CONTEMPORARY STONE BUILDING

STRATEGIES FOR SUSTAINABLE ARCHITECTURE IN LOAD BEARING STONE APPLIED IN A SWEDISH CONTEXT

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CHALMERS SCHOOL OF ARCHITECTURE
DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

2024

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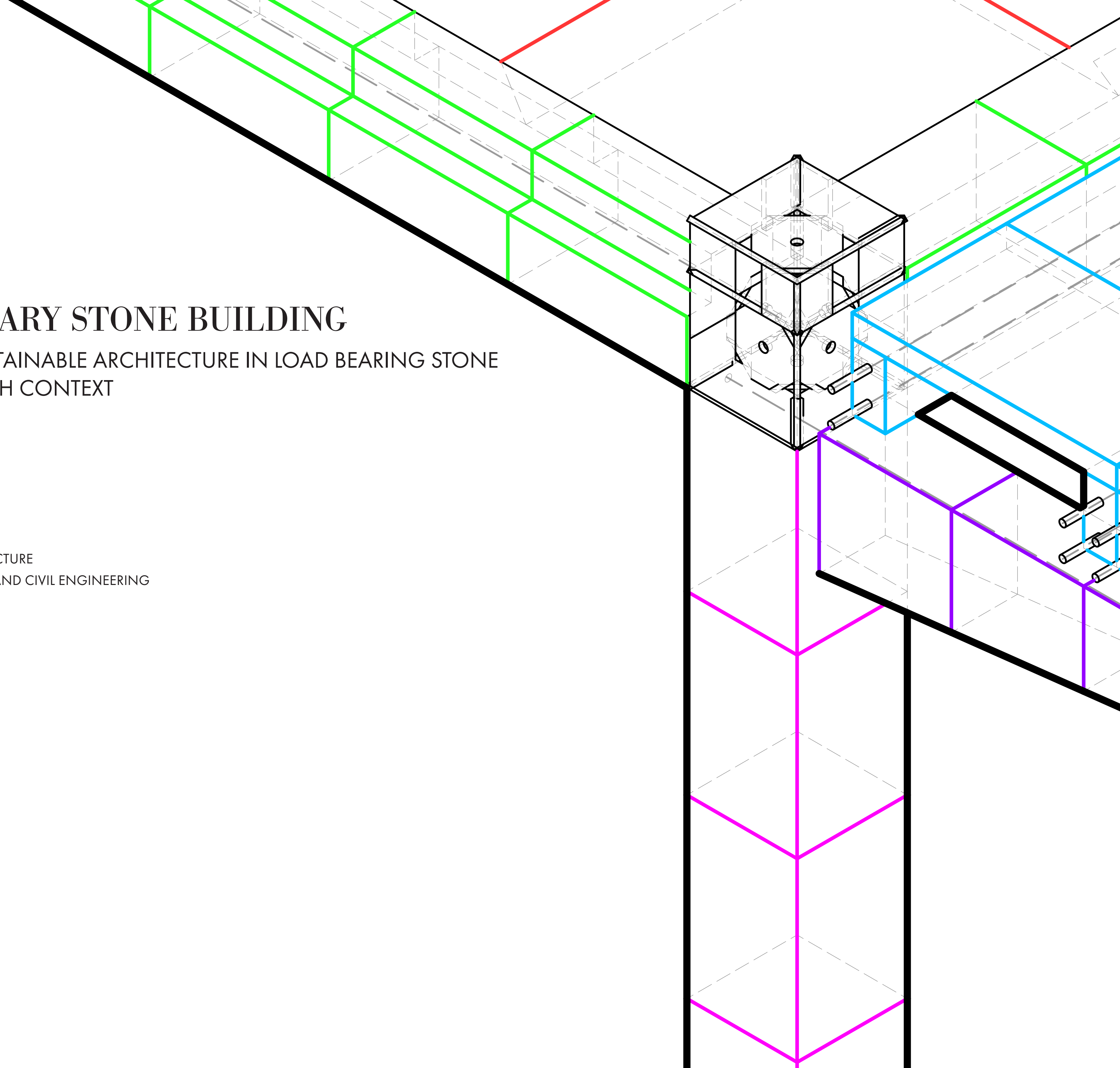
SUPERVISOR – JONAS LUNDBERG



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ABSTRACT

This thesis deals with architectural design that utilizes massive natural stone as a load bearing material with high architectural presence. The purpose is to put new eyes on an ancient material in the light of modern technology at a time of climate emergency.

Stone has many beneficial properties for a building material. In addition to unparallelled longevity and high compression strength it is also proof to fire, water and rot. But most importantly, stone is a natural material that can have substantial benefits to the planet as a sustainable alternative to steel and reinforced concrete. Despite all this, few people know that building in stone is even an alternative. This thesis wants to change that by promoting stone as a structural material with timeless architectural beauty.

A material investigation is conducted through literature studies, site visits and practical experiments. References are gathered from pioneering stone buildings and architectural research prototypes that push the boundaries of construction principles and the latest digital production technology. As no contemporary stone buildings yet exist in the nordic countries this thesis positions itself in that knowledge gap. A building design is made, following an existing project brief, in order to find out how stone can be applied as a critical architectural element in the design of a public bath in a Swedish context. The result goes into detail and presents various solutions, elements, constructive principles and aesthetic opportunities that displays how natural stone can be used as a major structural and aesthetic component in contemporary architecture.

KEYWORDS
Natural stone, stereotomy, dimension stone

STUDENT BACKGROUND

ACADEMIC

2020 - 2024	Master's Program, Architecture and Urban Design Chalmers School of Architecture
2021	Exchange Studies, Fall Semester 2021 École Polytechnique Fédérale de Lausanne, Switzerland
2017 - 2020	Bachelor in Architecture Chalmers School of Architecture
2010 - 2013	Bachelor of Fine Arts in Arts & Crafts, Iron & Steel/Public Space Gothenburg University, HDK Steneby
2008 - 2009	Arts, Craft and Design Grimslövs Folkhögskola

PROFESSIONAL

2022	Architect Intern Sunnerö Architects, Gothenburg
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TABLE OF CONTENTS

3 ABSTRACT
4 STUDENT BACKGROUND
6 INTRODUCTION
6 PURPOSE & AIM
7 RESEARCH QUESTIONS
8 THEORETICAL FRAMEWORK
11 METHOD & PROCESS
13 DELIMITATIONS
14 DISCOURSE
16 BODY OF WORK
17 MATERIAL INVESTIGATION
24 BUILDING DESIGN
46 DISCUSSION
49 BIBLIOGRAPHY

PURPOSE & AIM

In the face of a climate emergency the architectural community needs to reduce its material footprint by reevaluateing traditional building materials in light of modern technology. Stone stands out as an underutilized resource in contemporary construction. This thesis seeks to evoke an interest in stone as a structural material and explore its potential as a sustainable alternative to conventional options like steel and concrete.

The purpose of this thesis is to pioneer a renaissance of stone in architecture. By utilizing both the beauty and ecological advantages this research endeavors to expand the architect's palette of climate-friendly materials. Through innovative design solutions and a deeper understanding of stone's capabilities the purpose is to advocate for the adoption of natural stone as a mainstream building material.

By conducting a material investigation into the properties and applications of natural stone this thesis cataloges the different uses of stone from an architectural perspective, providing valuable insights for future design endeavors as well as investigate how building with stone can mitigate the carbon footprint of construction activities, contributing to global efforts to combat climate change.

By developing a building design centered around the use of natural stone the thesis demonstrates the materials potential to enhance both aesthetic and structural aspects of architecture. It aims to push the boundaries of architectural innovation by exploring the untapped potential of stone within the constraints of sustainable design principles, and showcase both the accessibility and beauty of stone as a building material while challenging old perceptions.

Ultimately the thesis wants to serve as an advocate for stone within the architectural community, promoting dialogue and develop sustainable design practice.
To expand the architect's material palette by identifying opportunities to replace traditional materials like concrete and steel with stone in diverse architectural contexts beyond the scope of this specific design.

RESEARCH QUESTIONS

Main question

How can natural stone be used as a major structural and aesthetic component in contemporary architecture?

Subquestion

How to apply stone as a critical architectural element in the design of a public bath in a Swedish context?

THEORETICAL FRAMEWORK

A significant amount of information and inspiration is derived from this London-based trio of professionals in practice and their respective companies. From three different fields they have joined efforts in developing the conditions for building in natural stone today.

Amin Taha, founder and principal of Groupwork Architects.
Steve Webb, co-founder of Webb Yates Engineers.
Pierre Bideau, founder of The Stonemasonry Company.

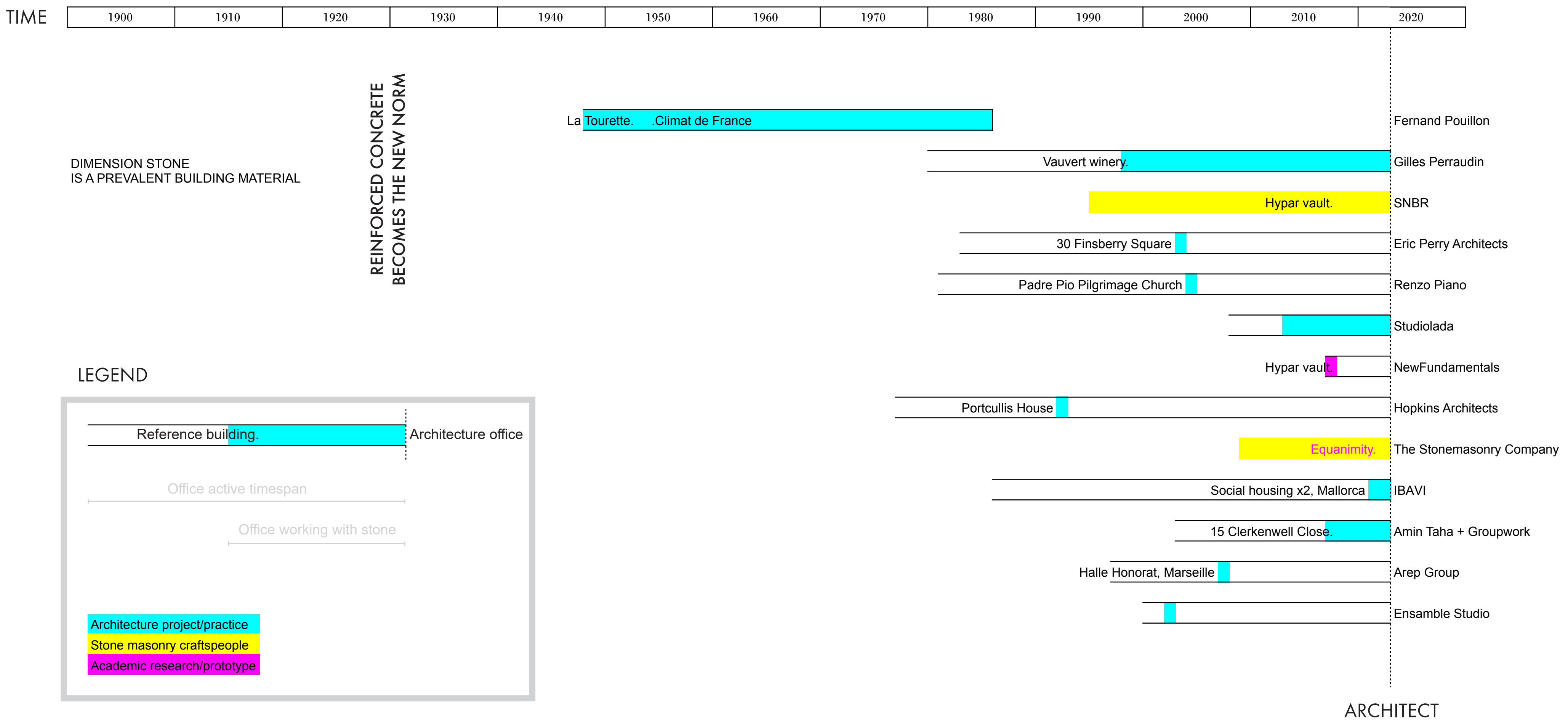
They have formed this informal trio of competences describing how the close cooperation between the disciplines is a catalyst and requirement to advance a new advent of a classic material and redefine it for sustainability. The curiosity from three professional angles, the people or the companies they represent, in some constellation or other, are involved in a large number of projects that represents a cutting edge of solid stone construction, pushing the limits forward in what is being built. Their material is not mainly written but instead based around very palpable and real life construction issues, researching the material aspects as it is needed in for their professional practices. Projects: -15 Clerkenwell Close; a building with an exo-skeleton in raw limestone. -The stone tower research project; calculates climate-, economic- and feasibility aspects of a 30 story stone office building. New Stone Age exhibition, Equanimity exhibition, Under marble skies Venice biennale pavillion, plenty of stone stairs, beams and flooring components, etc. Talks: Several talks on the general topic of building in natural stone Where they share their experiences and insights, for institutions like; Istructe - institution of structural engineers, ACAN!, AA School of Architecture, The Building Center. Topics include but are not limited to: Fire performance and regulation. Regulation/ building code or the lack thereof, trying to apply a material without definitions. Working towards creating those definitions or permissions, through testing (e.g. fire) or prototyping. A material that contains natural variations and how to navigate that, reaching code that is both safe and material optimized. Dealing with public opinion towards stone in construction, raw surfaces, fear of collapse. Quarrying. Sourcing material. Finding contractors willing to work

with stone. Structural principles applied. Resource reserves, amounts of stone available in comparison to timber. Co2 footprint of stone extraction and processing, comparison to other materials, climate benefits.
This collective information is directly related to and translated through the design in my proposal.

Giuseppe Fallacara is an Italian academic specialized in stereotomy. He has published several texts and realized several full scale research prototypes relevant for this thesis that are described below. He is coordinating the New Fundamentals research group affiliated to the Department of Civil Engineering and Architecture of the Polytechnic of Bari.
The text "An unfinished manifesto for Stereotomy 2.0" co-written with Maurizio Barberio is a text that defines Stereotomy 2.0 as a discipline. It starts out describing the classic stereotomy discipline and its genesis. It goes on to describe what the digital age has to offer production and formfinding in solid stone, what this means for the architect in control. How a continued evolution ("unfinished") is a joint venture between the digital and robotic and the rediscovery of the historical heritage buildings. Stereotomy's place as a part in the wider digital turn in architecture. Lists ten points to outline a reborn discipline based solely on digital tools. Also lists a number of projects to represent the expanding frontier of new applications exploring limitations to shape and architectural balance.
A similar approach to cataloging is found in "Architectural stone elements – Research, design and fabrication".(Fallacara 2016) The text lists twenty different elements divided between the categories hypar, interlocking, aequilibrium, pattern, skin, domes and helicoids. Designed and built between 2013 and 2016, the collection is composed "to demonstrate new applications, features, shapes and the unexpected and unexpressed potential of stone for a new contemporary design".

"On sustainability aspects through the prism of stone as a material for construction" written by Dimitra Ioannidou is a doctoral thesis that takes a broad sustainability approach onto stone with the outlook of providing tools and methods for the building industry with mainly a local focus on Switzerland and France.
The presented outcomes are part in providing me with a framework of reference and guiding decision making and design choices ranging from international strategy to detail execution.
Important take-aways are as follows:
-We are in fact already building extensively with stone, however in the form of aggregates.
-Despite the vast existence of rock material in the ground, regional accessibility can be problematic due to social factors. Geological availability (resource) does not equal accessibility (reserve). Despite an immense resource, depletion of stone is a risk to bear in mind.
-For a wall construction a massive block type construction can be a more sustainable alternative. A thin stone construction is not necessarily more sustainable depending on local availability and treatment grade. "The analysis revealed that even though the environmental impact of a stone product per m2 of wall is proportional to its thickness on a material level, the use of thicker stone products and the change in the structural system can present environmental benefits at the wall level."
-The case study of Résidence-le-Parc by Fernand Pouillon shows that the stone has no adverse environmental consequences and is "invisible" in comparison to the other materials. Further it establishes that it was an economical and time efficient construction and also that the buildings exhibit an aesthetic sturdiness even with minimal maintenance over a long time. The text also describes the quarrying process briefly.

For built references a wide search has been conducted and examples have been collected and compiled to form a base platform of reference as well as a solidification of the state of the art. These references are collected in Appendix A. Conditions considered are a range of different aspects that are of importance for the thesis. While many of the references are technical, others may revolve around ambiance, aesthetic material treatment, water or stone landscapes, thermal strategy, etc. As it is architecture the references most often deal with multiple aspects simultaneously. This appendix acts as a foundation for design where a multitude of aspects have been brought into the design proposal, sometimes as a finished solution and sometimes as a base for development. In the design process this reference material acts as much as a practical framework as it does a theoretical one.



The chart cathalouges architects, buildings and projects that are using natural stone in a pioneering way.

METHOD & PROCESS

The material investigation is focused around the material stone and aims to gain a deeper understanding of the material itself to prepare for and support the architectural design as the final outcome. Through visits to quarries, conversations with professionals, through literature and online sources as well as through real life stone carving with manual tools I study the methods with which stone is extracted and processed.

By selection and analysis of relevant reference projects a library of design principles is put together as a foundation for architectural design.

The architectural design will be conducted through action research in multiple iterations with the aim of designing a building. Concretized in the building program and guided by the research questions and theoretical framework. Tools are those common to the architect; sketching, diagrams, model making and drawing, with every iteration evaluated and critically reflected upon in between.

The design aims to stay true to the existing intentions from Göteborg Stad for a new public bath, planned to replace the current Valhallabadet. The plot is located north of Valhallagatan between Burgårdsparken and Mölndalsån. Rough definitions of size, program contents and functions are determined beforehand. In addition to that I work to define the program in further detail through reference analysis in order to design a fully functioning swimming facility.

This thesis explores how far the concept of a contemporary stone building can be taken. The intent is to use stone as much as possible. This is in order to really stretch the limits of the material. It is to shine a light on all the applications that are possible. To really give the stage to stone. That being said, this design will contain a large number of materials other than stone, and that is all according to plan. As an example a building needs insulation, something that stone cannot provide. A building needs glass for windows. There are electrical installations, sealants, tension rods, thermal pads, ventilation ducts and many other things that are not stone. And that is all within the concept – a contemporary building that serves all its purposes and wherever possible and realistic it is made up of natural stone.

The Swedish context is used as a framework to guide the design exercise. As mentioned a knowledge gap exists with no contemporary stone buildings in the nordic countries. References from other parts of the world will be analyzed for what they are and the information related to an altered context with slightly different conditions, where the most prominent one is a colder climate.

The thesis concept is to be seen as applicable to many other building types and scenarios. Over all the intent is to present a wide project that can offer something to many parts of architecture or be interpreted in a consecutive train of thought by any architect. The interface used here is a public bath in Gothenburg, but it could also be your next project.

DELIMITATIONS

The main target of this thesis is to explore possibilities for building design in natural stone. The exploration of different applications and approaches are conducted with the classical architect tool set of drawing design. In this thesis no numerical calculations will be done on the specific design – neither ecological sustainability or economy will be backed by tailored numbers. However all design presented is grounded in the research conducted and presented in this paper. A design that does not adhere to rules of thumb concerning carbon footprint and money spent would be irrelevant per default.

The thesis will not go into specific detail on the extraction, production or transport of each unique building block, unless there is a specific reason to do so. The build phase, maintenance and lifecycle will not be explained as part of the thesis result. All parts mentioned above are however relevant components in the material pre-study and not neglected in the design work.

The chosen building typology is to be seen as an interface for the primary task which is constructing in stone. This means that despite the considerable amount of work that has gone into developing the program and designing the flows and concepts that make up a public bath, the hierarchy is in favor of the stone building, its construction and the material investigation that the design rests upon. Considering these priorities and the size of the program, the definition of the public bath function is therefore consciously set lower as a means of limiting the scope of the thesis.

DISCOURSE

Up until industrialization dimension stone was a major building material having been established as such over millennia, however with the introduction of reinforced concrete – a material well suited for controlled industrial manufacture – stone quickly became marginalized. Today stone in building has been reduced to a cladding or finishing material – mounted on facades, interior walls and floors or used as ground cover outdoors. (Shadmon, 1989) Stone in the form of aggregates is extracted on a large scale as a main ingredient in concrete – our most widely used building material. (Ioannidou 2016) Nowadays, after a century-long gap, neither the stone industry nor the building codes are set up to handle the implications of building in load bearing stone. (Building Center, 2020)

There are a small number of architects, engineers and craftsmen presently practicing building in load bearing stone, however they remain a very small niche within architecture – for this reason contemporary stone architecture is still at an infant stage and there is a lot of room within this field to search for architectural concepts going forward. (Fallacara 2018) (AA School of Architecture, 2021) As of today no contemporary large scale buildings using structural stone have been erected in the Nordic countries according to the research conducted in this thesis.

Stone is often associated with high end production and hence considered an expensive material. In these cases the stone goes on top of other materials, as does the cost. When applied in load bearing construction however the use of stone can be proven cost effective – the Stone tower research project (2020) confirmed this through the simulation of a 30 storey office building where the cost for load bearing components were 25% of that of an equivalent steel and concrete structure. Likewise for economical reasons stone is the material of choice for Mallorcan social housing architects IBAVI (El Croquis, 2023) as well as social housing by French architect and solid stone building pioneer Gilles Perraudin. (Perraudin 2013) Also case studies on the 1961 Residence le Parc by Fernand Pouillon have established the structure and process as economical. (Ioannidou 2016)

In a building stone has the potential to do the job that normally takes several products, materials or layers in a conventional construction. This is an important factor to consider when attempting calculations of for example economy, sustainability or build time. (AA School of Architecture, 2021) Stone is in its natural state load bearing, fireproof, waterproof, frost proof and rot proof. Another selling point of stone is the outstanding longevity. Further it is fully and easily reusable. If the lifecycle has really come to an end, stone can be discarded and deposited without implications and anywhere since it is a natural material.

For a material with as high compression strength, and in comparison with others, stone has a low carbon footprint as long as it is sourced locally or domestically. (Ioannidou 2016) As it is found in the ground stone has no embodied carbon. It is thus the extraction process along with transportation emissions that constitutes the majority of built-in carbon. A key to note here is that the extraction process consists of relatively few steps to reach the finished product, steps that can be undertaken using renewable energy. No additives are required to the natural material. (Perraudin 2013) According to Stone Tower Research Project (Jackson Cole et.al 2020) a stone superstructure saves between 95-60% of CO_2 emissions compared to steel or concrete.

Stone is available in great abundance in the bedrock beneath us. This is the case also when considering it as a building material in comparison to others. (Building Center, 2020) The resource exist in vast enough amounts as to be labeled inexhaustible by some. (AA School of Architecture, 2021) Ioannidou (2016) however caution about the consequences of expanded extraction. However the author also stipulates that stone already is a major building material but in the form of aggregate in concrete. Land use is one important factor in a sustainability discourse, one where timber faces significant upcoming challenges according to Searchinger et.al (2023), whereas stone doesn’t have this issue due to the high rate of extraction per sqm. (Building Center, 2020) Despite the seeming contradiction, a stone wall can be more sustainable if built from thick material rather than thin, depending on the level of processing involved and the geographical sourcing. Fernandez (2005) presents a similar argument, that a thick stone building displaces less material than one in glass or aluminium despite the skinny plan. He calls this the “rucksack” of displaced material connected to a material.

Stone structures become imbued with certain immaterial properties due to its materiality according to Ioannidou (2016) She states such attributes to be solidity, quality and prestige. Further she states that the historical use is associated with particular skill and workmanship and that a stone building is perceived as grounded and conveys a belonging to the earth.

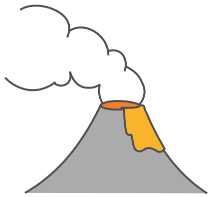
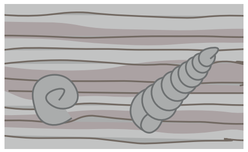
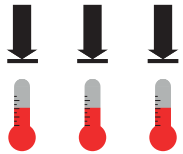
MATERIAL INVESTIGATION

GEOLOGY

QUARRYING

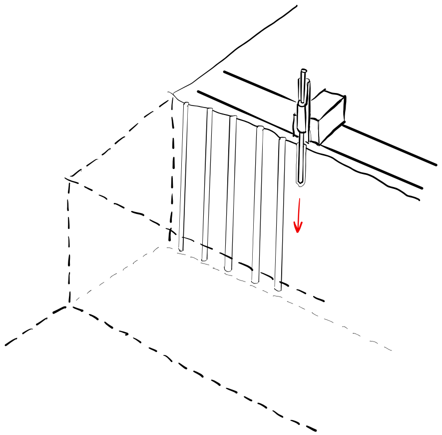
PROCESSING

Geology and the classification of rock types is a vast and complex science. However, all types of rock can be classified into three main groupes depending on how they formed. Properties can vary greatly yet all three groups are utilized for different purposes in construction. Characteristics are stated below (Ioannidou 2016):

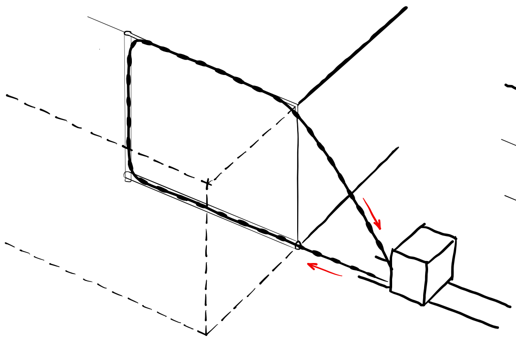
CLASSIFICATION	IGNEOUS	SEDIMENTARY	METAMORPHIC
	Igneous rocks form from the solidification of molten minerals, known as magma, beneath the Earth's surface. This type of rock is often used as dimension stone due to their durability and strength. Igneous rock forms 95% of the earths crust to a depth of ut to 16km. Granite is the most common type and have a dense structure with low porosity and water absorption. Its primary components, quartz and feldspar, contribute to its high compression strength and chemical resistance.	Sedimentary rocks form through the weathering and erosion of older rocks or the accumulation of animal shells. Fragmented by water, ice, or wind, rock particles are carried by rivers to the oceans and form sedimentary beds of mud or sand. Alternatively, shells of deceased marine life settle on lake or ocean floors, consolidating over time into solid rock through diagenesis. These rocks are typically hardened and suitable for structural use.	Metamorphic rocks result from the recrystallization of older rocks under intense heat or pressure, or both, altering their appearance, density, crystalline structure, and often mineral composition. Examples include slate, marble, and quartzite. Marble consists of a single mineral, either calcite or dolomite, with a dense structure and low porosity. Similar to limestone, marble exhibits a compressive strength ranging from moderate to high.
TEXTURE			
EXAMPLES	granite basalt	limestone sandstone	marble slate
FORMATION	 MOLTEN lava	 DEPOSITED layered	 TRANSFORMED heat pressure

EXTRACTION IN THE QUARRY

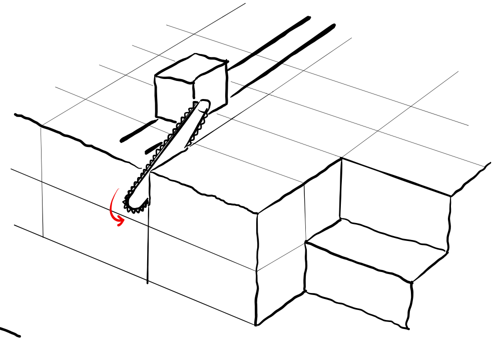
There are many different techniques to retrieve a main block from the solid bedrock. The method varies depending on the type of rock, natural splitting direction, setup of the quarry etc. The extraction method also affects the surface of the stone and the need for further processing. The main block is then divided into smaller blocks. Below are described a few of the most common methods of extracting dimension stone.



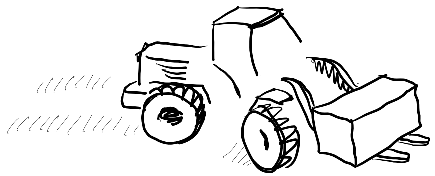
Controlloing the split through intermittent drilling is a versatile method that has been in use for a long time. For industrial production this is not the most efficient method.



Wiresaw. By drilling two pilotholes that meet up inside the bedrock a dimond wire can be inserted and then powered to saw a lagre and relatively smooth cut in the rock.



Sawing with a rail-mounted chainsaw or circular saw. This is common with softer stone e.g. limestone and samdstone. These blocks can be sawn to smaller and ready-to-ship sizes.



..blocks are moved out of the quarry pit using front end loader or forklift, for shipping or further processing on site.

A stonemasons workplace at Ävja quarry

MANUAL PROCESSING

Lots of processese are mechanized today and the basics of the stone indusrty are changing even more with the digital turn and introduction of more advanced CNC-controlled production lines. However even today many parts in a stonemasons job can often look the same as hundred years ago with templates, hand tools and craftmanship as the fastest or the only way to get a job done. Man and machine have a symbiotic relationship also moving into a future of stone building.

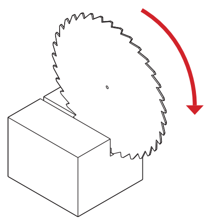
Set the chipper along an edge and chip off protruding parts.

Use the scriber to break up the mineral structure by scribing a line and control where the split will fall.

The point can chip away unevenness in the middle of a surface, little by little.

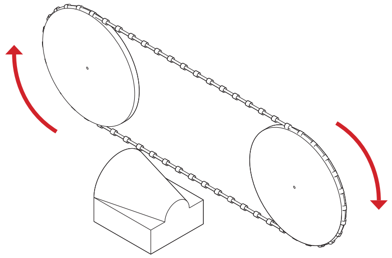
The fine engraving chisel is for detailing. Most often in softer stone like this limestone.

BRIDGE SAW



A circular saw mounted on a track and controlled via a computer is a basic tool for bulk cutting and the go-to machine at most production facilities. The machines are reliable and the processes have a large amount of control and automation. The machines can run day and night, even without supervision, and change the blades automatically when needed. Blades can be upward of three meters in diameter. The saw is limited to straight cuts. Movement in three axis.

LINE SAW



A line saw follows the same principle as a band saw but is outfitted with a cutting wire with diamond cutting segments. The size of the cut is often considerable and the possibilities for freeform cuts are considerable. The standard is a trackmounted saw as seen in the figure above but smaller line saws can be mounted on a n industrial robot arm for even more flexibility.

CNC-MILLING

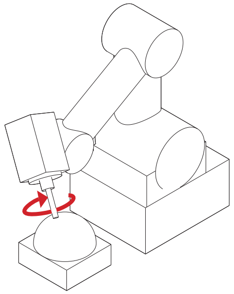
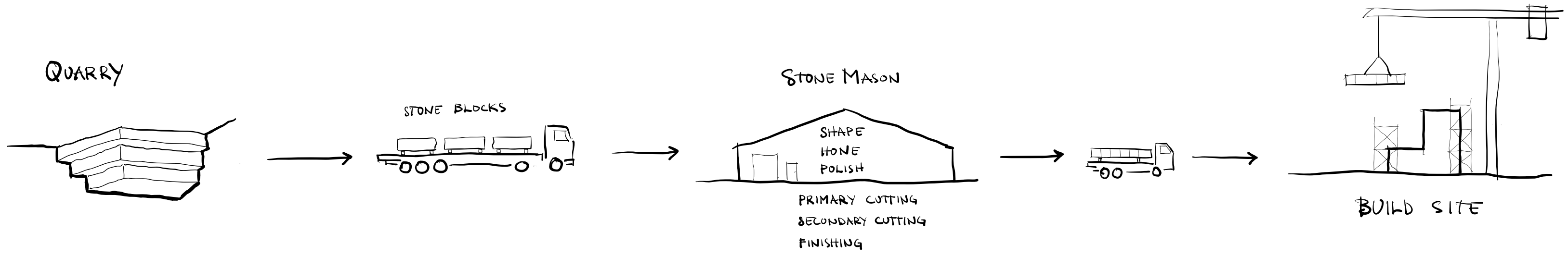


Image by Fallacra (2016)

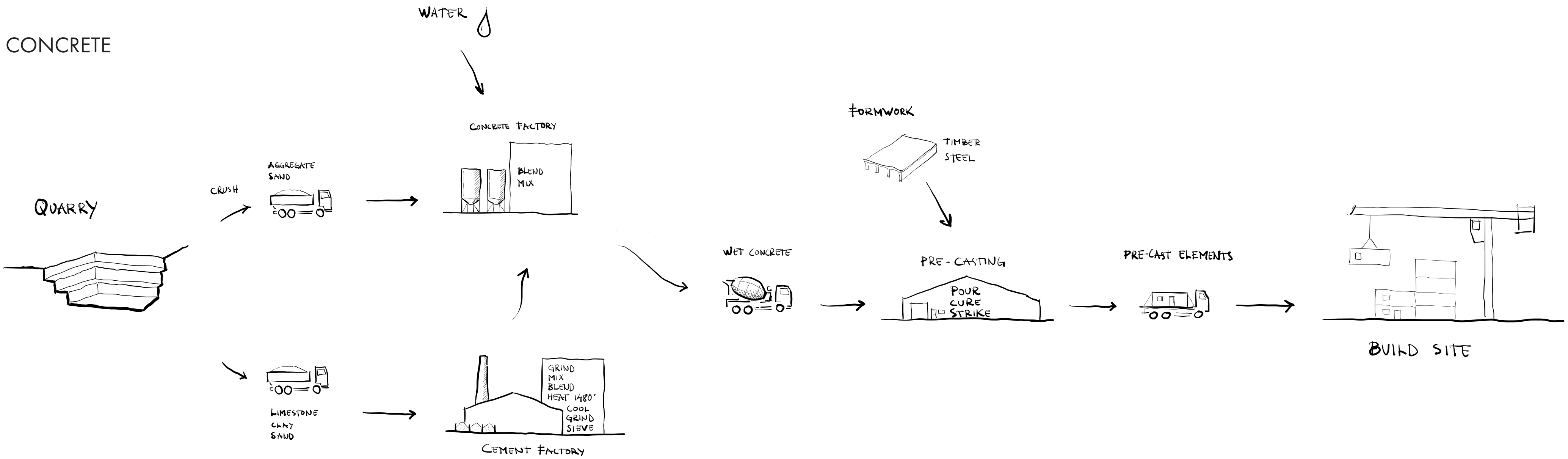
Milling of stone is done with hard-metal cutting segments mounted on a spindel. The process is CNC-controlled and, depending on the machine, fully freeform cutting can be undertaken. The process is highly accurate yet relatively slow.

STONE

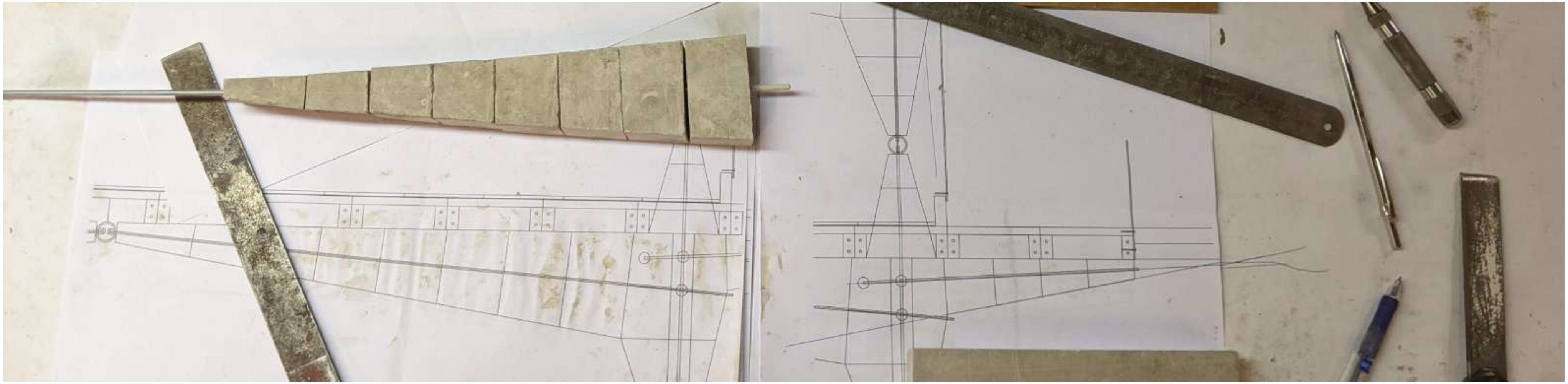


Comparing the manufacturing process of dimension stone vs that of pre-cast concrete we see that stone has many fewer material moves, facilities and added resources involved. In the end a more energy efficient product.

CONCRETE

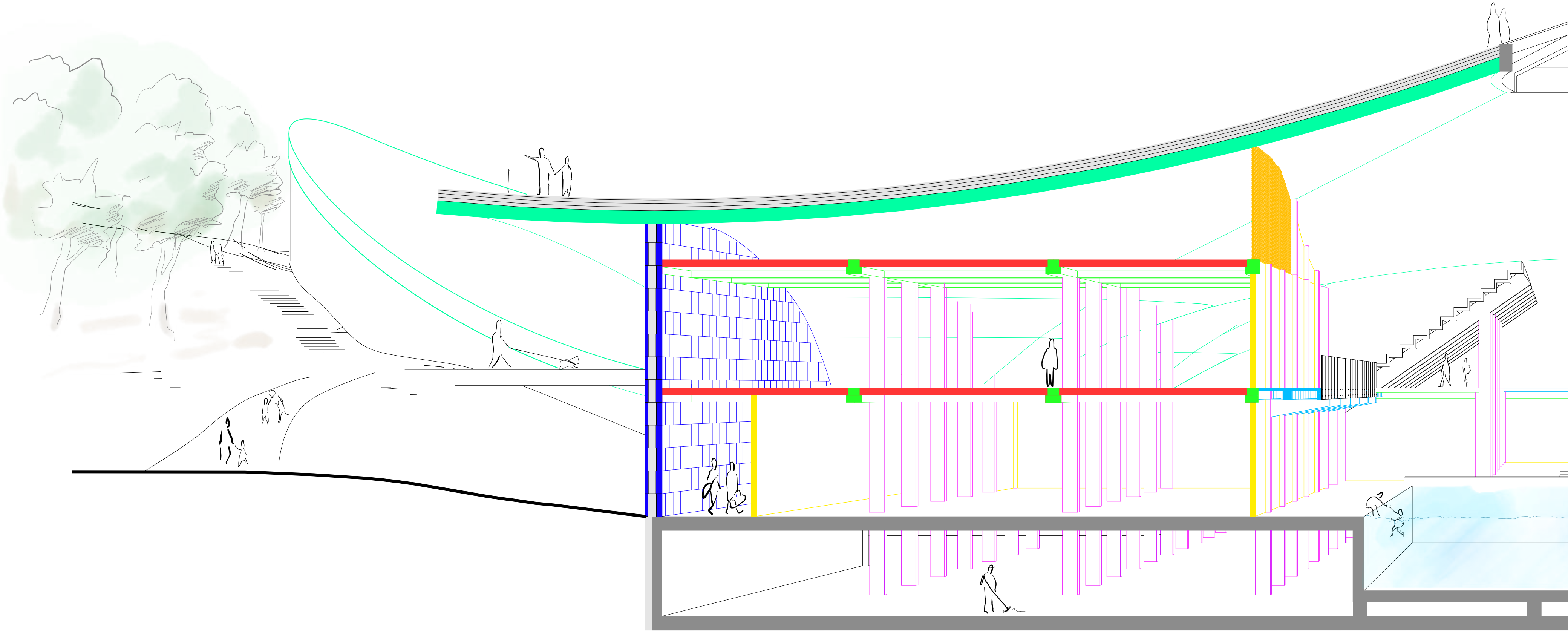


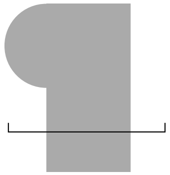
DESIGN PROPOSAL



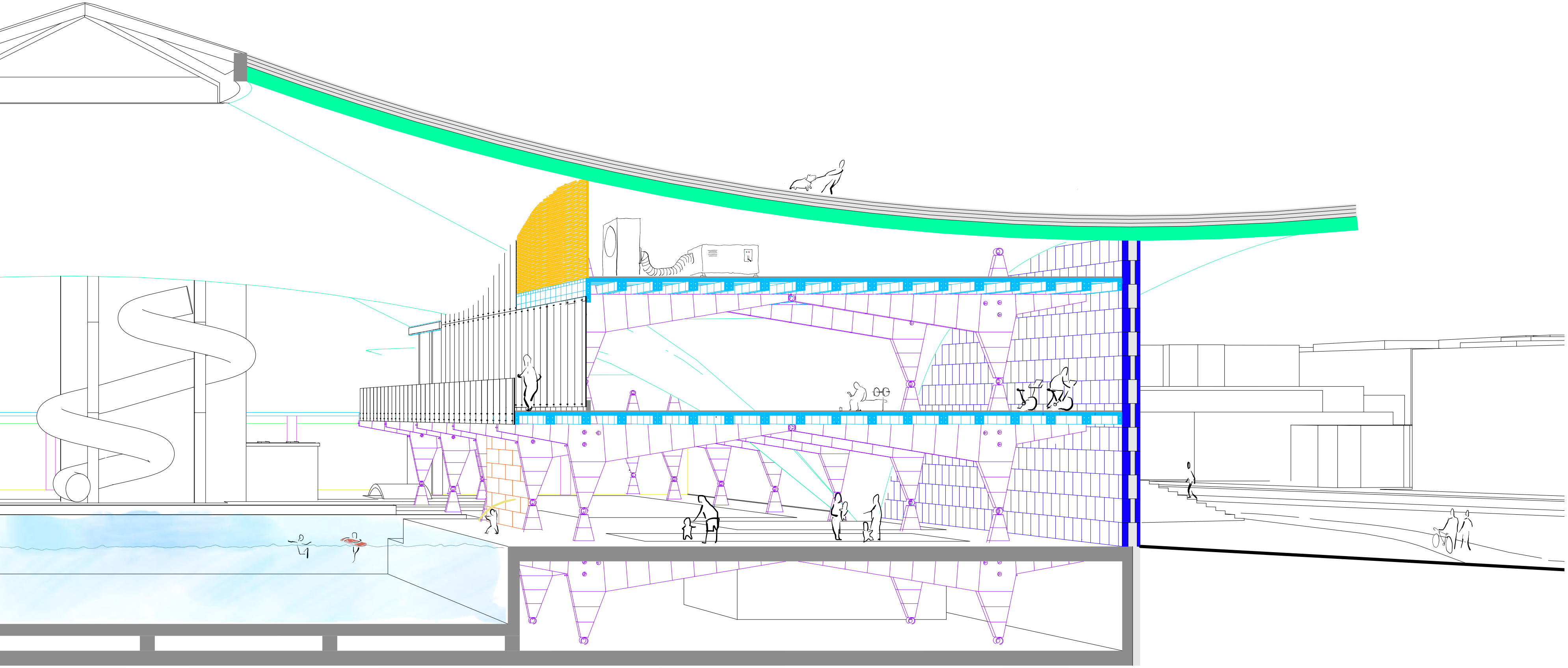
STRUCTURAL STONE

SITE AND BUILDING





SCALE 1:200 (A4)



RESEARCH QUESTIONS

-How can natural stone be used as a major structural and aesthetic component in contemporary architecture?

-How to apply stone as a critical architectural element in the design of a public bath in a Swedish context?

This is a building designed to investigate how natural stone can be used in contemporary architecture. The design is based around an existing brief for a new public bath in Gothenburg intended to replace the neighbouring Valhallabadet.

Follow the color-coding to explore the different components that make up the building.

Post tensioned beams. To make a beam from stone is not as counter intuitive as it may sound at first. Not if you combine stone with a couple of steel rods. The principle is the same as with any reinforced concrete beam — stone handle compressive forces and steel the tensile ones. Blocks of stone are cut to size and drilled out to make a steel rod pass through. Stone components like these are ideal for prefabrication.

This pillar grid is used in the part of the building that houses changingrooms and a spa — programs that can be accomodated within the shorter span of 7x7 meters. Blocks are stacked with only a thin layer of grout and held in place by the weight of the construction itself. Freestanding pillars are not dressed but have the raw surface that is left from quarry production. This gives a strong material character, saves time, money and emissions.

This floor slab is based on a masonry principle developed in the seventeen-hundreds and it forms what is called a flat vault. The tight fit of each stone restricts any movement and weave the stones together into a beautiful pattern. Within the field of stereotomy — the art of cutting and fitting blocks — a lot of knowledge has been forgotten over the past onehundred years. Building in stone today is about rediscovering as well as developing new technology.

Bricks like these are made from surplus stone, stock that is otherwise discarded solely due to visual incoherrence. The process is straight-forward and highly mechanized. Properties of the final product are very similar to a clay brick — the major difference is a climate footprint that is only one quarter of conventional fired brick.

The roof and global structure of the building is based on a geometric shape called hyperbolic paraboloid or saddle shape. It is a double-curved surface that is made up of straight lines. Double-curved means structurally strong, and straight lines in this case means that straight tension rods in two directions can be combined with precision-cut blocks of stone to form the buildings roof.

Sandwich wall. With modern equipment stone can be cut to ever thinner dimensions. A fibreglass and epoxi reinforcement on one side makes it stable to handle. Thin stone can even be curved with the right techniques. In this example a core of foamglass — another mineral based material — is sandwiched between two layers of thin stone to form a strong but light wall element.

Three-hinged frames. These components are developed to create a long span and accomodate open spaces with pools underneath. The individual blocks are tensioned together using steel rods. The material is mostly limestone however the endcap pieces are made from granite since they are smaller. Granite is stronger in compression and also by volume better at withstanding fire, being a igneous rock formed from molten lava.

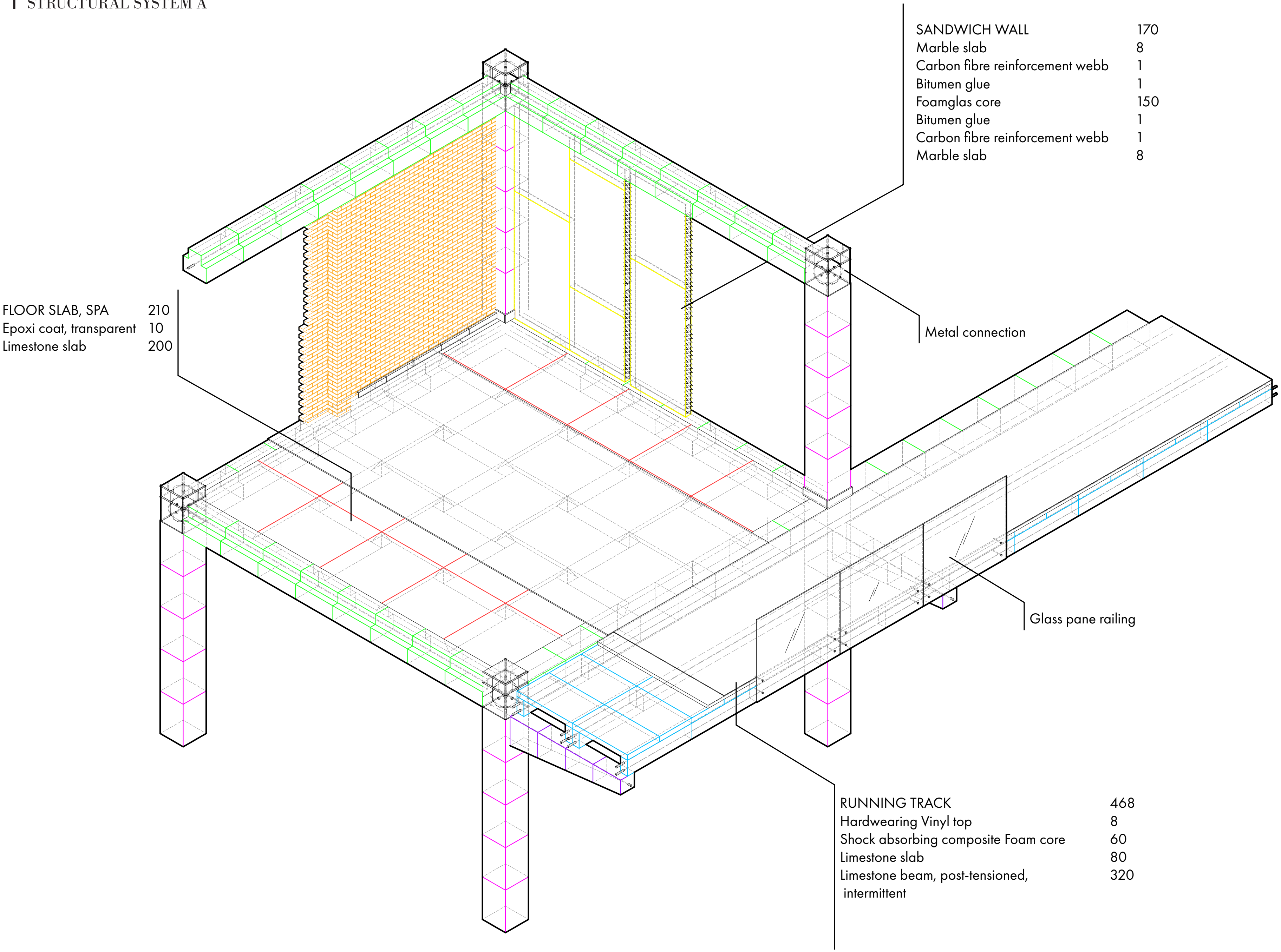
A massive inner wall for lateral stability. Built from "dimension stone", meaning massive blocks of ston that are cut to specific size. The assembly is simple and traditional — stacking with overlapping joints. A 3 mm thin layer of grout between the blocks ensures a tight fit and good seal. These blocks are limestone that is easy to cut and to process with circular saws.

Post-tensioned floor slabs. This component is the stone equivalent of a concrete hollow-core slab. While a bit more expensive to produce it doesn't need an additional screed on top. The bottom side exposes the limestone while the top needs a built up floor for accoustic reasons. In this building the slabs are used to create larger open space for the pools underneath and cover a span of 14 meters.

Outer wall. Approaches to using stone in load-bearing facades and outer walls range from completely freestanding exoskeletons to massive blocks, thin veneeres or self-suppporting weather screens. This wall need to be insulated and the solution used is a hybrid block with a load bearing inner side. Made up from two pieces seperated by an insulated void and a thermal packer at connection points the component aims to preserve the feeling of a heavy stone wall.

ISOMETRIC AXONOMETRY

STRUCTURAL SYSTEM A

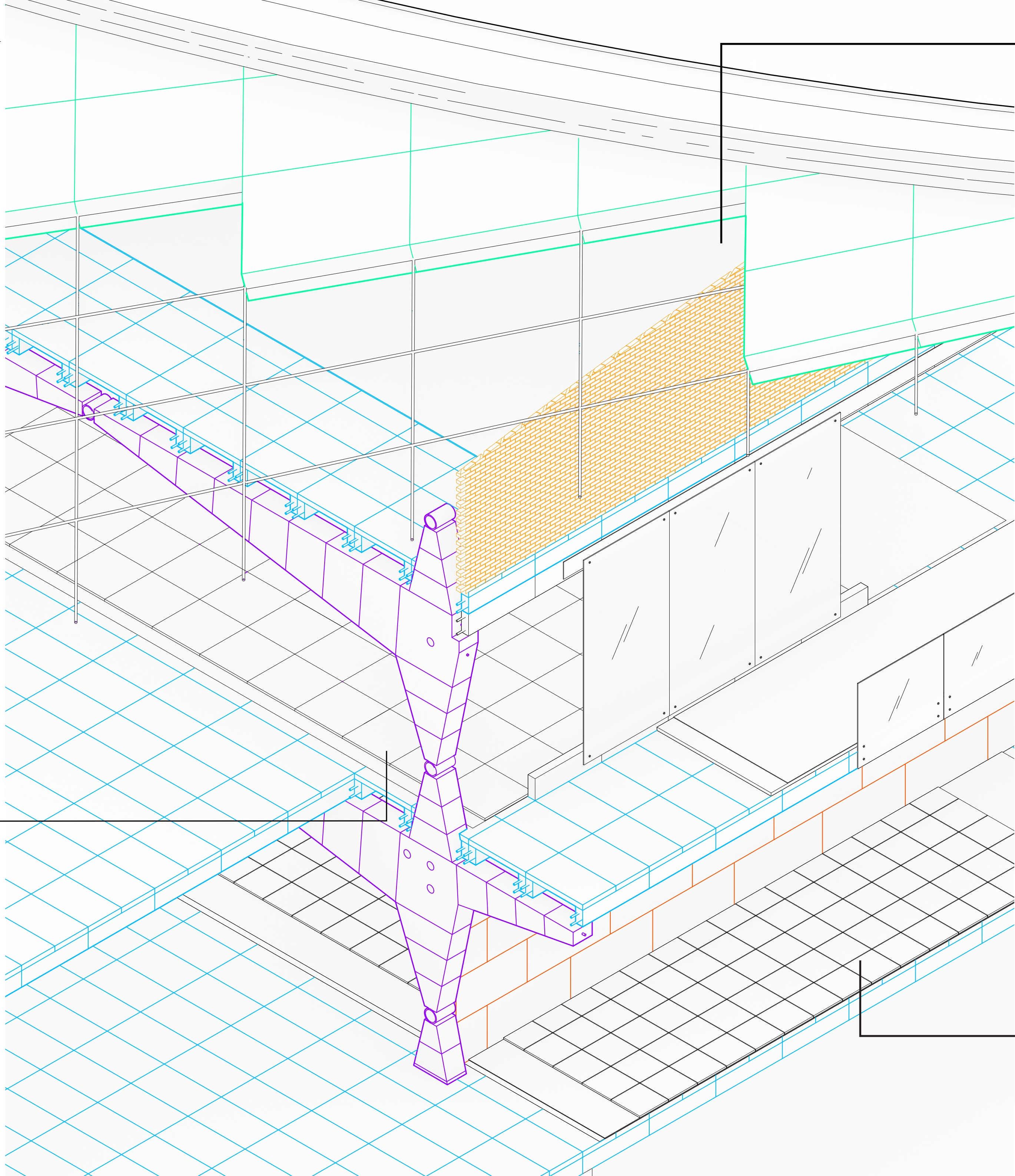


 SCALE 1:100 (A4)

Models of structural system A in scale 1:20

ISOMETRIC AXONOMETRY

STRUCTURAL SYSTEM B



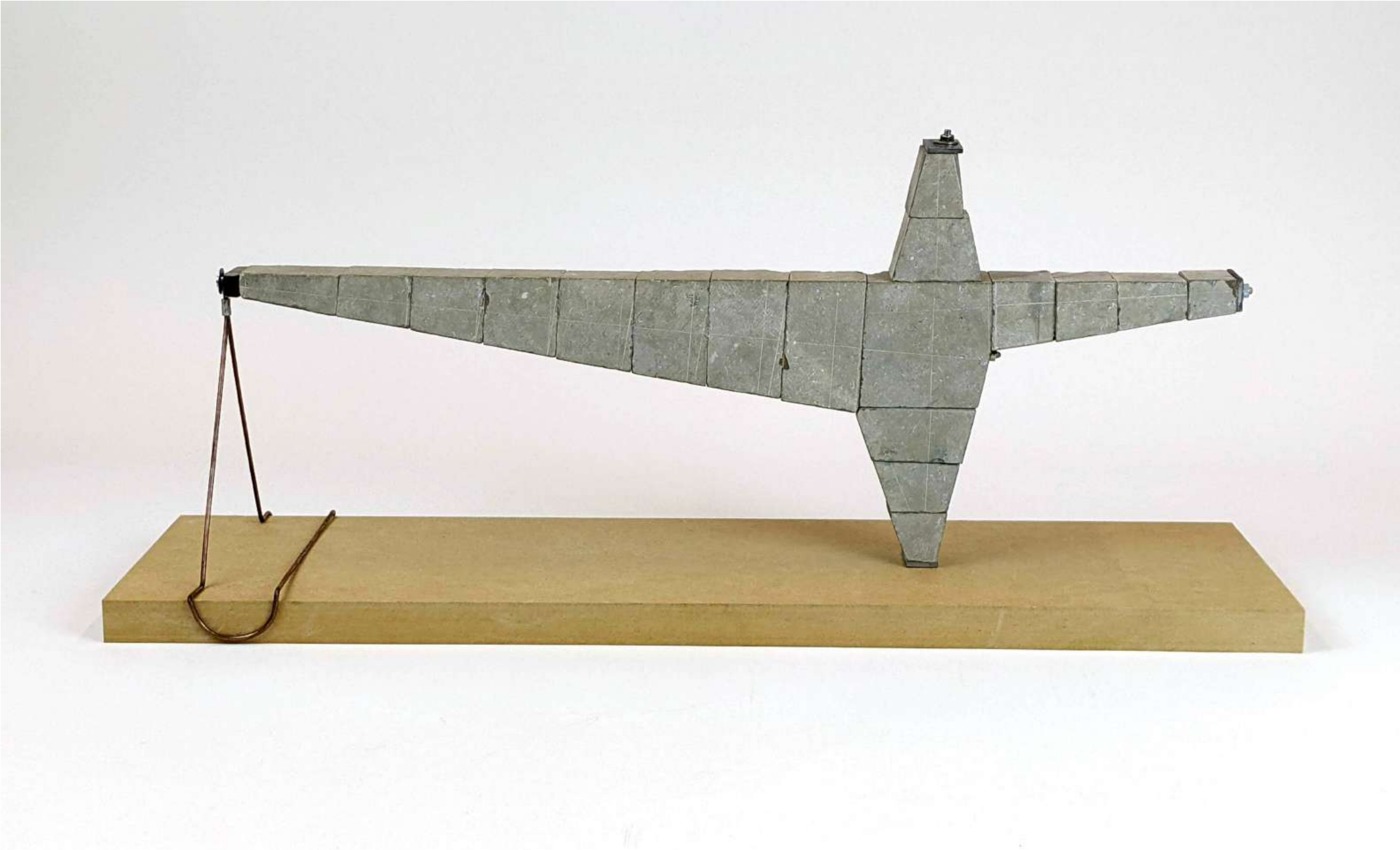
ROOF 1157
Sedum vegetation 30
Water retension 10
Draining membrane 17
Foamglas, set in bitumen 600
Limestone, post-tensioned 500

FLOOR SLAB, GYM 440
Tiles, polypropelen 40
Primer sealant
Limestone slab 80
Limestone beam, post-tensioned, intemittent 320

FLOOR, POOL ROOM 430
Limestone tiles 20
Setting grout 10
Membrane
Limestone slab 80
Limestone beam, post-tensioned, intemittent 320

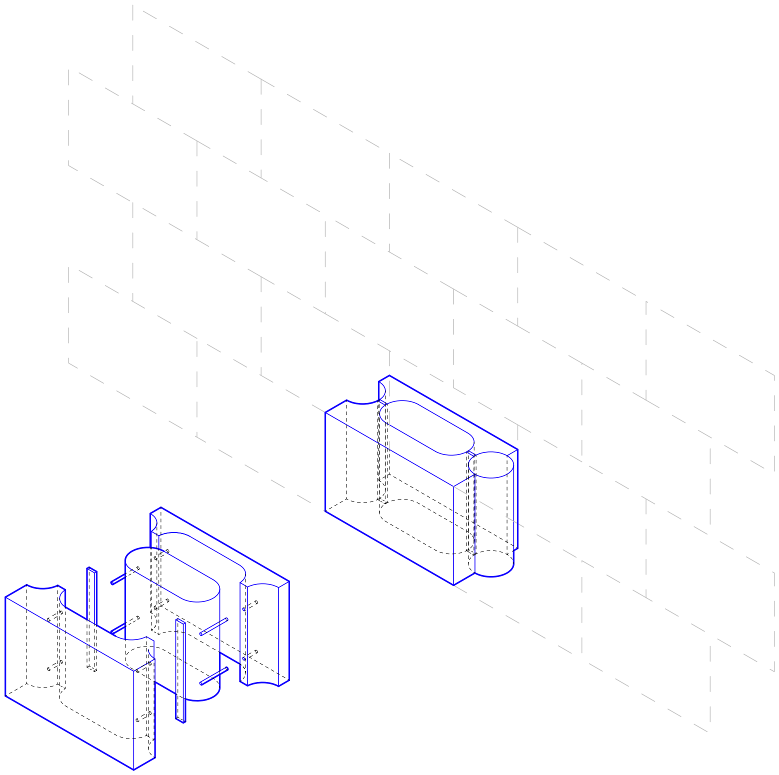
SCALE 1:100 (A4)

Model of structural system B in scale 1:20



Model of structural system B made from post-tensioned limestone in scale 1:20

Model of structural system B in scale 1:20

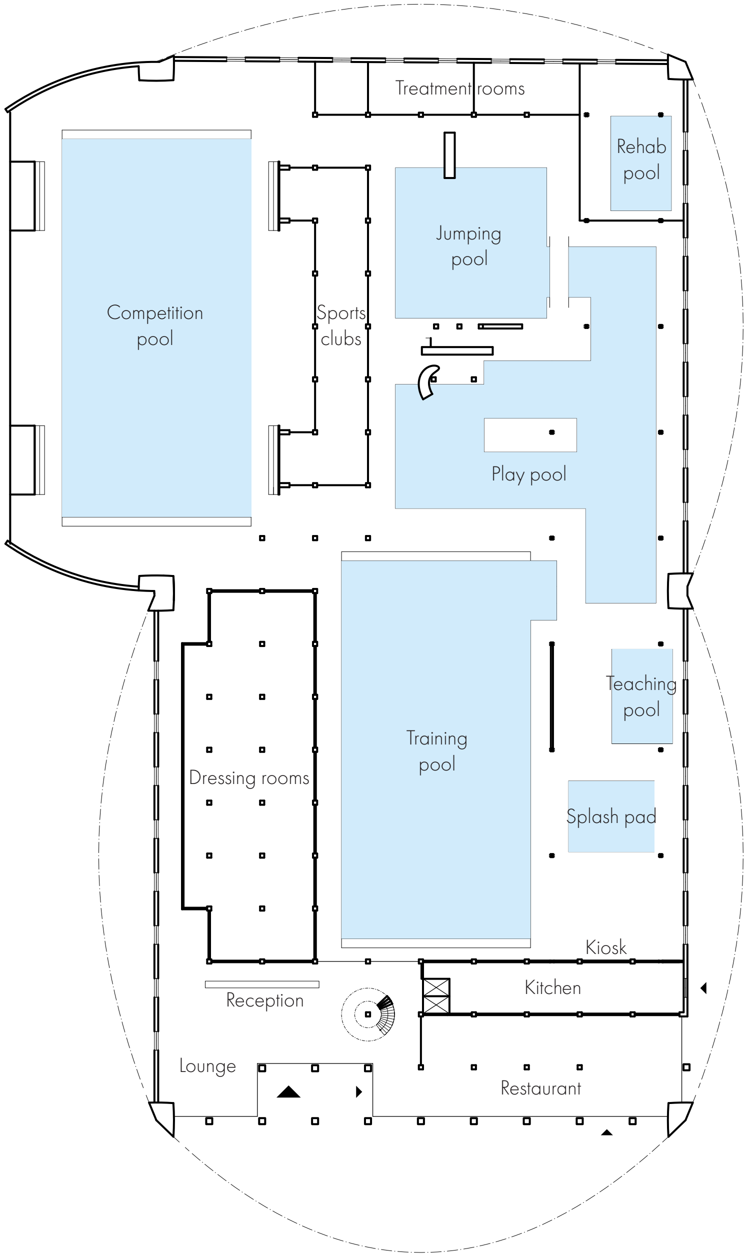


Isonometric axonometry of outer wall block element in scale 1:50

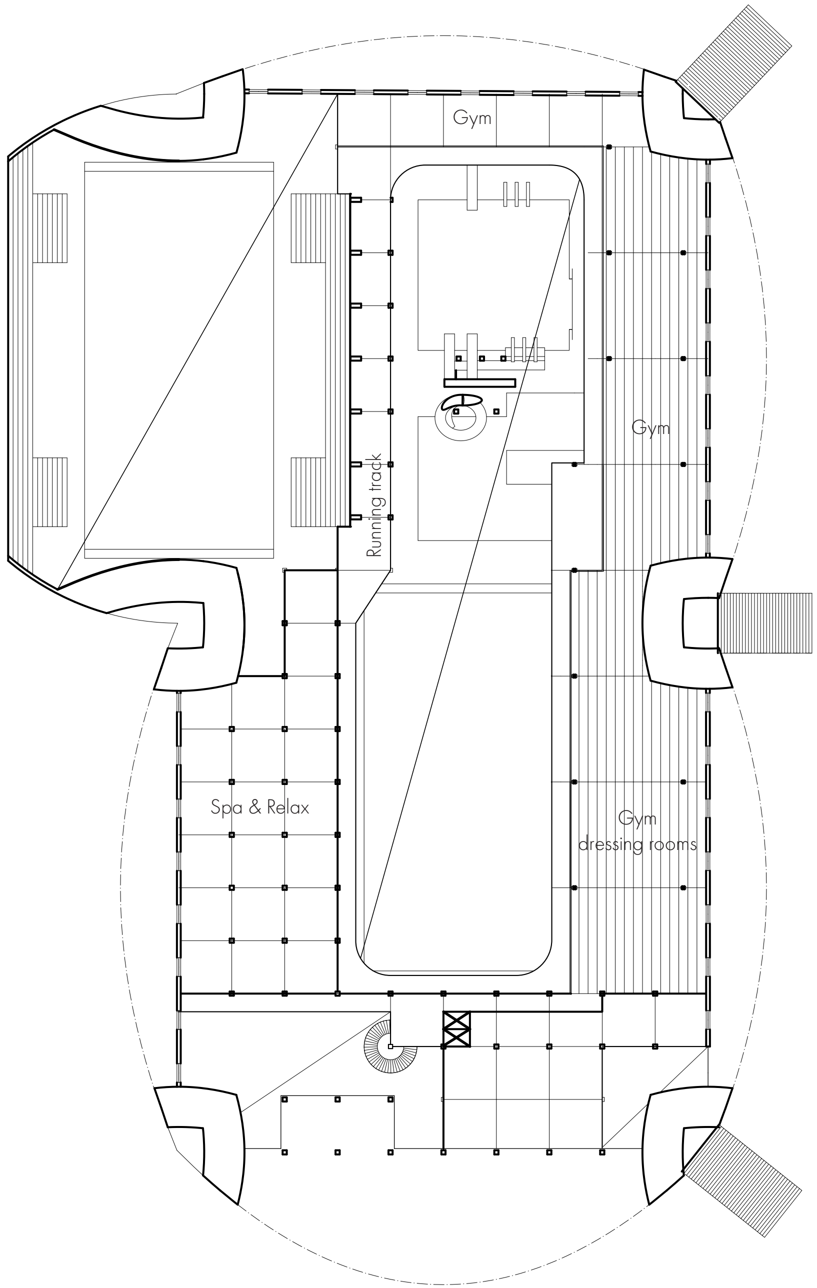
Model of outer wall block element in scale 1:50

The global shape of the building roof is made up of several sadel-shapes, combined and trimmed. Here a complete sadle shape or hyperbolic paraboloid - a double curved geometric surface made up from straight lines. Model in scale 1:500

Model of the building volume in scale 1:500

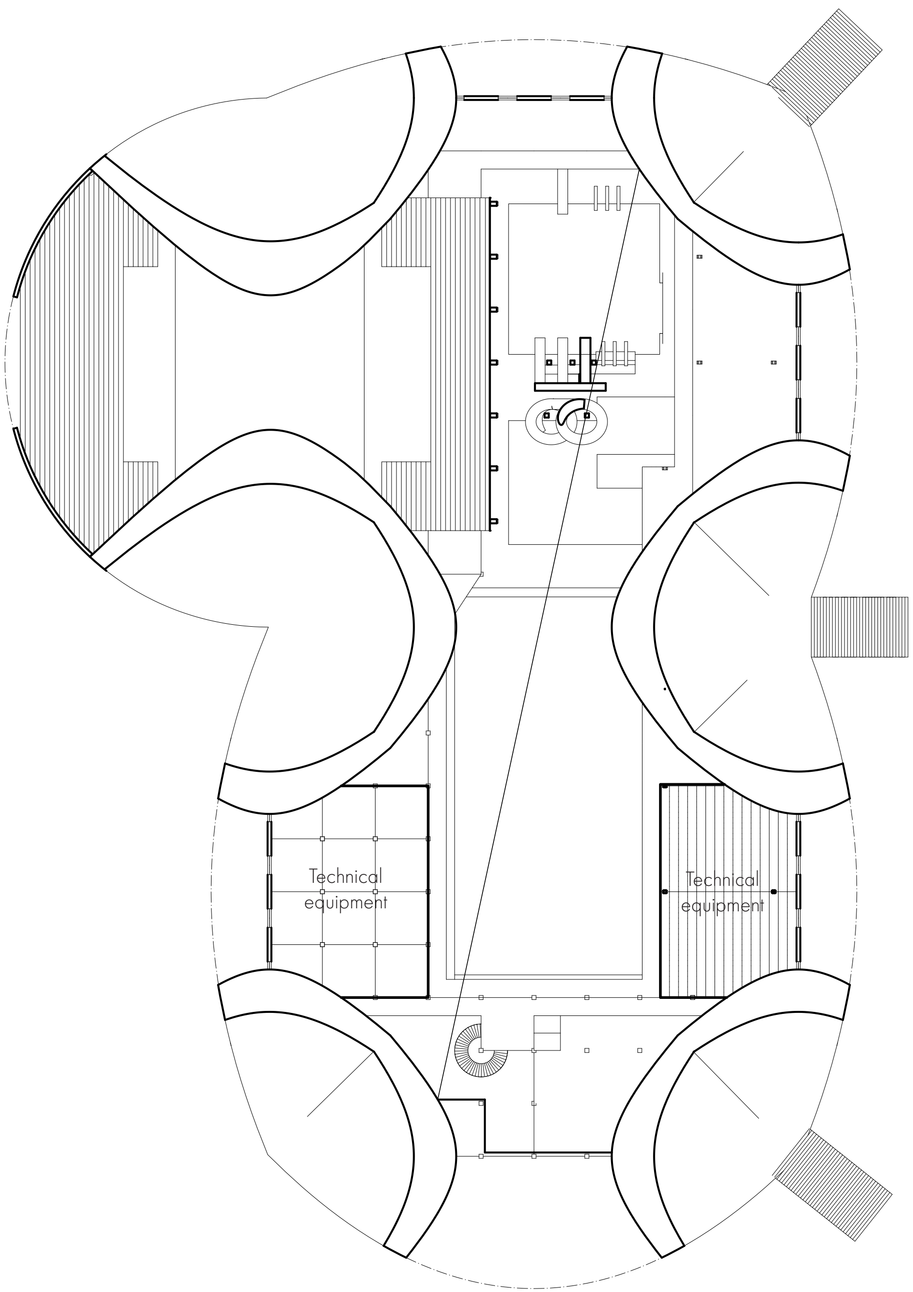


GROUND FLOOR

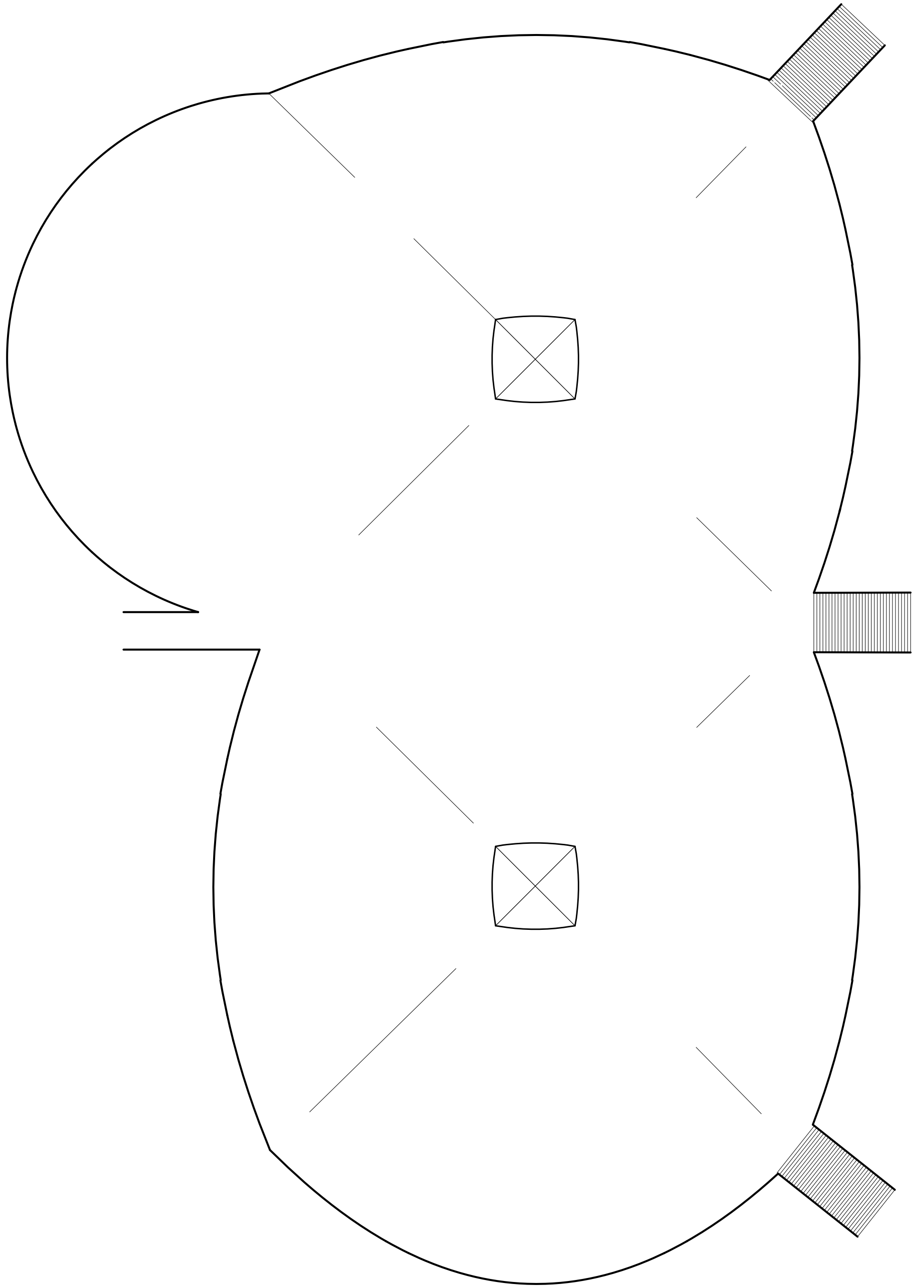


2nd FLOOR

SCALE 1:1000 (A4)

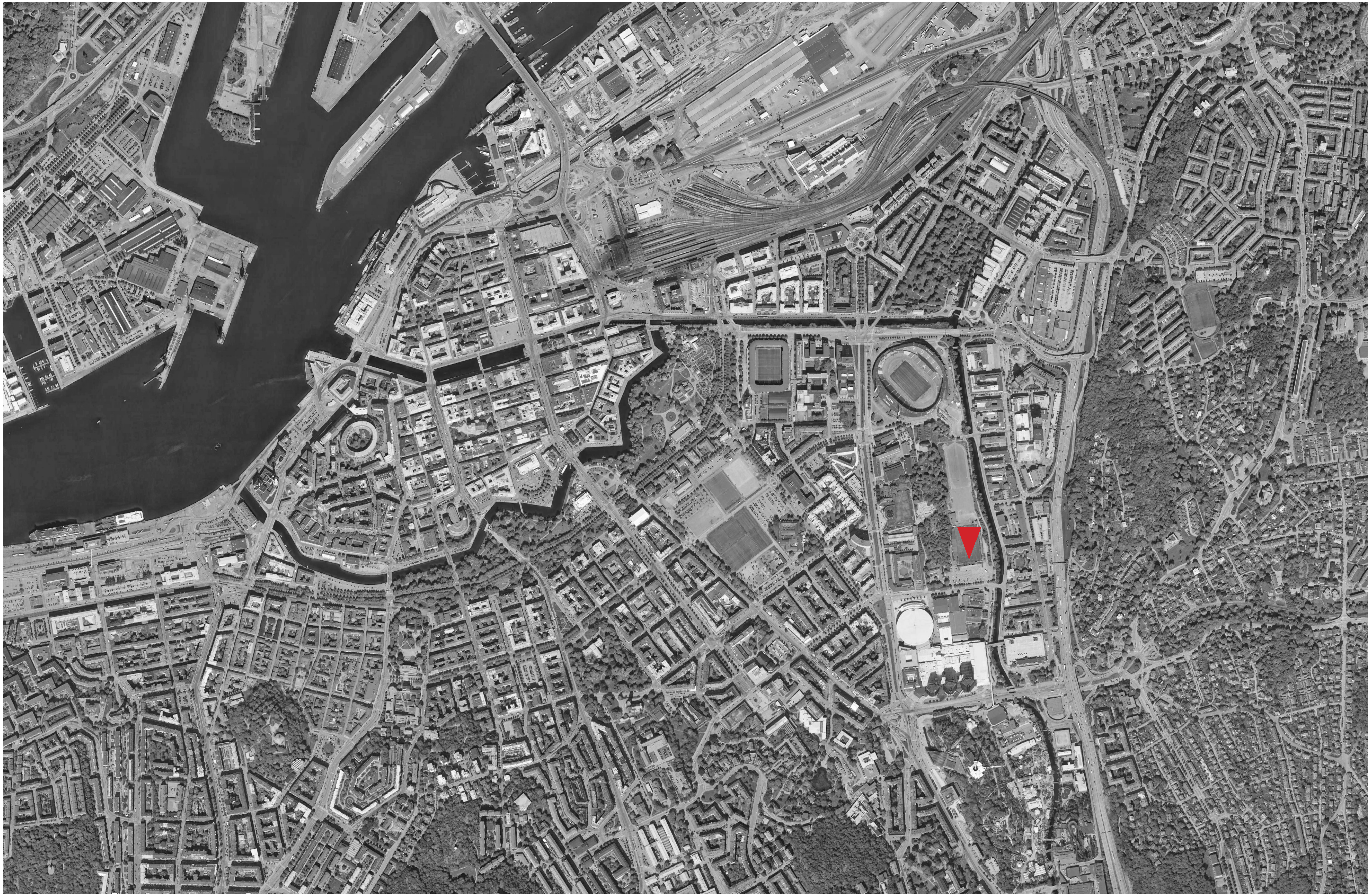


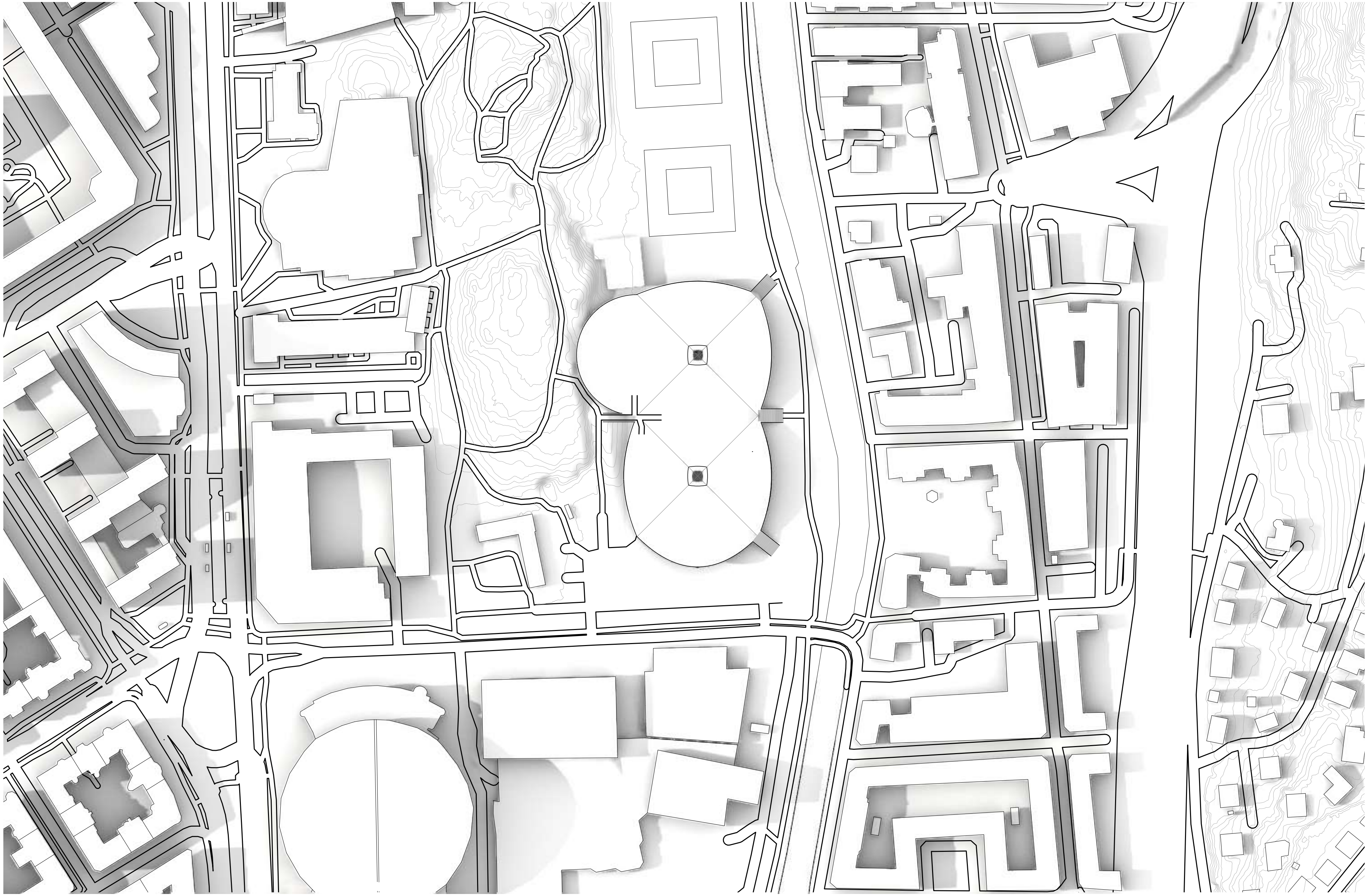
3rd FLOOR



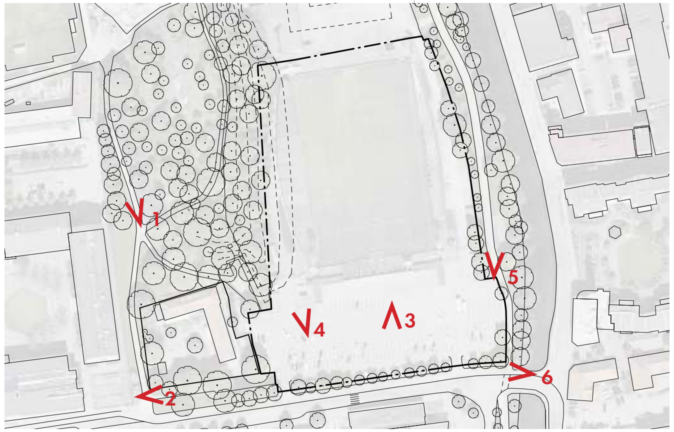
ROOF

SCALE 1:1000 (A4)






1




5


3


4


2


6

DESIGN CONDITIONS

Gothenburg municipality is in need of a new public bath to replace the old Valhallabadet across the street to the south. The program brief describes the new building like this:

A new public bath comprice of two 50-meter pools adapted for competition with two thousand seats for spectators, a high diving pool with platforms up to 10 meters, two teaching/rehab pools, one part for families and one spa/relax. Along with are functions for changing rooms and food service for both dry and wet parts. A gym with dressing rooms that can operate separate from the bath.

As part of the thesis a more detailed program has been developed as below:

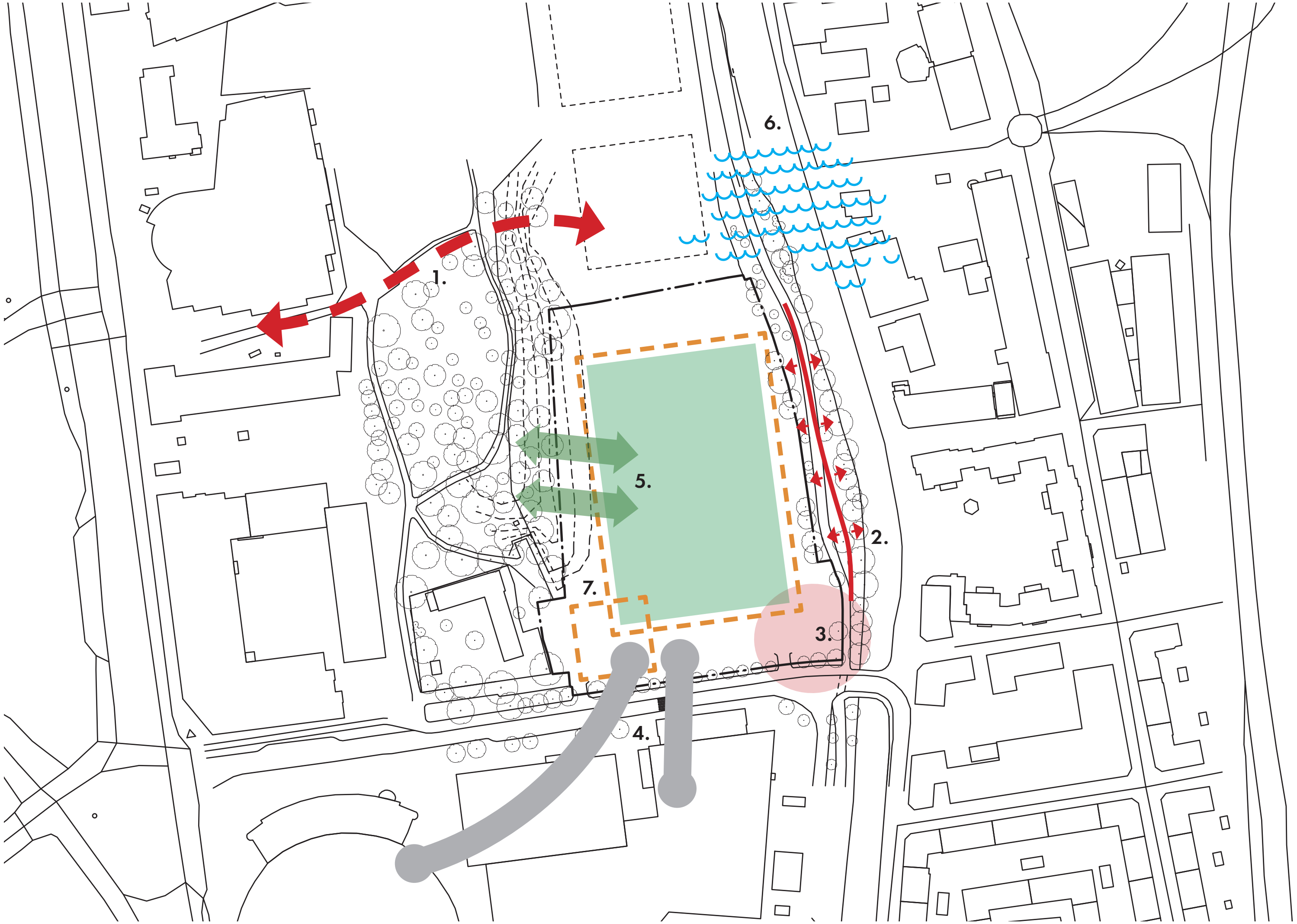
PROGRAM

Visitors ≥ 1 000 000 / year

	FUNCTION	SUB-FUNCTION
	BTA total	
	BYA footprint	
Exterior	Main entrance	
	Gym entrance	
	Delivery entrance	
	Staff entrance	
	Gate to pool/club activities	
	Storage club activities	
	Parking*	60-70 st
	Accessible parking	6 st
	Bike parking	
	Outdoor pools*	
	Relax outdoor area*	
	~~Kiosk window*~~	
	Doors to cafe	
	Outdoor seating cafe	
Dry	Foyer	Reception, lounge, WC, event coat racks
	Dressing rooms	
	Gym	Weights, machines, group training
	Staff areas	Office, cleaning, paus/kitchen
	Cleaning	
	Cafe	
	Bleacher access	
	Sports club areas	Storage, massage, hang/eat, office, changing

	FUNCTION	SUB-FUNCTION
Changerooms	Ladies	Sauna, showers, lockers, vanity, shoe rack
	Herr	Sauna, showers, lockers, vanity, shoe rack
	Family	
	Gender neutral	
	Sports club	
	Coach or so	
	Rehab	
	Relax	
	Gym	
	Babyswim	
Basement	Technical installations	
	Access ramp + gate	
Wet	50m pool	Arena seats
	50m pool	Adjustable deep end. Dividable
	Jump pool	
	Bleachers	
	Family/adventure	Babysplash, adventureswim, jacuzzi, waterslides
	2 x rehab-/teachingpools	Adjustable depth
	Relax	TBD.
	Cafe/eating	
	Storage sports clubs	
	Cleaning	
	Dry jumping?	

Illustration from the report Fördjupad lokaliseringsstudie av ett nytt centralbad (2018) by Tengbom for Stadsledningskokntoret Göteborg. The diagram shows the present day conditions of the site, with schematic projections of the new public bath in teal and other planned development in gray.



DESIGN CONSIDERATIONS

Takeaways imperative to architectural design, derived from Göteborgs Stad official documentation on the new pool building.

1. An east-west connection to increase the flow of people through the area.

2. The walking path along the river is a positive quality. A large building can make the path feel narrow. Contious facade design to relate to the human scale.

3. The spot where Valhallavägen meet the walking path, a potential for a public place, inviting to pedestrians, joining the facility, park and walkways.

4. Synergies between the other arenas in the event area. Creating a psychological sense of belonging as well as sharing physical built functions and strategies for handling large crowds during events.

5. Integration with the park area. Possibility to create green roofs accessible to the public as an extension of the green space.

6. The area next to the river is at risk of flooding during extreme rains.

7. Access for emergency vehicles to the building perimeter. Areas outside to gather in the event of an emergency.

DISCUSSION

It is definitely possible to find solutions to present day building challenges and to heavily utilize stone in the process. The biggest challenges to wider use in construction is not within the material itself nor on the technological or processing side of things – spreading the word and gaining acceptance from a conservative and slow moving industry I believe will prove harder yet. This is an issue that architects are the best suited to drive – of course, as examples have shown, in close cooperation with other disciplines and stakeholders.

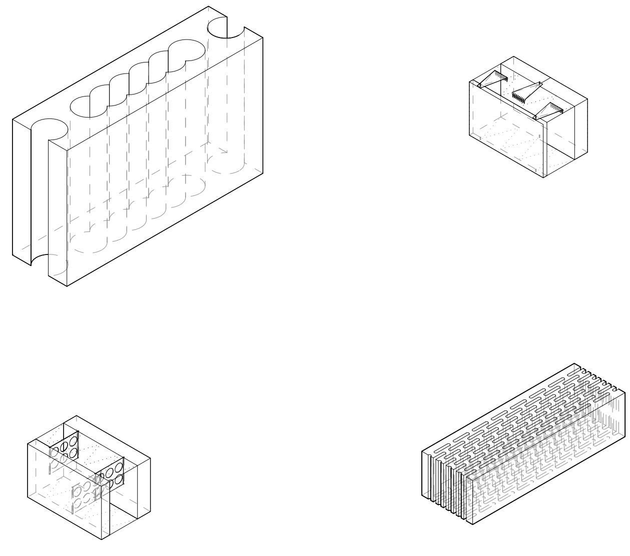
This thesis is expressing possibilities rather than rationalities. A lot of solutions are coming together, forming a smorgasbord of applications – rather than striving for a strict and polished silver bullet, I want to convey to the reader the plethora of options that lay at hand. Even with such an ancient material – the very image of the never-changing, the mossy rock – has so many more adaptations than are presented here. Or perhaps the other way around – even such a young material-science in this digital era already harboring so many possibilities for the architect. Imagine then what is to come. For me the greatest joy in this process is to have the privilege to explore and learn a new vocabulary through a material. To search the world for clues, for what has been done. To extend the lines with a scribbly pen into the unknown, feel around for a foothold and find whether a hypothesis will break or hold up.

I look at stone and see a similar situation to where engineered timber was at a few decades ago – a small niche for the super interested, not yet developed and not yet endorsed as the material of the green transition that it is now, central to the discussion at every university. Stone is not there. Neither is it the holy grail to solve all problems. But I have no doubt, after concluding this thesis, that stone has all the potential to become one of the pillars in a new, green and transformed building practice.

The choice to do both material investigation and a large building design has had the benefits of having a readily available interface on which to try out design solutions and relate theory to practice. It also created a wide scope for the thesis. This has resulted in less time allocated to each part of the assignment. The resolution of the building design is therefore lower, in priority of the material and building technique. This thesis digs deep in the topic of solid stone construction – one for architecture normally obscure and uncharted realm – but does not claim to have turned every stone or exhausted the many aspects this fascinating material has to offer. Two specific tracks come to mind as possible ways forward.
The foundation is an area where I have not solved a design in stone. I have not gone into this for the scope of the thesis was not large enough to contain it. However, foundation is a highly interesting area of study – the material stone really wants to be in the ground, more so than concrete will it last over time. With a future development of this thesis, foundations would be a splendid area to research and develop. It is a concrete- and steel heavy part of a building and therefore much climate gain is there to be had by developing a greener alternative. With the background knowledge from this thesis I judge the task fully doable. What it would take is the time for a deeper delve into the conditions of foundations for large buildings.
The other track would be to develop a much smaller building concept, one that is more manageable in size and also easily comparable to existing formats. For this building then in detail calculate material costs, greenhouse emissions and together with manufacturers develop a system design for production, transport and construction. This in order to advance realism through uncovering more hard data.

One aspect that is not sufficiently exhausted – neither in this thesis nor in the general discourse of the field – and that bears a lot of potential in connection to stone construction is re-use and design for disassembly. While it is discussed to a similar degree as with other materials I argue that it is the suitability of the material that is especially suitable and should warrant the extra attention in this case. The combination of longevity, assembly process and recyclability lay an exceptional foundation to further explore architectural design, specifically designed on an element level to disassemble and re-use. As stone buildings are few and far between today and real life examples are not prevalent it is natural to start the development on how to build up and not on how to disassemble. However the possibilities given by longevity is one of the biggest strengths and strongest selling points of using stone. A problem however is calculating sustainability profits over longer time spans. As the potential lifetime of stone buildings run beyond human life cycles and way beyond the cycles of short-sighted profit this is a continuous problem that architecture and urban planning is facing.

To not lose the stone surface or the feeling of solidity that is inherent in a block of stone is something that has presented a challenge during this process. A wall that is properly insulated always ends up being some version of a three layer sandwich. This is not a problem in itself. To build a solid and load bearing stone wall that is on the outside clad with insulation is a rational and straightforward undertaking – perhaps in combination with foamglass insulation, another mineral based material that goes well along with the stone. But is there a way around this? Is the question redundant in itself? Is a thin stone the same as a thick



Iterations of outer wall elements

one? Through a number of design iterations this has been investigated. The building design contains several different types of walls that represent different approaches. For the final version of the outer wall a form of hybrid block has been designed. A thicker and load bearing inner part, connected with tie-rods and a thermal packer to a thinner stone profile with a raw cleft exterior side. Between the two halves is an insulated void, cut to shape with a line-saw and filled with foamglass that is cut to fit and sealed in with bitumen glue. This is probably not the most economical or thermally rational option. However it is a solution that aims to convey the gist of a cyclopean stone wall, the heavy, the reliable rock.

To build in stone, in the case of this thesis, means to build in only stone as far as possible. This is to preserve a strong and undiluted concept and to give every opportunity towards showcasing the surprising versatility of the material. Very little attention is directed towards any type of hybrid buildings. In spite of this I do believe that a hybrid relationship is a more likely way forward. No one material is an island and when stone emerges as mainstream its place will be in close co-operation with its family of other natural building materials. In the appendix of built references are some examples of hybrid structures. The joint venture with steel for post-tensioning is fundamental and straightforward. The combination with epoxy and carbon fiber opens new doors to tensile, lightweight, razor thin, bendable and even fluidly double curved applications. Personally I must admit that these are less appealing on an emotional plane – what we know as a stone, a heavy and brittle material full of grit; is it still a stone when it is flexing, flying and draped in glossy coats? Did it lose something on the way, its soul perhaps? A much more down to earth hybrid is presented by Gilles Perrudain. Massive pre-cut stone makes up the walls from inside and out. Timber makes the floors. It is honest and it is beautiful and it is also the most convincing example of contemporary sustainable architecture that I personally have ever seen. In a french climate adding insulation would cost more carbon equivalents than what is saved. Perraudin also rejects PVs on his builds with reference to the dirty production process. It is low tech, far from click-bait architecture and glossy magazines. But is logical and understated good enough to win any sympathies today? Perhaps the strongest of the many advantages of stone is the unparalleled longevity. This is also a very strong sustainability aspect, given of course that the building is allowed to stand. I see enormous opportunity in stone as a building material. What I perceive as threat is using something that is under our noses, under our feet – is a solution so easy also too mundane?

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