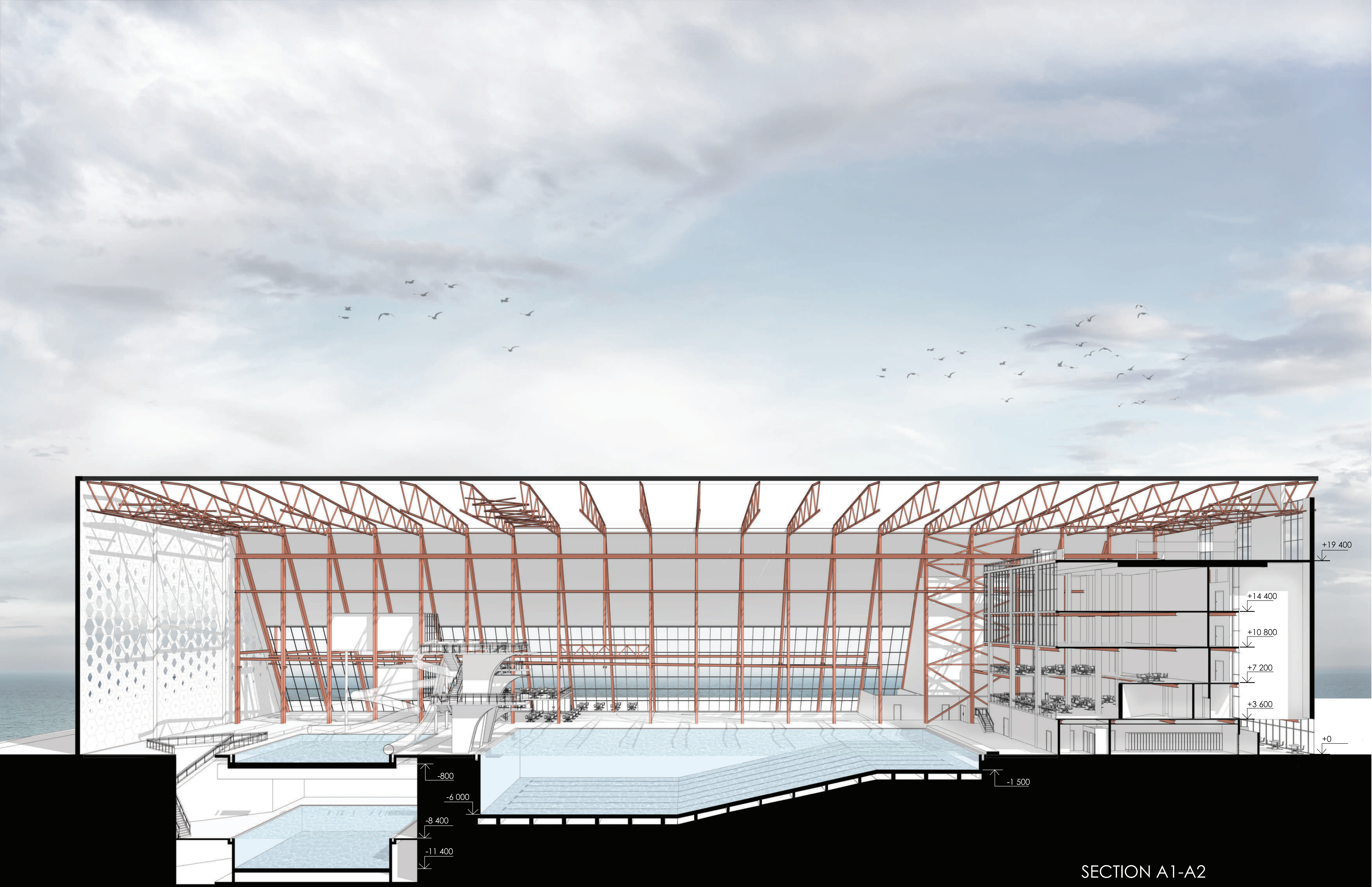
2 FLOOR PLAN



6 FLOOR PLAN

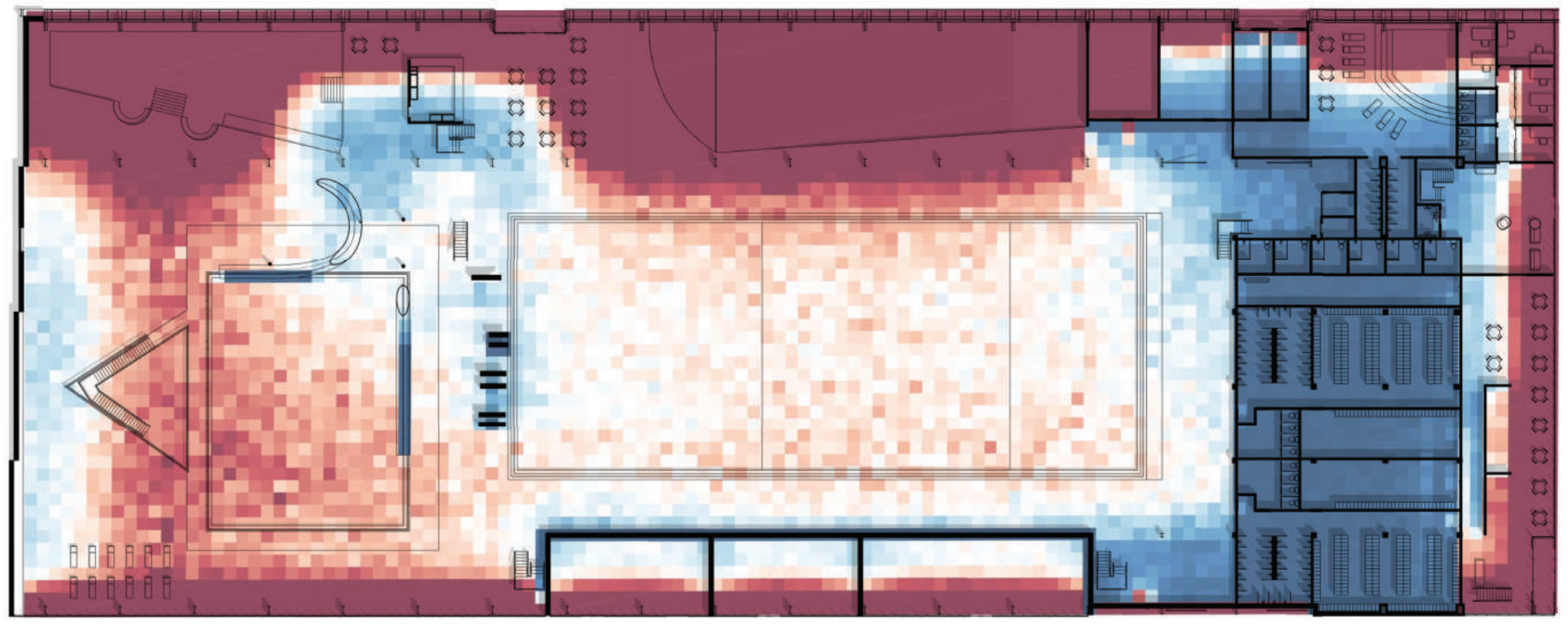


SITE PLAN

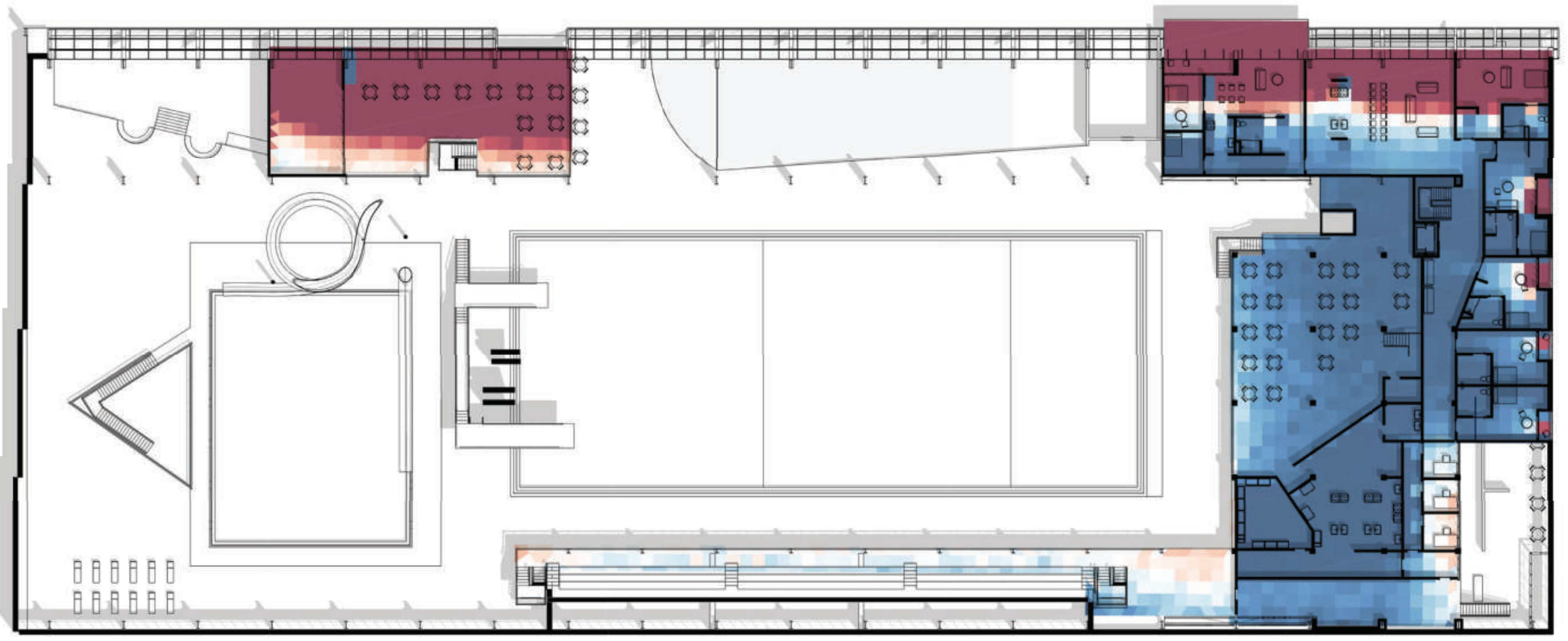


SECTION A1-A2

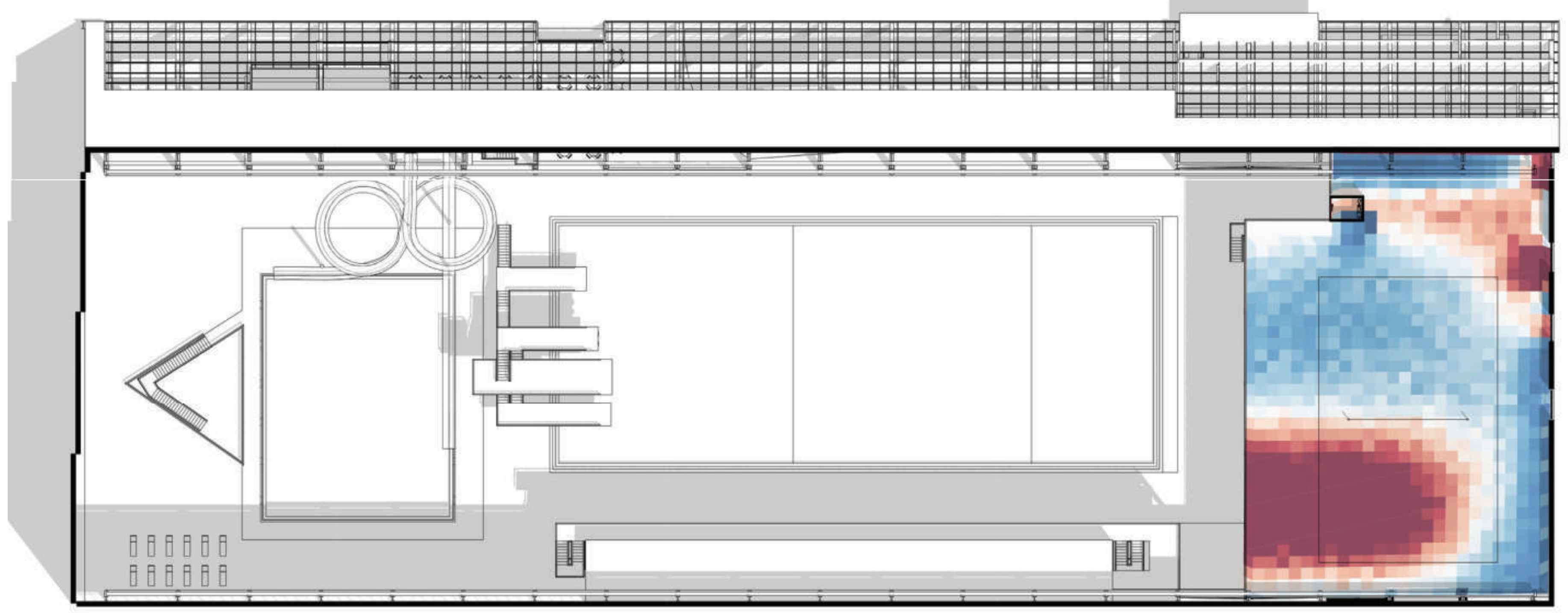
DAYLIGHTING ANALYSIS



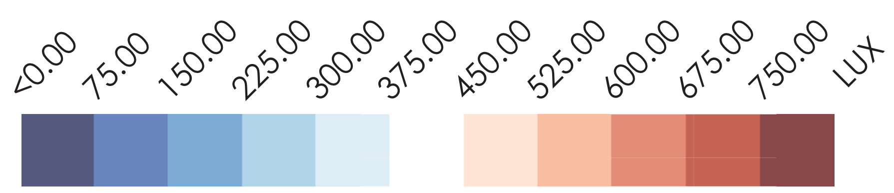
1ST FLOOR



2ND FLOOR



6TH FLOOR



For the public pool, there are several guidelines of regulations determining specific daylighting conditions. The UK's Chartered Institution of Building Services Engineers(CIBSE) Society of Light and Lighting(SLL) specifies the requirements of the level of illuminance for a wide range of applications.

According to SLL Guide 4: Sports Lighting, levels increase depending on the level of competition, from an Olympic televised pool to local leisure center. Typically most pools require between 200-700 lux. Generally, over 300 lux is enough to indoor pool but in case of competition pool it may require 500 lux or more.

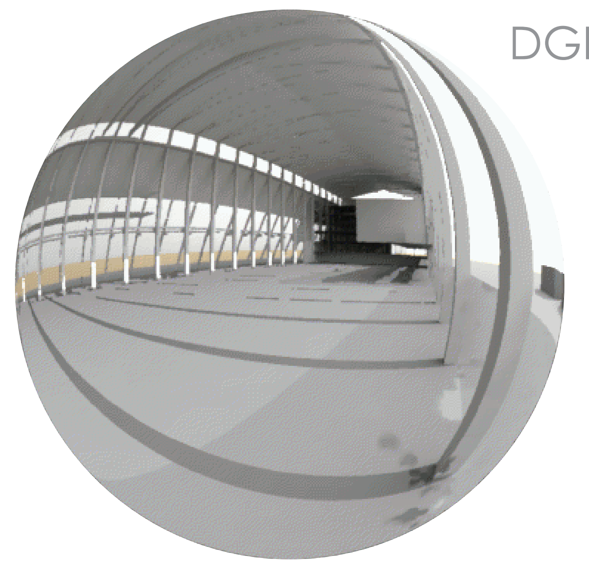
The guide divided regulations into 3 different classes in terms of the size and capacity of facilities. The project is catergorized in Lighting class II, a mid-level compeition level which can accommodating county regional competition, and has medium spectator capacities with medium viewing distance. The programs the building accomodates comply with the recommended illuminance level of indoor pool such as volleyball court, and fitness trainning as below. However the uniformity(U0), the ratio of the minimum illuminance to the average illuminance(Emin/E) was not able to reach to the recommended level.

< Table of recommendation of illuminance level >

Group	E_{av}	U_0(E_{min}/E_{av})
swimming/diving /racing/polo/synchronised*	300 lux	0.7
volley ball(indoor)*	500 lux	0.7
fitness training*	500 lux	0.8
Canteen, pantries**	200l ux	-
writing/typing/reading data processing**	500 lux	-
residents(no visual task)**	180 lux	-

* CIBSE SLL Guide 4 : Sports Lighting
** EN 12464-1
*** EN 12665

Glare from light fixtures or glazed openings must be minimized to the lifeguards' advantage and eliminated where eyesight cannot penetrate the water's surface through to necessary depths. This potentially dangerous glare results from the light being reflected off the water from a light source located in front of the lifeguard and can be reduced by using indirect lighting sources or using light sources at a steep angle of incidence(Strange et al., 2017). However since the plan for the indoor lighting is out of the project scope, only glare resulting from daylighting is examined. The glare is imperceptible level with a DGP(-Daylight Glare Probability) of 0.29 from the ground floor.



< Glare examination from 1st floor >

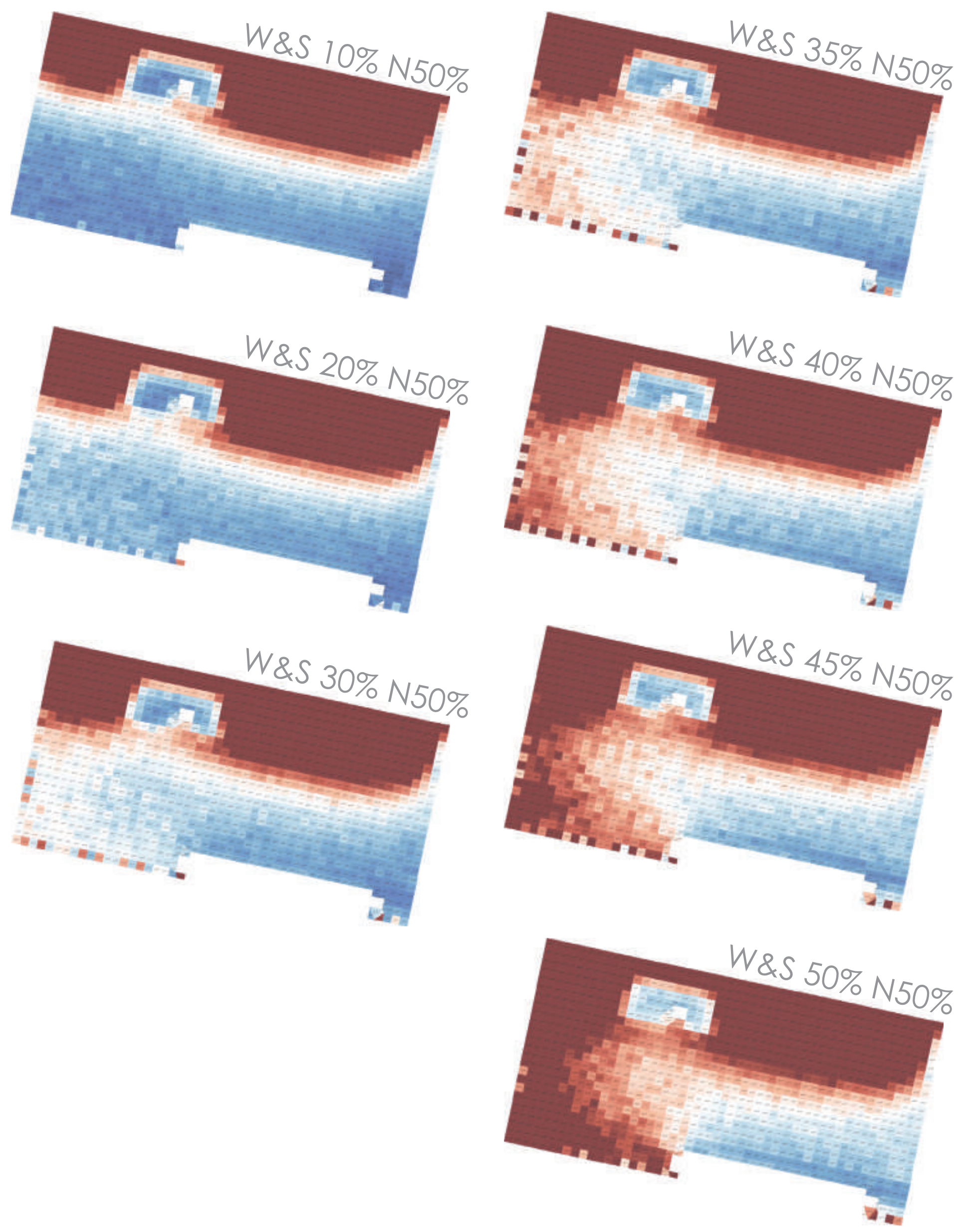
< Daylight glare comfort classes and relative DGP thresholds >

Criterion	DGP
Glare is mostly not perceived	DGP ≤ 0.35
Glare is perceived but mostly not disturbing	0.35 < DGP ≤ 0.4
Glare is perceived and often disturbing	0.4 < DGP ≤ 0.45
Glare is perceived and mostly intolerable	DGP ≥ 0.45

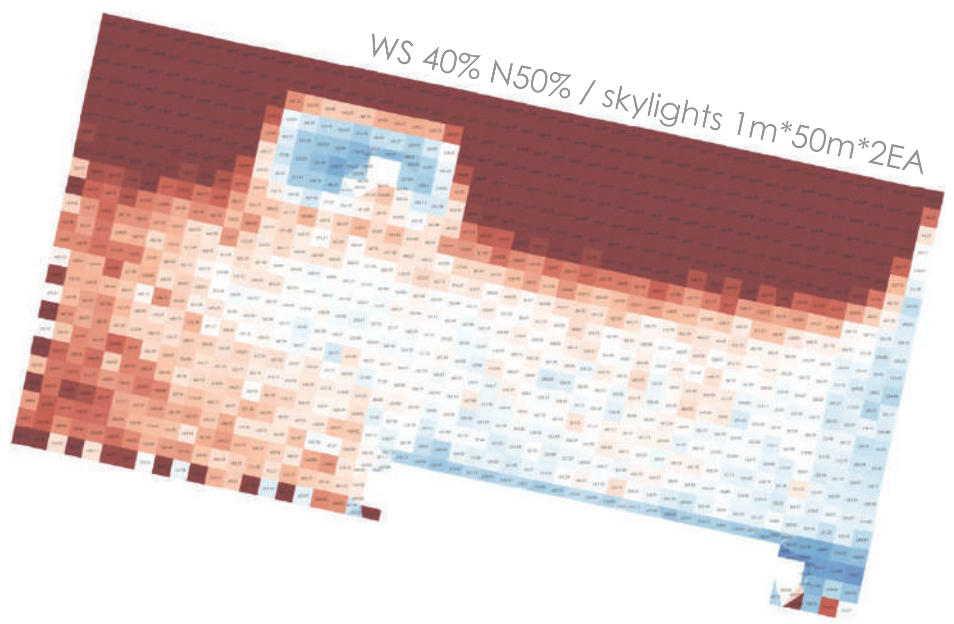
Source(Wienold, 2009)

FACADE OPTIMIZATION

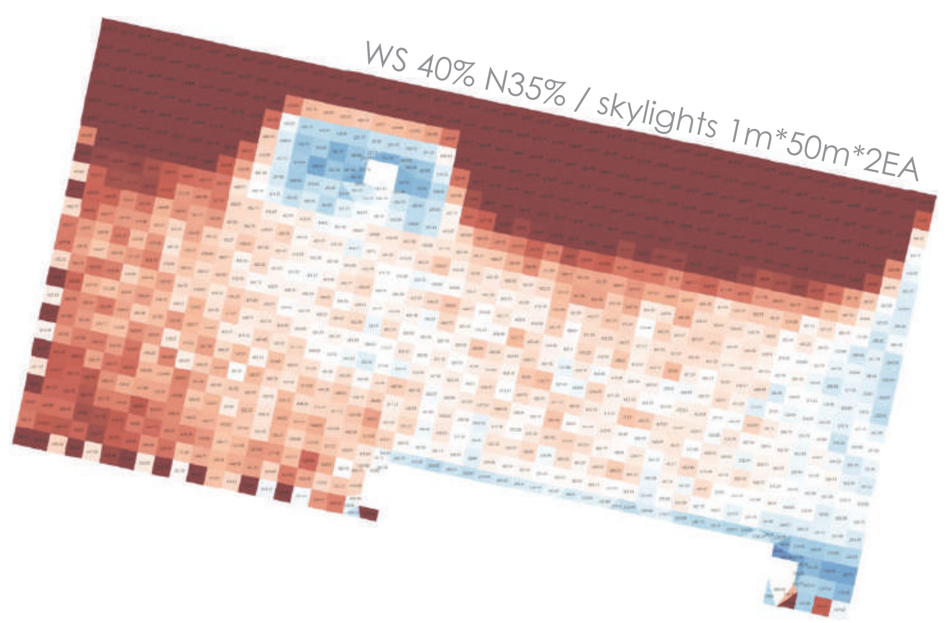
Window wall ratio (WWR) is an important factor to decide not only indoor daylighting conditions but also energy demand of the building. In order to optimize WWR of the pool it was tested with the fixed north glazing while modifying the south and west facades since the north view facing to the the canal is regarded significant element for the users' quality experiences. Also, the east side is neglected for the simulation as there is an internal walls shared by the nursing home section. The tests collected area percentage which ranges from 300 - 750 lux. A careful examination was needed particularly on the competition pool as it has a two-floor-high office on its south which blocks the direct sunlight into the pool.



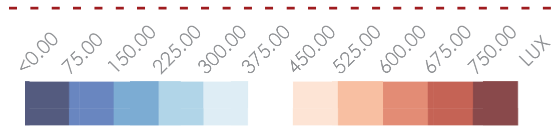
TEST ROUND 1 Adjusting WWR on west and south facade



TEST ROUND 2 Optimizing area of skylights



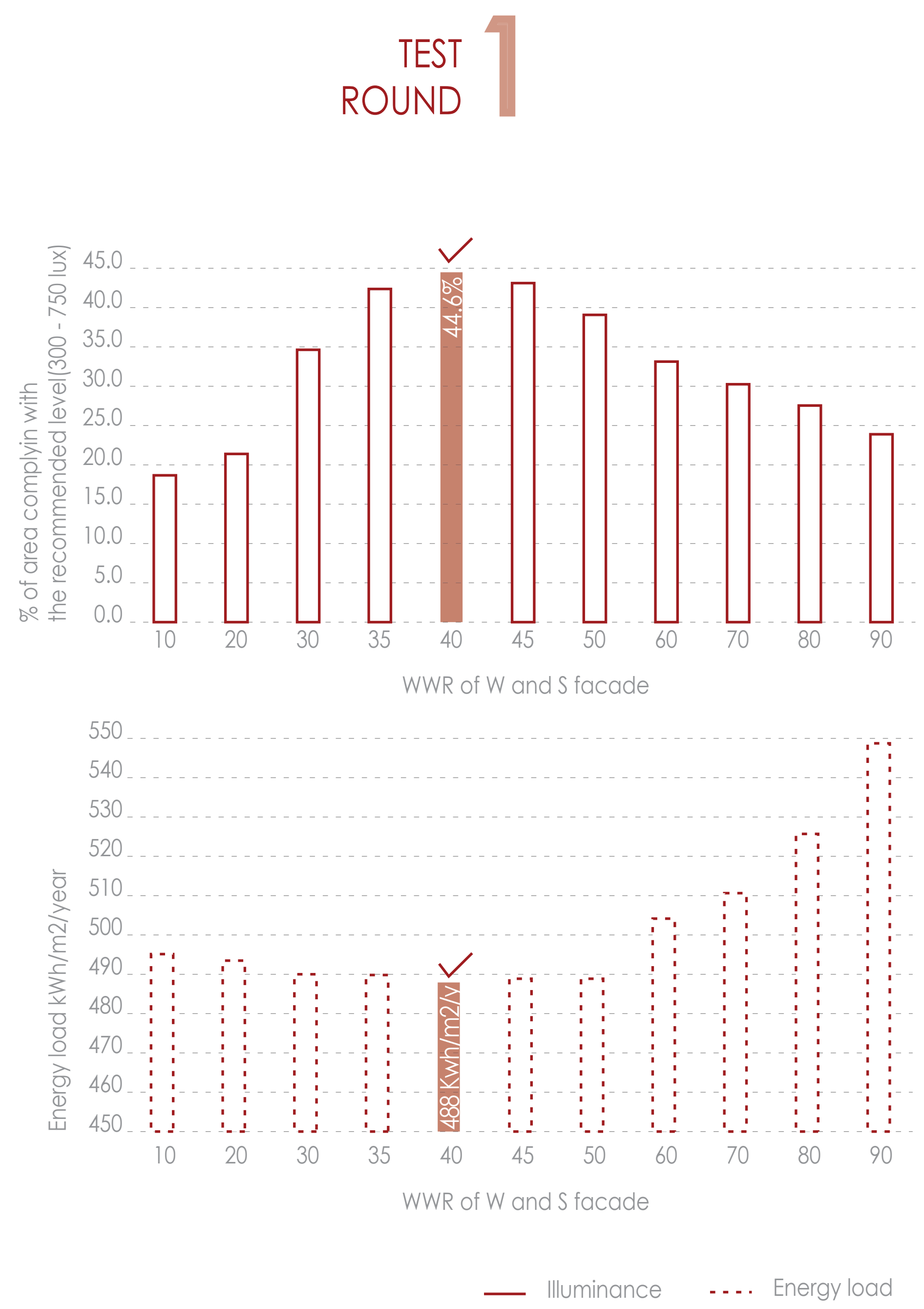
TEST ROUND 3 Adjusting WWR of the north facade



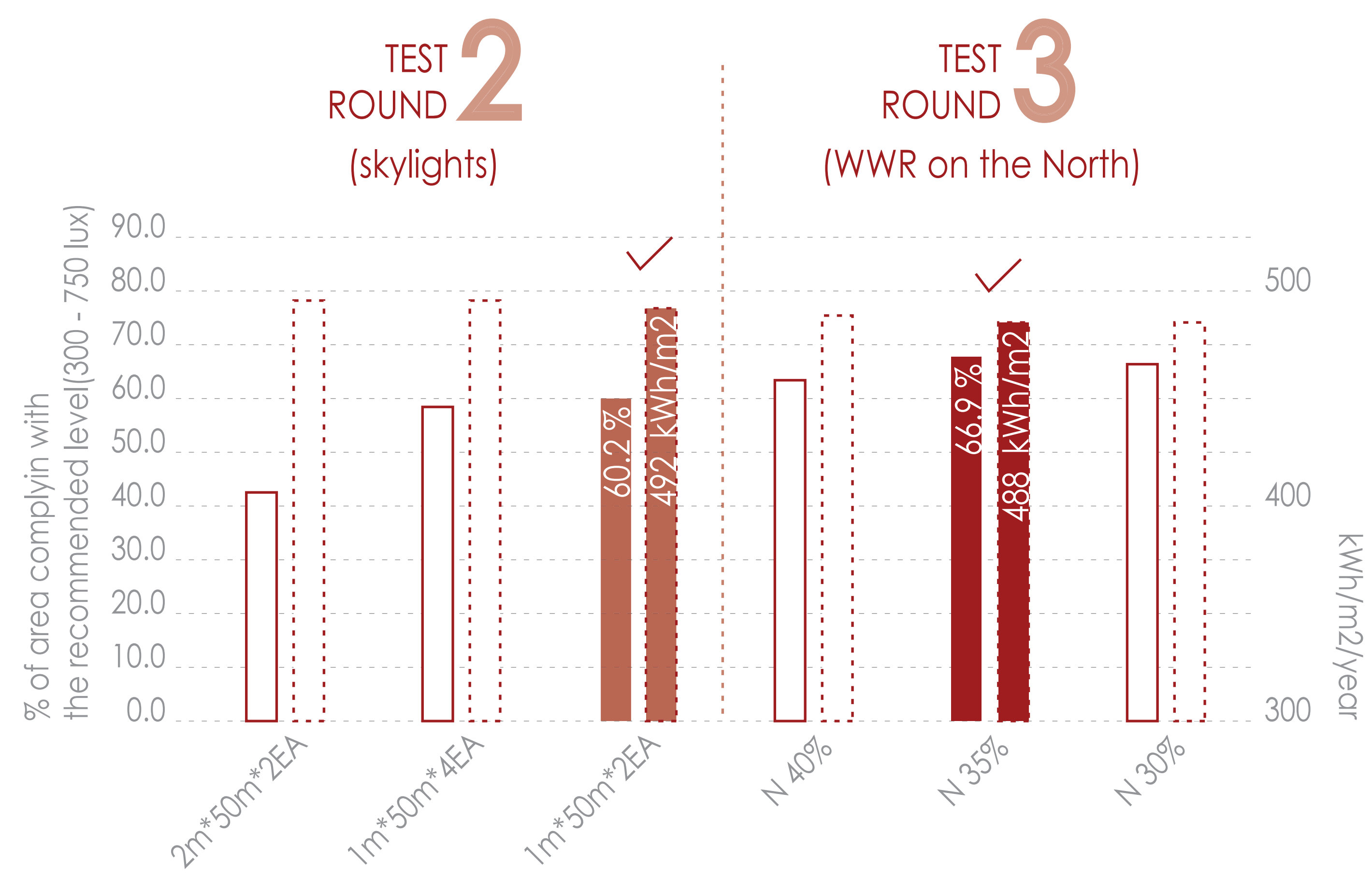
As a result of the first test, 40% of WWR is the most efficient ratio for the west and south facades considering both energy demand and illuminance level. However additional adjustment was necessary as the water surface on the competition pool was not still bright enough to meet the requirement. Several scenarios of the skylights were simulated and the horizontal glazings along the long span of the competition pool with the dimension of 1m*50m turned out the most efficient one distributing daylights evenly on the water surface with the lowest heating demand. However, the energy load for lighting is not much affected by the addition of skylights.

Generally, glazings on the north facade affect the energy demand of the building significantly. Adjusting the WWR on the north side showed that heating demand is changing a lot depending on its ratio. As a result, 35% of the glazing is considered an optimized ratio on the north side taking into account daylighting conditions.

Because these simulations are to figure out what the best envelope scenario is, the energy model from Grasshopper was made as simple as possible with general input values therefore the results of the energy demand are not really realistic.



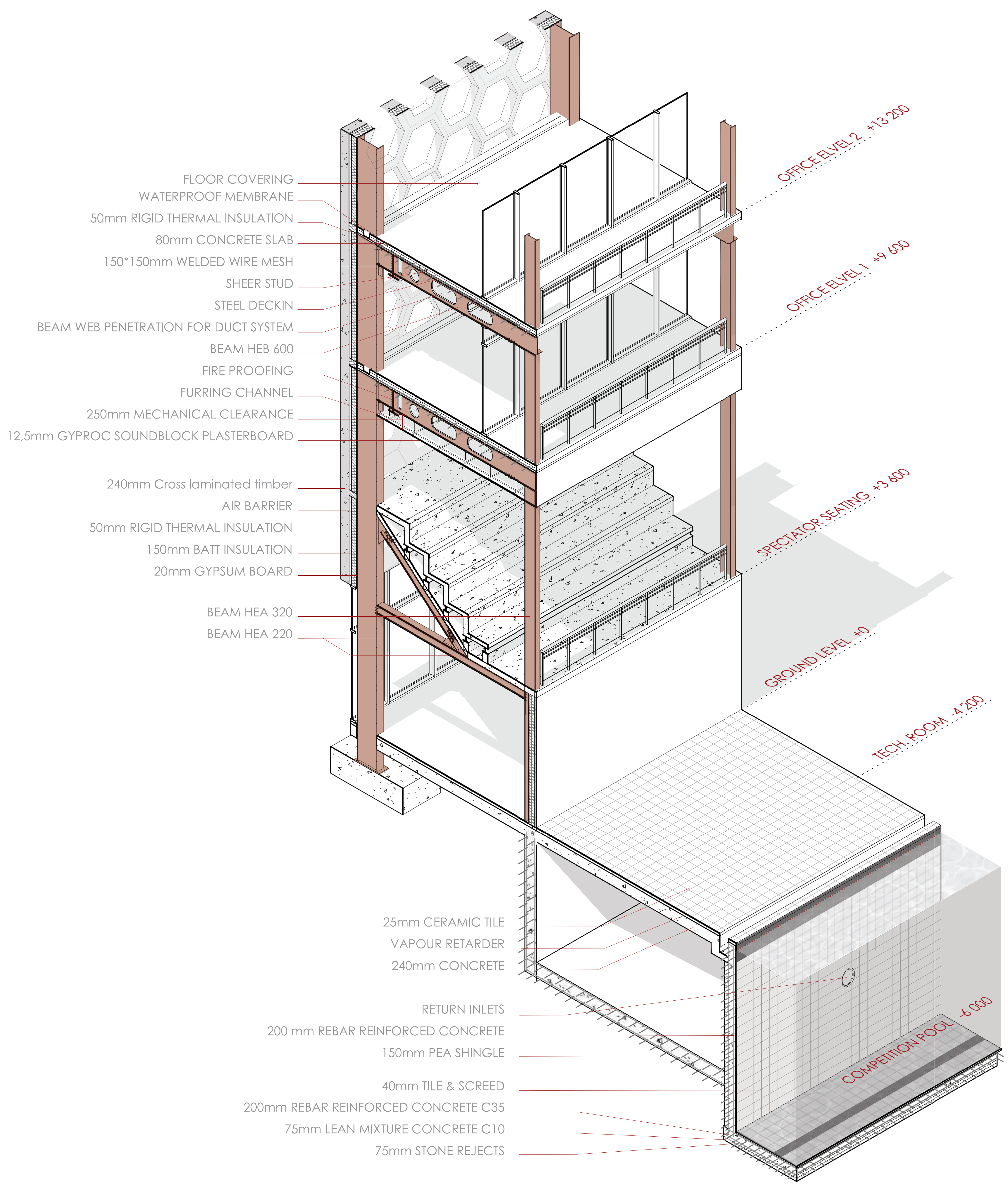
< Illuminance level and energy load depending on WWR >



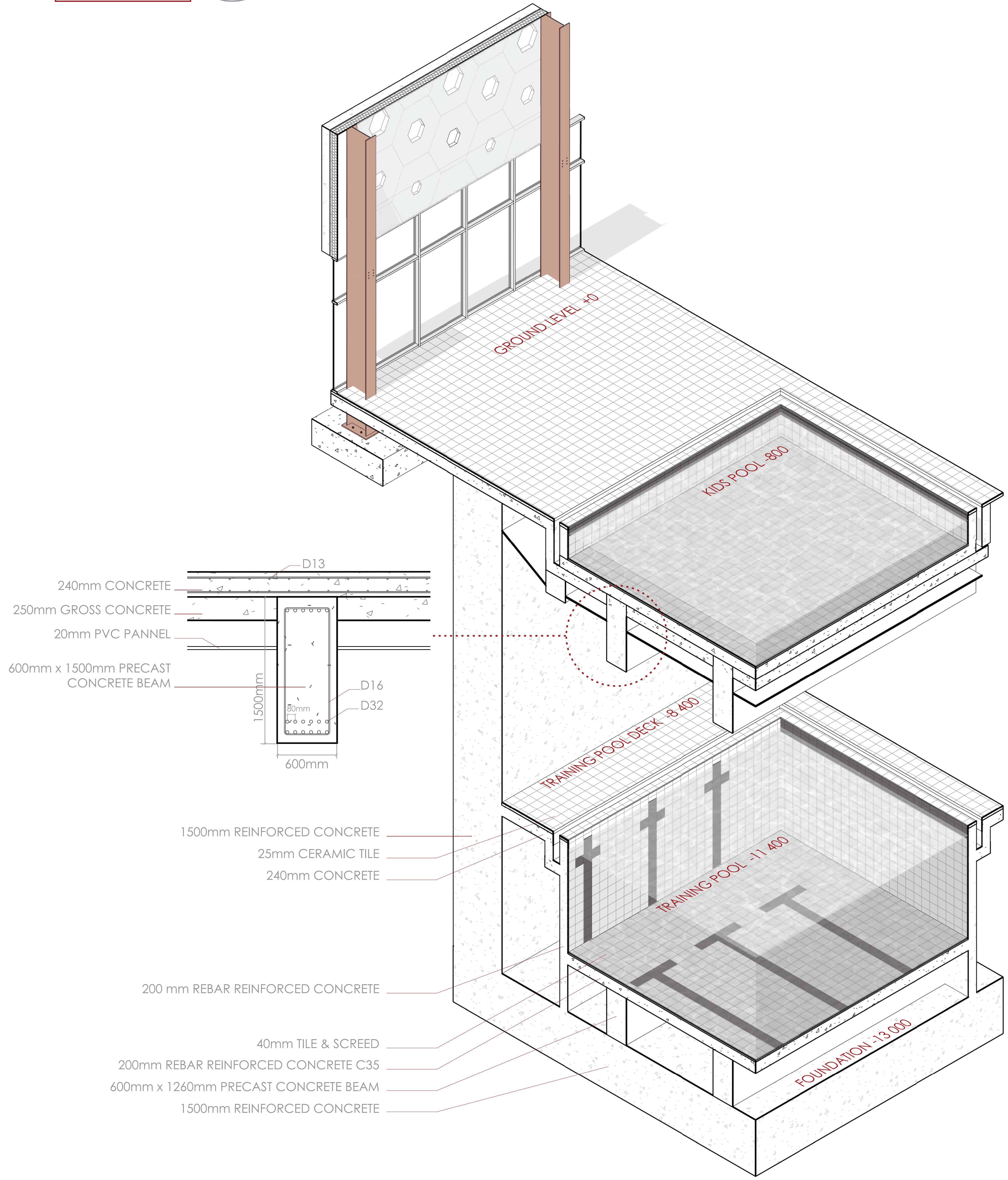
< Optimizing WWR and skylights >

STRUCTURAL DETAIL

AXIS 3-4



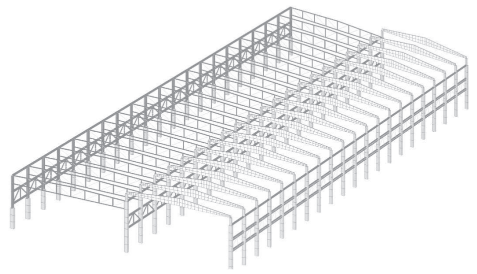
AXIS III-VI



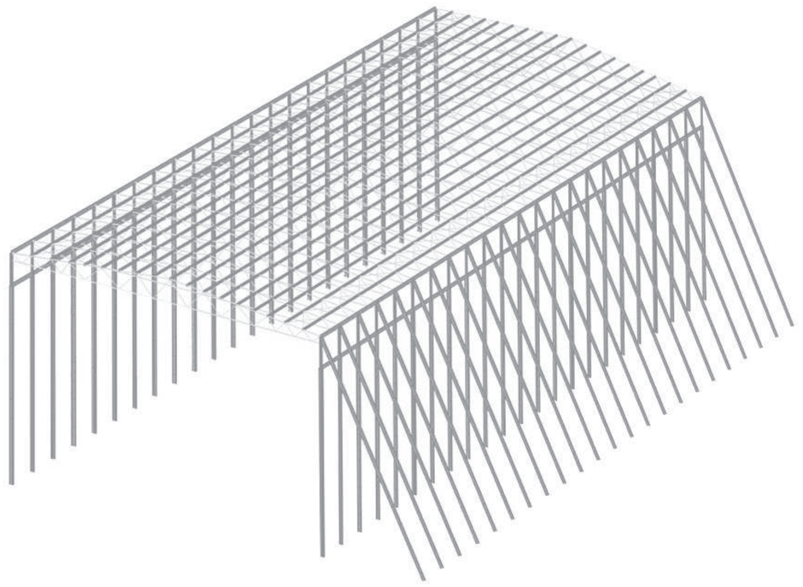
PROPOSAL
STEEL JOIST SLAB SYSTEM

According to a report from Bioregional(2009), there is a 96% environmental impact saving from reusing steel sections compared to procuring new steel. However, due to the lack of incentives for steel reuse and barriers to hamper its resue, it is estimated that the resue of steel sections at merely 6% compared to 93% being recycled(Sansom & Avery, 2014). In order to reuse as many existing steel materials in the project, a steel joist slab system was proposed by OsloMet. The project has 6 floors covering the eastern part of the plot where it was previously a big void space that is going up to 27 meters high. These slabs could be assembled by taking advantage of huge material sources from two other halls. Unfortunately, the steel elements of hall A were too old and rusted also most of them are combined with concrete elements together so it was not possible to collect them to assemble the slab system. However, hall B, the largest structure among those three industrial buildings, has a significant potential for reuse. Because most of the elements are not welded to each other but connected with bolted stud connections, it would not be difficult to salvage beams and columns without significant damage.

As a result, it could save more than 1 000 tons of steel from two other halls. As they have different dimensions for each element, the height of the slabs might differ from each other ranging from 600mm to 1 200mm. Since there are technical barriers to structural steel reuse, it is recommended to develop an automated deconstruction process in order to reduce deconstruction times and labor load. For design teams, it is highly recommended to start sourcing out all the elements at an early stage of the project. In addition to the technical barriers, there are three other main concerns; sourcing of steel, cost of steel resue, and the re-certification which are out of the project's scope but should be carefully handled(Tingley, 2014).



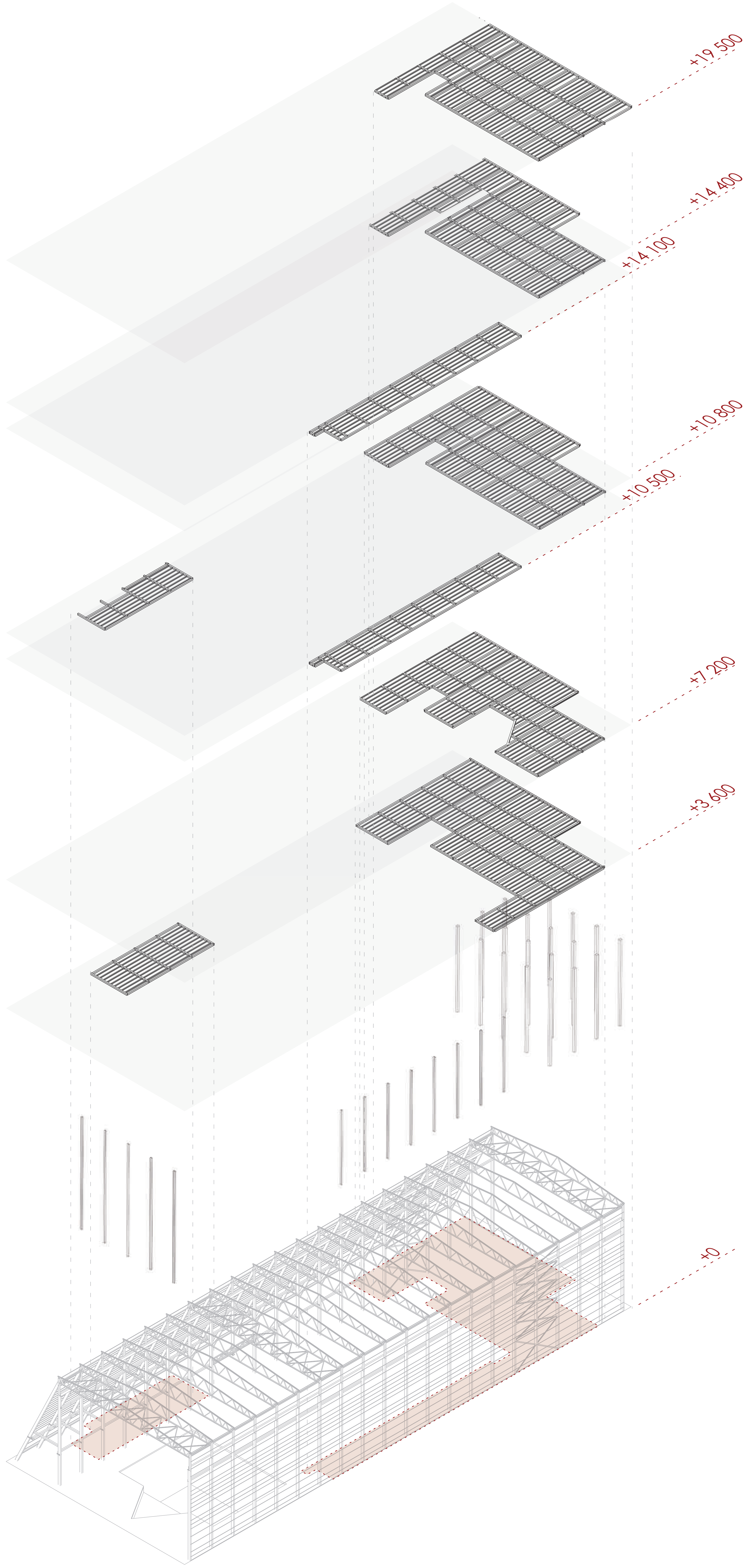
< The structure system of hall A >



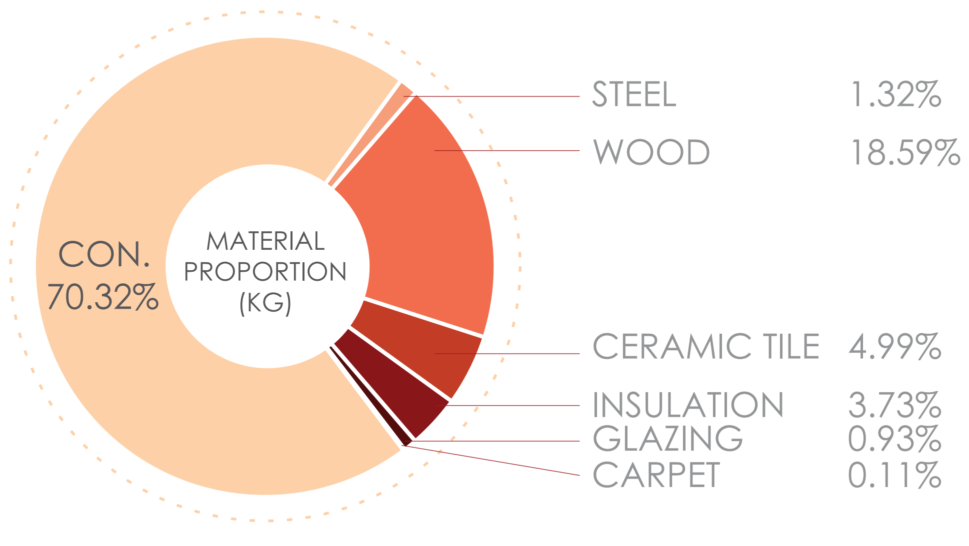
< The structure system of hall B >

Element	weight(Ton)
HEB 600*	530.83
HEB 320*	287.53
IPE 600*	92.18
UNP 160*	30.58
UNP 180*	60.35
HUP 100X100X5*	28.80
TOTAL	1030.26

< Material list of the steel joist system >

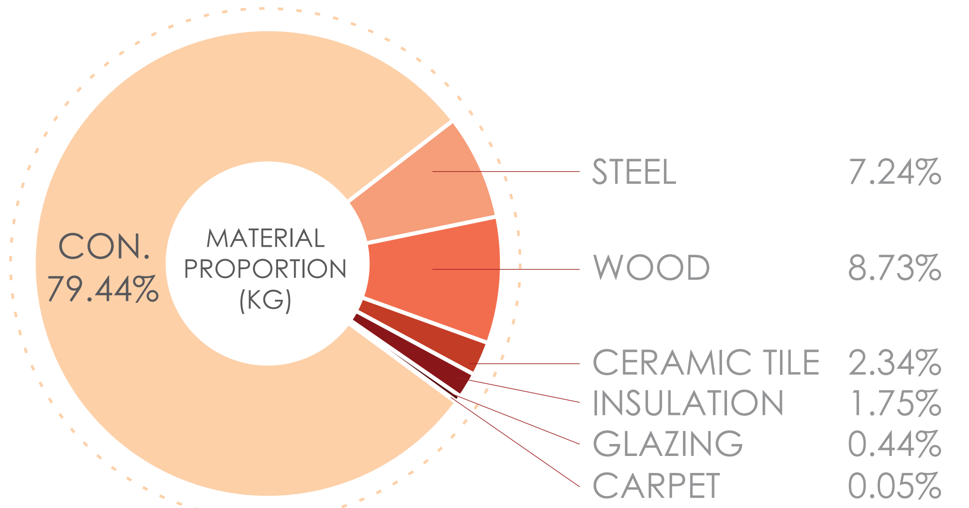


MATERIAL



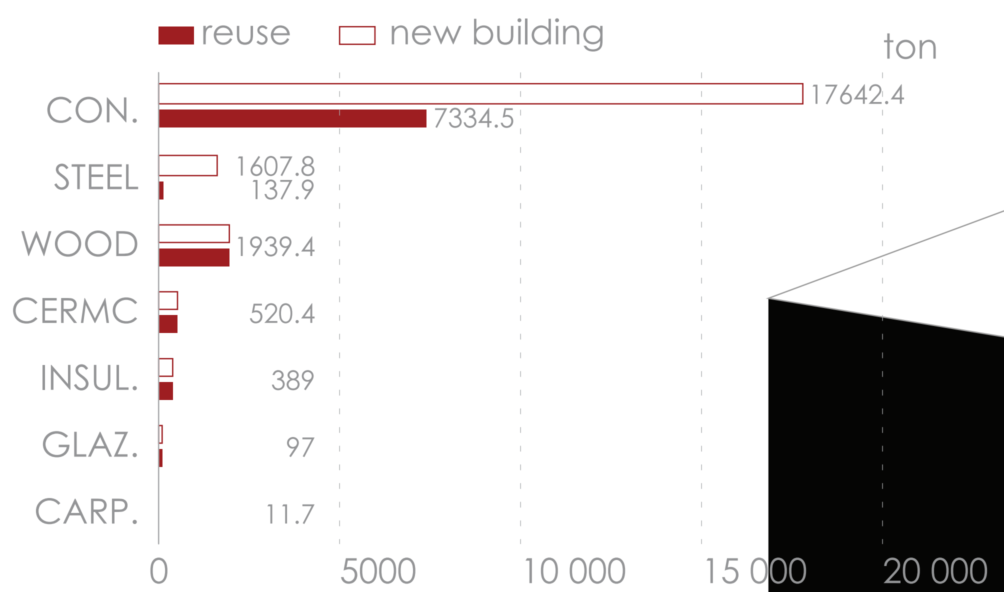
< REUSE SCENARIO >

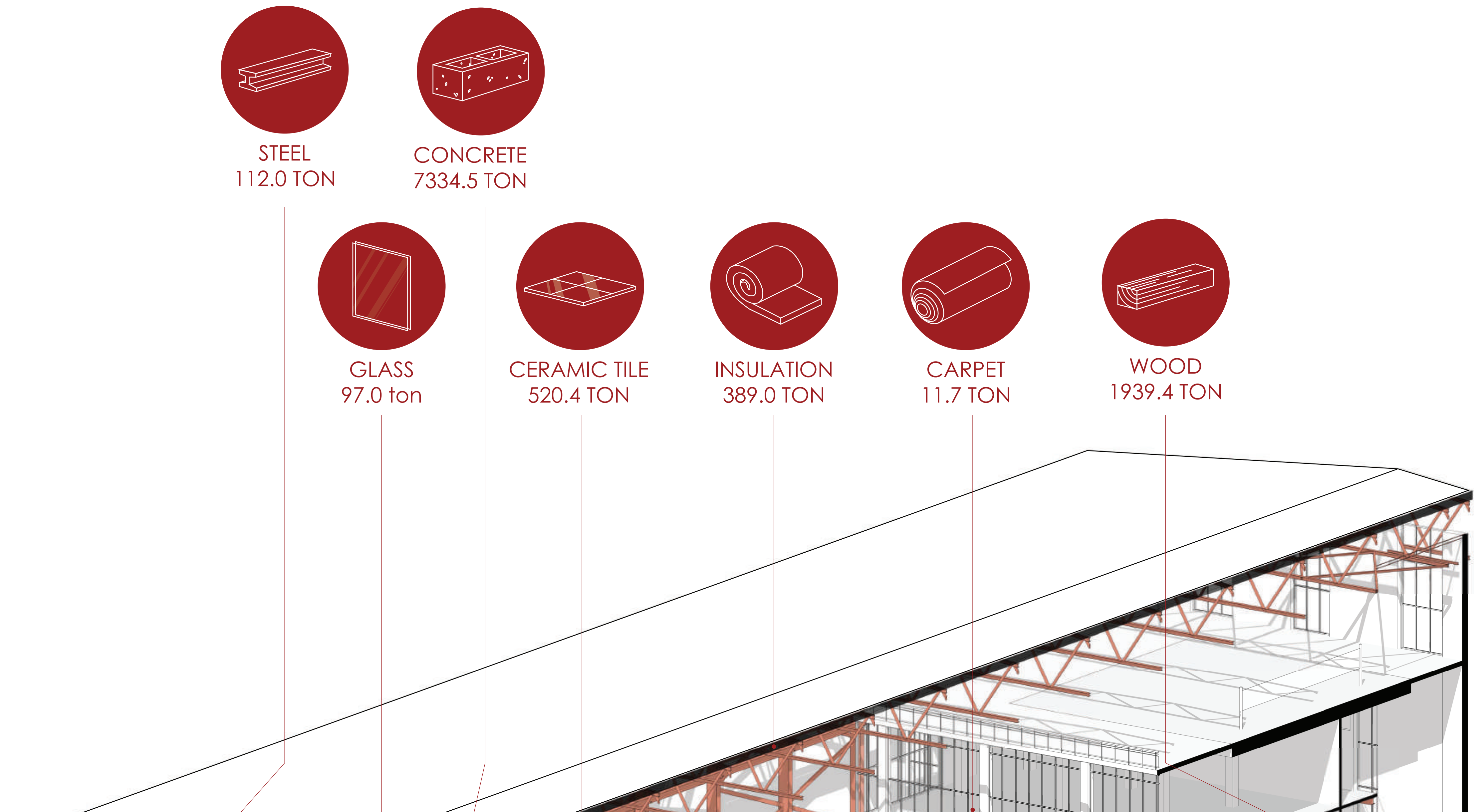
The main intention of the project is to reuse as many existing structural materials as possible to save extra embodied emissions in a lifecycle perspective. It has a significant potential to save a tremendous amount of materials, approximately 10 300 tons of concrete and 1400 tons of steel. Comparing two scenarios between reusing existing materials and creating totally new building, the steel material takes part of 1.32% and 7.24% of the whole material use respectively. Even if the concrete is the major material of the building, it is impossible to reuse existing concrete from old buildings. Instead of reuse, the project used recycled concrete for the extra slabs and walls. The project keeps only the first-floor slab with the foundations and pool walls which are 1500mm thick going down to 13 meters deep so the project saved 10307.94 tons of concrete. The rest of the slabs which laid on the north side are demolished and new slab systems were covered on the east side for the nursing home section.

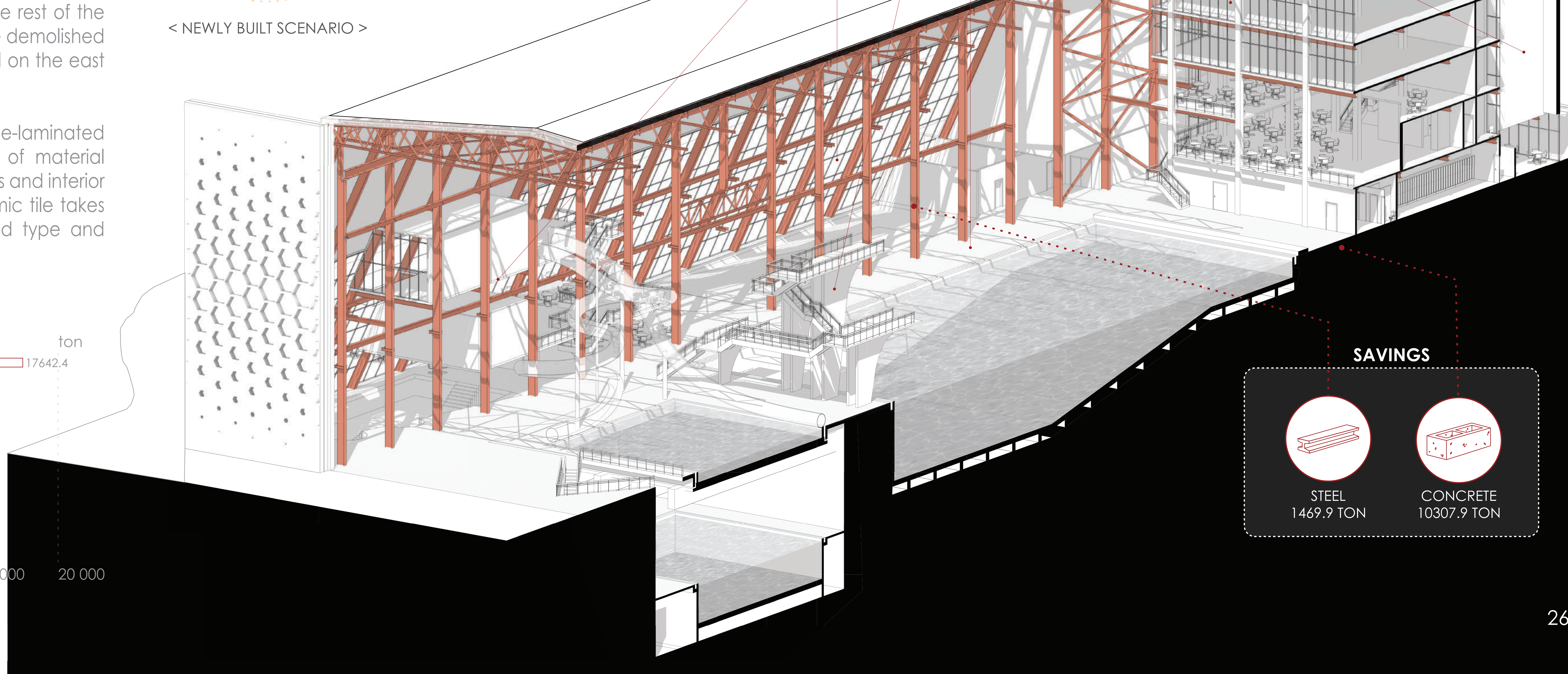


< NEWLY BUILT SCENARIO >

Crossed laminated timber and glue-laminated timber come next largest amount of material after steel. It is mainly used in facades and interior walls of a nursing home. Then ceramic tile takes the 4th and insulation for both rigid type and fiberglass type got 5th.







As the project starts, the material lists of the three halls were given from Asplan Viak. Unlike hall B and C, the steel frame structure of hall A was mainly combined with concrete. During the site visit, I and the engineering students from OsloMet were able to check the condition of the steel material of hall A which was very old and rusted and we decided to use hall B as a main resources for reuse. The table is set to sort out which profile of steel beams and columns from Hall A and B could be reused for assembling the steel joist slab system. Hall C keeps most of its structures except for bracings on the north and south facades thereby it has 439.68 tons of steel frame.

The steel connections and bolts used to be easily neglected as it is regarded that their amount and impact would not be powerful. Surprisingly, it turned out that the project has over 8 tons of steel joint plates and over 2 tons of bolts. Since it was hard to estimate the exact amount of the elements and the type of the steel connection among a variety of classes from the given materials and documents, only major elements were considered in the calculation based on the detailed plans. Considering this assumption, it is expected that the building has much more elements than 10 tons in total. From the other two halls, 1030.26 tons of steel materials are collected to assemble the steel joist slab system.

In addition to the existing steel connections, the extra steel connection elements are needed to join the steel joist slabs. Due to the difficulties to figure out the exact amount, it is roughly assumed that the amount of them would be proportionate to the amount of the steel material used. As a result, utilizing the amount used in Hall C, 20.37 tons of extra plates and 5.53 tons of extra bolts are needed for the slab system.

Element	Class	Weight(Ton)
Steel columns	HEB 600	191.31
	IPE 600	72.64
	HEB 600*	530.83
Steel beams	UNP 160	37.66
	UNP 180	16.98
	HUP 150X100X5	1.14
	HUP 100X100X5	16.76
	HEB 320	87.07
	HEB 320*	287.53
Steel joist slab	IPE 600*	92.18
	UNP 160*	30.58
	UNP 180*	60.35
	HUP 100X100X5*	28.80
Steel joints_Hall C	Gusset plate	0.57
	Fin plate	7.91
	Bolts	2.30
Steel from Hall C		439.68
Steel from Hall A&B		1030.26
Total used existing steel		**1469.94**
Concrete slab	-	2050.65
Concrete Isolation	-	3638.19
Concrete wall	-	4623.48
Total used existing concrete		**10307.94**

* Materials collected from Hall A and B

< Reused material list >

Resource	Country	kg/m2(BTA)
Ready-mix concrete, C28/35, XC 1, CEM II/A-V 52,5 N, Grön väggbetong (Skanska, Stockholm area)	Sweden	311.28
Ready-mix concrete, C35/45 (B35 M45), low-carbon class extreme (Skedsmo Betong)	Noway	292.82
Glue laminated timber (Glulam), 468 kg/m3, 12% moisture content (Holmen Wood Products AB)	Sweden	90.11
CLT (cross laminated timber), 430 kg/m3, moisture content 12% (Södra Skogsägarna)	Sweden	67.17
Concrete beam, C45/55 (B45 M60), low carbon class B (Block Berge Bygg)	Norway	47.92
Precast reinforced stairs and landings, 2400 kg/m3, low carbon class B (Contiga AS)	Norway	17.36
Aggregate (crushed gravel), generic, dry bulk density, 1600 kg/m3	Norway	16.74
Sand, loose dry density, 1555 kg/m3	Norway	13.76
Ceramic tiles, Italian average, 10mm, 19.9 kg/m2 (Confindustria Ceramica)	Italy	9.67
Hot-dip galvanized steel sheets, Steel thickness range: 0.4-3.0 mm (0.015-0.12 in), zinc coating: 20 µm (787.4 µin) (0.28kg/m2 / 0.057 lbs/ft2 sheet steel), 80% recycled content	Norway	9.20
Insulated glazing, double pane, 20.6 kg/m2	Germany	7.95
Laminated plywood, waterproof, 10.2 mm (Fibo Trespo)	Norway	4.18
Glass wool acoustic ceiling insulation, with glass fiber coating, 55 mm, 7.8 kg/m2, Parafon Decibel Mute (Paroc)	Norway	4.01
Flooring for sports facilities, 0.310in, 44.7 oz/ft2, 38x38in, Duo Tile (Mats Inc.)	North America	3.36
Gypsum plasterboard, 12.5 mm, 9 kg/m2, Normal – Standard (Gyproc)	Norway	2.54
Mono-crystalline photovoltaic module, per m2, average 226 Wp/m2, 10.73 kg/m2, Maxeon 3 (SunPower)	Mexico	2.21
Glass wool insulation batt, unfaced, L = 0.034 W/mK, R = 1 m2K/W, 45-195 mm, 19.8 kg/m3 (uncompressed), Formstykker λ34 (Isover)	Denmark	1.99
EPS insulation panels, L= 0.038 m2K/W, R=1 m2K/W, 38 mm (10-200 mm range), 600 x 1200mm, 0.57 kg/m2, 15 kg/m3, Lambda=0.038 W/(m.K), Styropor S80 (Vartdal Plastindustri AS)	Norway	1.47
Tufted broadloom carpet tiles, 3.42 kg/m2, pile material polyamide 6, Epoca Rustic (egetaepper a/s)	Denmark	0.9
Plastic vapour control layer, 0.15 mm (Tommen Gram)	Norway	0.07

< New material list >

ENERGY ANALYSIS

An indoor swimming pool requires higher water and energy demand levels due to the need to provide appropriate thermal comfort conditions. Statistics Norway published a report in 2011 indicating that the average FAEC(final annual energy consumption) of 21 Norwegian swimming facilities was 280 kWh/m2 of usable area(Kampel, 2015). However, this is an average value of all swimming facilities ranging from small local size to huge natatorium size which would bring nonsense to compare with the project's specific size. Kampel(2015) mentioned that a swimming facility can be better described as a process plant due to its complex technical systems for water purification and climate control. In order to comly with realistic energy demand, the project needs a proper standard to follow up. Since there is no specific energy load requirement for swimming facilities from TEK 17 and NS 3031, the project benchmarked the real energy budget of Norway's first passive house swimming pool completed in 2017 in Asker municipality.

Net energy req.	411.3 kWh/m2/y
Energy delivered	304.3 kWh/m2/y
Total area(BRA)	12194 m2
PV areas	2500 m2
PV production(in use)	41.2 kWh/m2/y

< Key figures >

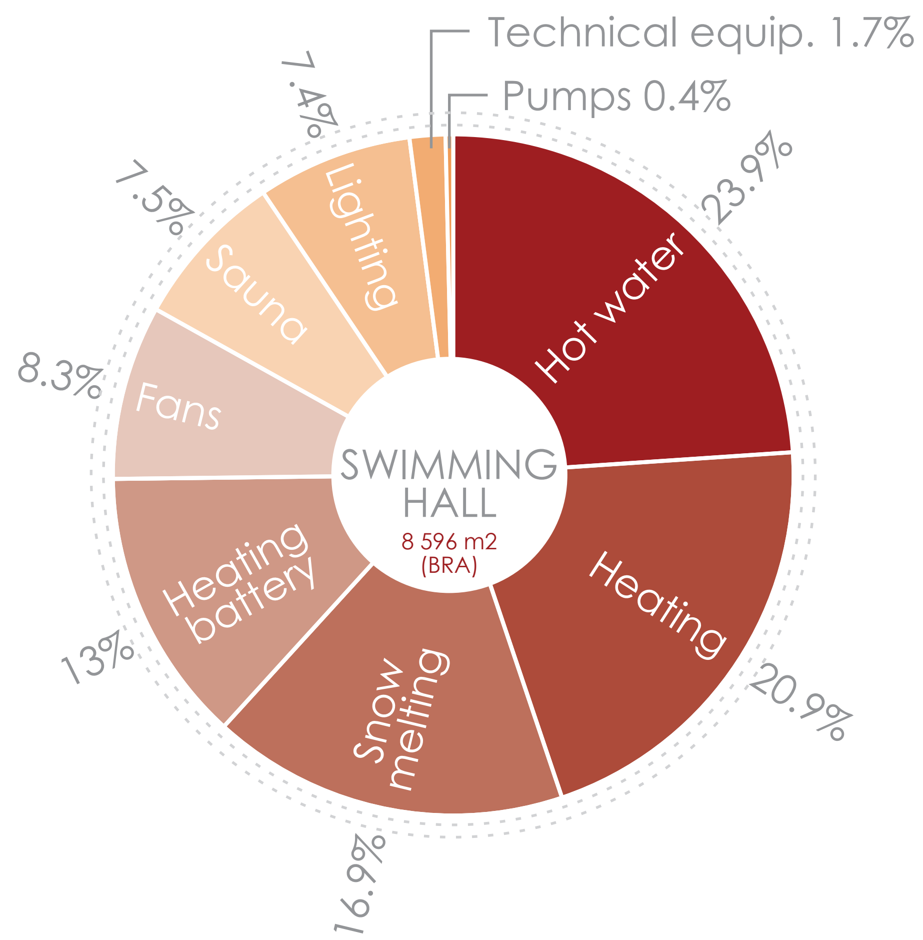
Division	kWh/m2/year
Heating	57,8
Heating battery(Vent.)	36,1
Hot water	165,6
Sauna	20,7
Fans	22,9
Pumps	1,0
Lighting	20,4
Technical equip.	4,7
Cooling battery	0
Snow melting *	46,9
GWHR *	-99.36
Total need	**276.79**

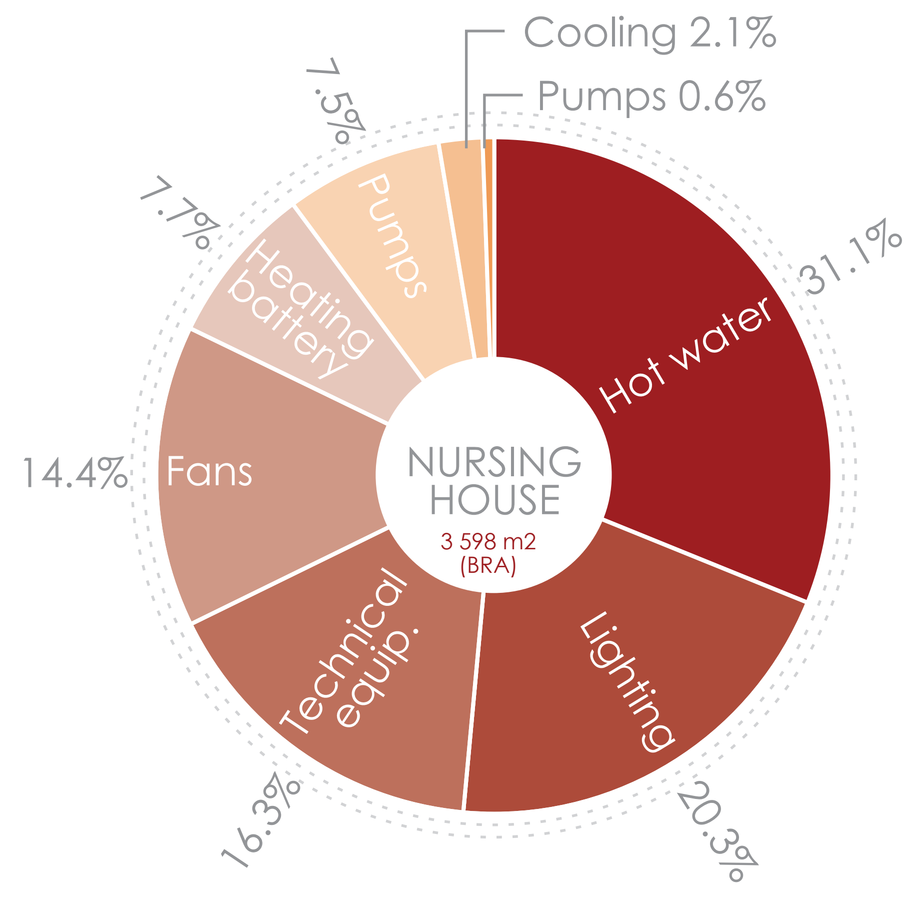
* Energy load for snow melting and grey water heating recovery are roughly calculated assuming they would proportionate to m2 of the areas for each program of the reference building

< Energy budget of the swimmng hall >

Division	kWh/m2/year
Heating	10,8
Heating battery	11,0
Hot water	44,7
Fans	20,7
Pumps	0,8
Lighting	29,2
Technical equip.	23,4
Cooling battery	3,0
Total need	**143,5**

< Energy budget of the nursing home >



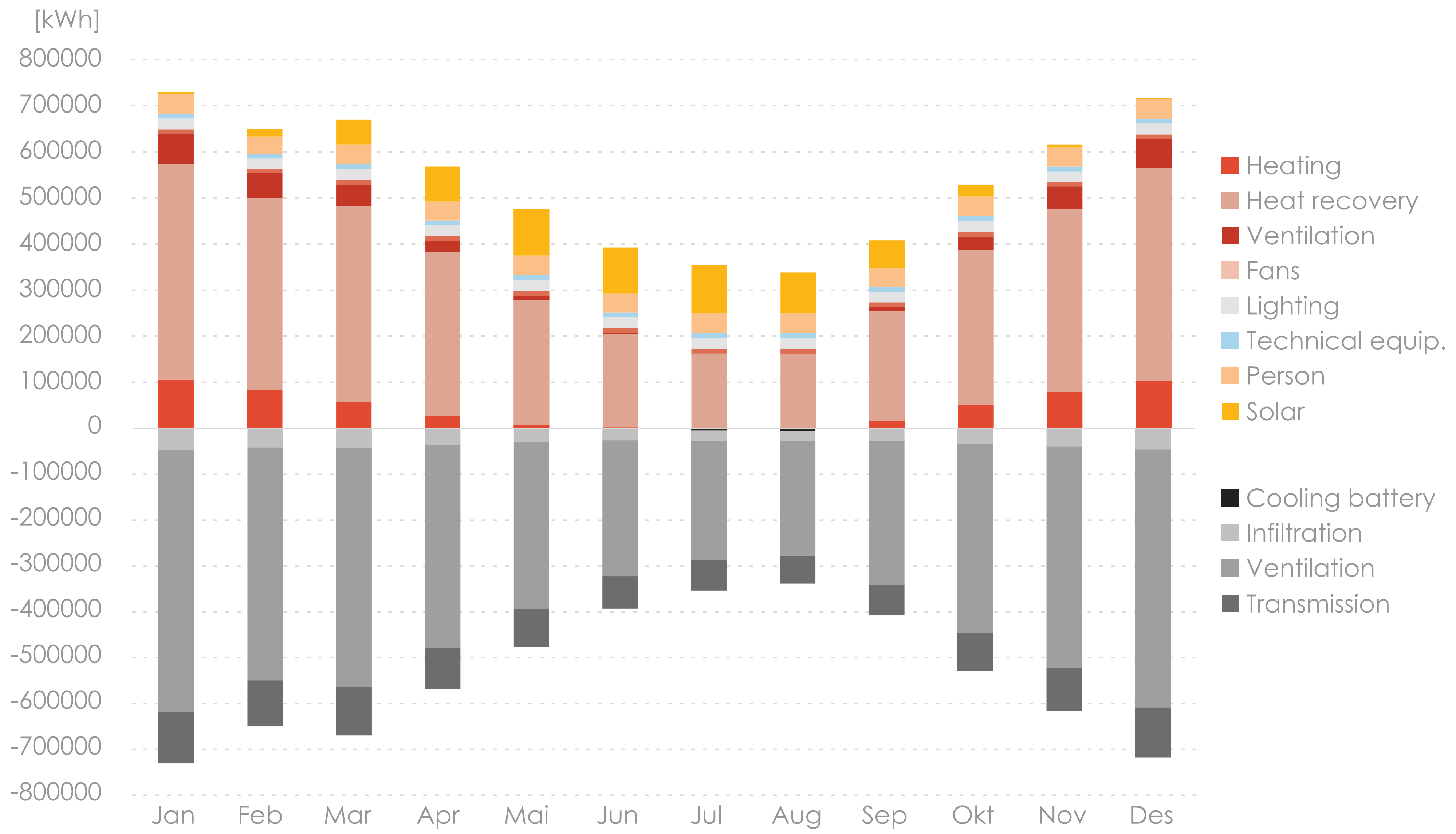


Area	Electricity grid	Heat pump	PV
Swimming hall	230.9 kWh/m2/y	36.3 kWh/m2/y	-41 kWh/m2/y
Nursing home	103.5 kWh/m2/y	10.6kWh/m2/y	-
Total		304.3kWh/m2/y	

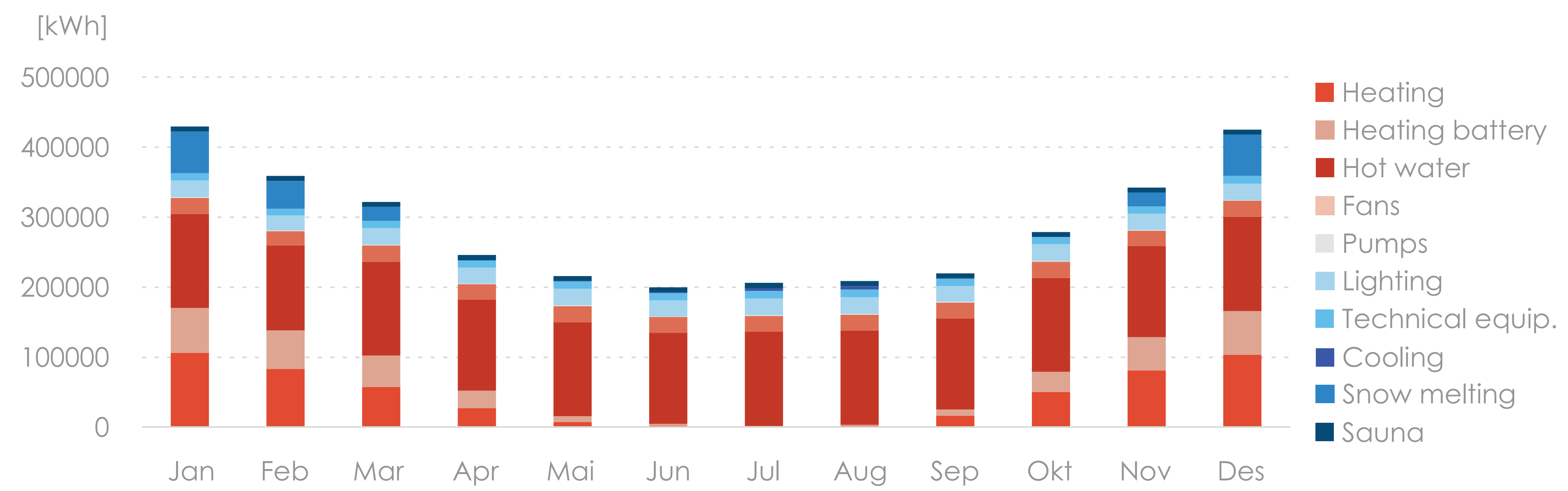
< Delivered Energy >

As shown in the table, total energy load for the project is 411.3 kWh/m2/year, with 276.8 kWh/m2/year for the swimming hall and 143.5kWh/m2/year for the nursing home respectively. With 60% of heating coverage from the heat pump and 40% of the electricity grid system, the net delivered energy demand reaches 304.3 kWh/m2/year. Since the huge amount of energy load for the heating water, grey water heat recovery systems are considered to cover heating water demand. The Source of grey water may be collected from showers, handbasins, kitchen sinks, washing machines, and some of them from swimming pool water losses. That grey water contains huge amounts of ready-to-use thermal energy. Liebersbach et al.(2021) proposed a GWHR system which could cut energy consumption by 37% up to 67% for pool water preheating and domestic hot water. It results from daily hot water demand of 50 l/person per day out of 160 l/person per day of total water consumption based on the European Guidelines. Savings are biggest in the swimming pool after the recreational pool(56%) and children's pool(48%). Considering that the project accommodates all the programs, it is simply estimated to save 60% of the energy demand for pre-heating the water. As a result, it could save up to 99.4kWh/m2 yearly.

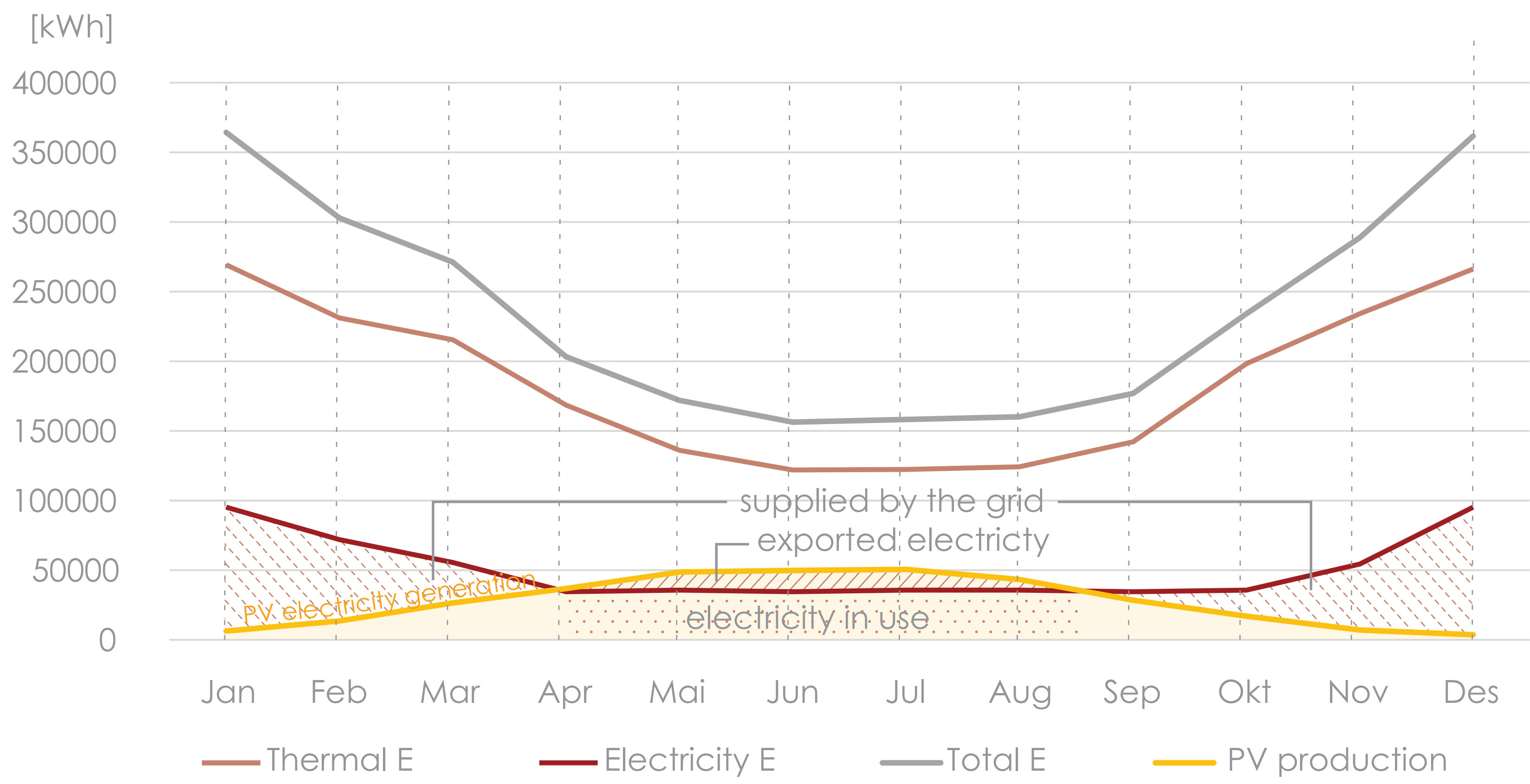
Considering the cold climate in Tønsberg, it is important to preserve the internal gain in order to reduce the heat demand. To save as much heat gain as possible, low U-values in constructions of 0,12 W/m2K for the exterior wall and 0,7 W/m2K for the windows are applied. A thermal bridge is also a strong factor contributing to the heat loss significantly. The thermal bridge is controlled with 0.03W/m2K. As shown in the chart below, it has a high-efficiency heat recovery system covering more than half of the internal gain. On the other hand heat loss is occurred with the same amount as the heat gains. Ventilation takes the major contributor to the heat losses after the transmission in the second place.



< Monthly energy balance >



< Monthly net energy demand >



< Energy profile >

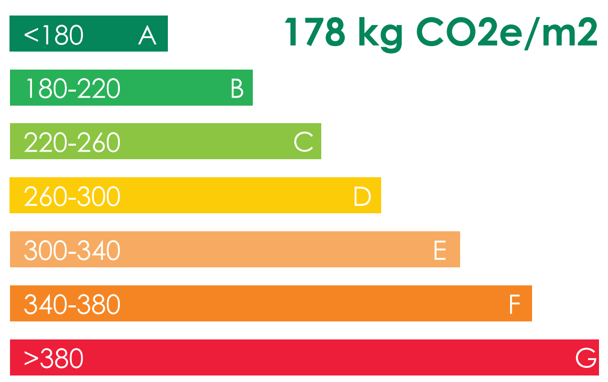
In order to decrease the delivered energy, 2 500m2 of PV panels are installed on the south roof with 6-degree tilt angle, generating 499 819 kWh yearly. Since there is a discrepancy between the period of the peak energy generation and peak energy demanded, surplus energy is exported to the grid system in the summer. On the other hand, in the winter, as it cannot produce enough energy to cover the high demand, the rest of the demand should be supplied by the grid system. As a result, the PV system could compensate for the entire need for electricity from April to September

U value	
Exterior wall(pool)	0.12 W/m2K
Exterior wall(nursing home)	0.18 W/m2K
Windows	0.71 W/m2K
floor slab	0.08 W/m2K
Ceiling	0.08 W/m2K
Roof	0.09 W/m2K
Thermal bridge	0.03 W/m2K
Air leakage(n50)	0.60 /h

< Building technique >

LIFECYCLE ASSESSMENT

CO2 13.32 kgCO2e/m2/year
4 386 Tons CO2e

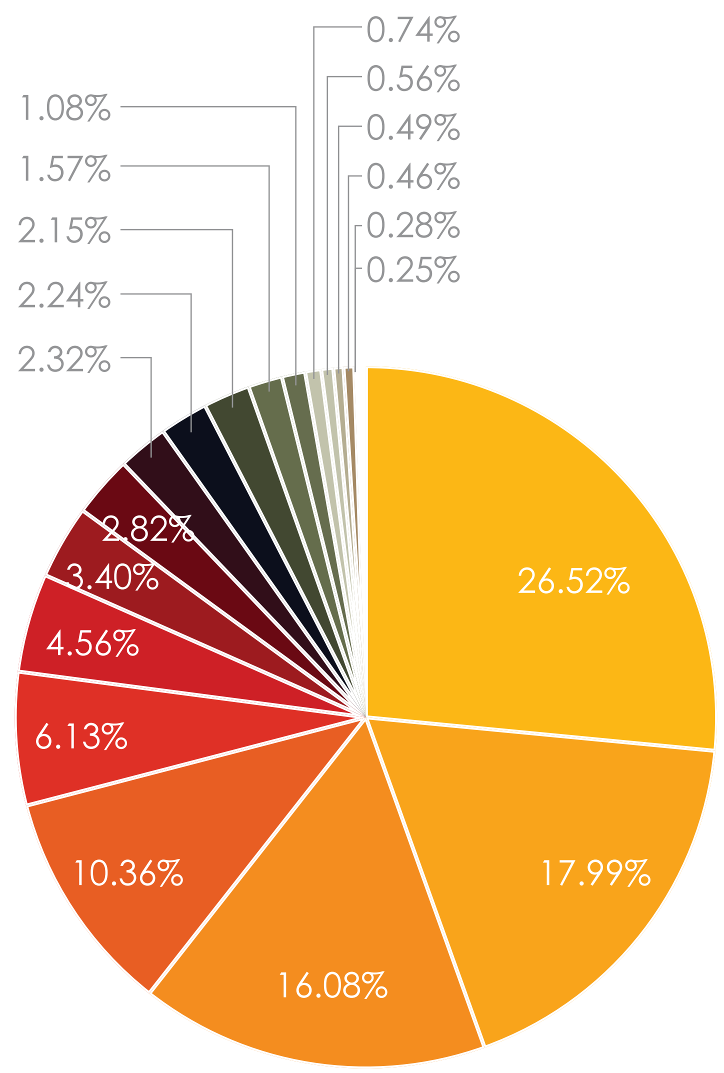


Cradle to grave(A1-A5 / B4-B5, C1-C40

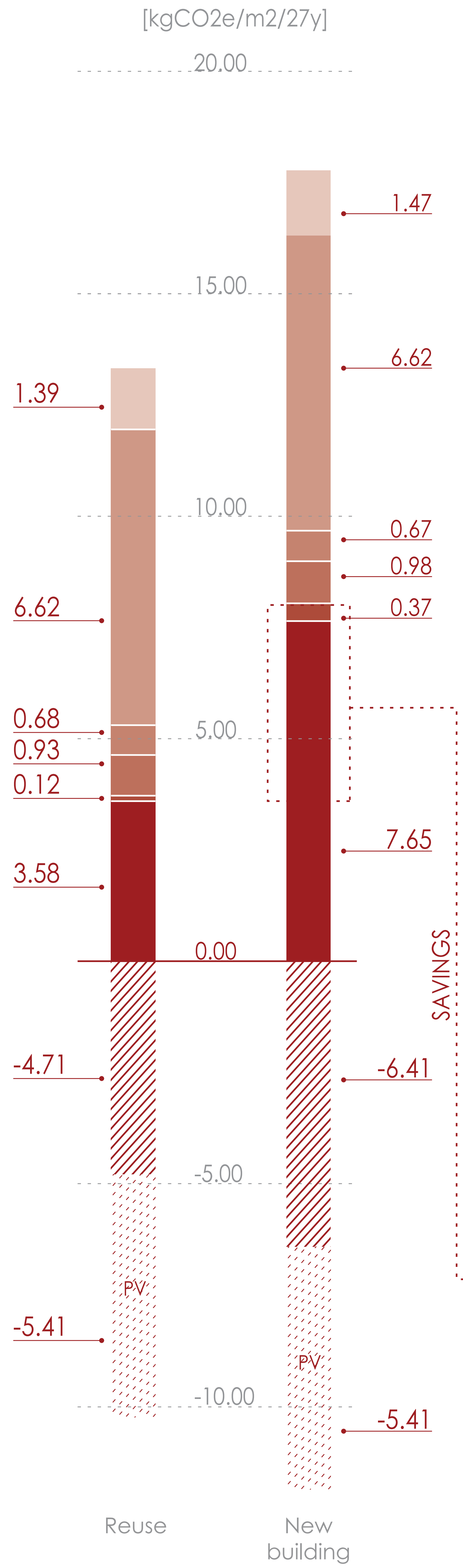
For the embodied emission calculation, it is presented with 13.32 kg CO2e/m2/year and gets an 'A' grade in the carbon benchmark that does not take into account the building operational phase. The most powerful material is ready-mix concrete taking up over a quarter of the total amount of emission of the materials. Besides existing steel structure for reuse, the project has several parts made of steel such as new steel connections for the steel joist system for the floor slab and layerS in the roof and floor slabs. This brings the steel material taking the second place in the emission.

A majority of the part of the emission in the whole life cycle is mainly from B6 phase, the operational phase. The photovoltaic modules on the south roof generate 499 819 kWh/m2 yearly which can compensate up to 65 976 kgCO2e including the surplus energy. This amount could cover five-sixths of emissions of the energy used in the building operation. The emission factor 132gCO2/kWh is selected by what ZEB currently has used(Kristjansdottir et al., 2014).

Material list	kgCO2e/m2(BRA)
Ready-mix concrete	26.24
Hot-dip galvanized steel sheets	17.80
Mono crystalline photovoltaic module	15.91
Insulated glazing, double pane	10.25
Concrete beam	6.07
EPS insulation panels	4.51
Glue laminated timber (Glulam)	3.36
CLT (cross laminated timber)	2.79
Composite PVC membrane for tunnels	2.30
Glass wool acoustic ceiling insulation	2.21
Tufted broadloom carpet tiles	2.13
Laminated plywood, waterproof	1.56
Polyethylene vapor barrier membrane	1.07
Ceramic tiles, Italian average	0.73
Steel bolt, for rock support, corrosion protected	0.55
Gypsum plasterboard	0.48
Glass wool insulation batt, unfaced	0.46
Flooring for sports facilities	0.28
Glass wool insulation batt, unfaced	0.25
TOTAL	**98.94**



< Global Warming Potential of the materials >



Unlike recycling, the reuse of steel structures extends the steel life with lower impacts, because steel recovery through the melting process is not needed(-Vares et al., 2018). Savings of the emissions from the production and manufacture phase reach up to more than 100% than new building scenario. This amount contains not only the reuse of existing steel but also concrete structures. The lifetime for the project is set to 27 years according to the service time of the existing Finish industrial halls. In order to measure the emissions from the construction phase which cannot be simply estimated from OneClickLCA tool, the project relied on hypothetical assumptions. Vares et al.(2018) assumed that the deconstruction of the steel frame is the same process as its erection with an additional effort to maintain the integrity of the disconnected components. Such additional effort measured with workload multipliers ranges from 1 to 2 depending on the amount of reused steel. This project takes advantage of the average multiplier of 1.5. In addition to A1-A3 phases, it could also save extra emissions from the transportation phase since the resources are already on site.

As a result, comparing two scenarios, this transformation project could save a total 1 539 tonCO2e. Therefore, subtracting all the compensation, it creates 3.21 kgCO2e/m2 of heated area per year while a newly built scenario might emit almost double amount of the carbon. However, the processes of excavating the ground for creating the pools and assembling the steel joist system were not taken into account in the calculation due to the difficulties to estimate the workloads. Moreover, the realistic emission estimation of the construction, end of life, and beyond construction lifecycle need to be calculated with a variety of detailed information further.

- A1-A3 PRODUCTION & MANUFACTURE
- A4 TRANSPORTATION TO SITE
- A5 CONSTRUCTION PROCESS
- B1-B5 MAINTENANCE &REPLACEMENT
- B6 OPERATION
- C1-C4 END OF LIFE
- D EXTERNAL IMPACTS
- EMISSION COMPENSATION

	Emission saving materials	A1-A3	A4
HALL A&B	Steel beam, columns(HEA, HEB, UPE, UNP, IPE profile)	604	
HALL C	Steel beam, columns(HEA, HEB, UPE, UNP, IPE profile)	251	
HALL C	Steel connection plates	17	
HALL C	Steel connection bolts	2.8	
HALL C	Ready-mix concrete_isolation, foundation	211	
HALL C	Ready-mix concrete_basement pool	269	
HALL C	Concrete slab C50	100	
	TOTAL (tCO2eq)	**1454.8**	**84.2**

< The emission balance for the project over 27-year life >

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