Aperture

- An architecture to amplify aspects of competitive swimming

by Erik Styrbjörn Odd Torell

Thesis submitted to the faculty of Virginia
Polytechnic Institute and State University in partial
fulfillment of the requirements for the degree of

Master of Architecture

Heinrich Schnoedt (Chair)

Edward G Becker

Hilary Bryon

April, 2019
Blacksburg, Virginia

Architecture, Aquatic Center, Urban Connections, Swimming

Abstract

Architecture can amplify aspects of life.
The proposal in this thesis is to present the nature of competitive swimming through four specifically defined architectural moments. The vehicle for the thesis is a natatorium with four specifically designed architectural apertures that present the extraordinary motion of the swimmer, especially to the younger general public.

The focus will be on the motion of swimming below and above the surface of the water. Below the water surface, the approaching swimmer and the moment of the turn will be framed. Above the water surface, two apertures penetrate the roof above the pool. One directs sightlines to moment of a race's start, while the other seeks to emphasize the linearity of swimming.

Table of Contents

Introduction

Sweden and Swimming

REF. 1 © NAIA Nationals 2017/Ryan Sweat

Me swimming the 100 yards breast stroke at NAIA Nationals 2017

Although Sweden has produced several great swimmers in recent years and is home to Uppsala SS (est. 1796), the oldest still operating swim club in the world, swedes have historically been considered poor swimmers.

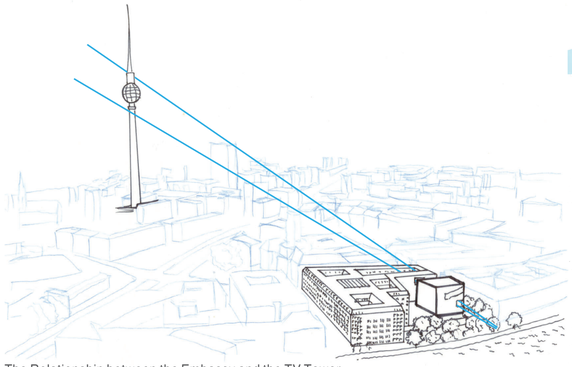
The first known organized teaching of swimming didn't occur until 1760 and was intended exclusively for Naval officers in the military. In 1899, 12% of adolescent students could swim, and only 9% of the students of a lower class learned how to swim. Due to major efforts in raising awareness combined with modifications of the physical education system, the country saw a rapid increase in the ability to swim during the following century. Statistics from recent years show that 80% of the students in 5th grade from rich neighborhoods can swim a distance of 200m while the national average is only 60%.

While the trend is progressive, there certainly seems to be a correlation between socio-economic standings and the ability to swim. Apart from swimming as a lifesaving skill, the sport can foster a sense of community and improve general wellness. In other words, public pools usually serve functions applicable to all tiers of society and all levels of athletic proficiency.

Although a significant investment over time, aquatic centers are key buildings in establishing an identity as a public center for athletic activity.

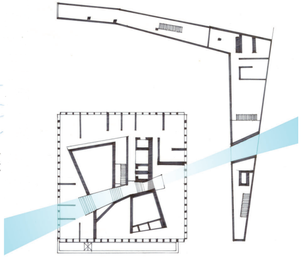
The project is proposed for the second-largest city in Sweden, Gothenburg. The architecture of a new aquatic center and public pool aims primarily to entice the younger generation to engage in the sport. The specific apertures are intended to present aspects of swimming as an attractive sport and an important part of Swedish culture and lifestyle.

Architectural Apertures



The Relationship between the Embassy and the TV Tower.

Diagrammatic Section

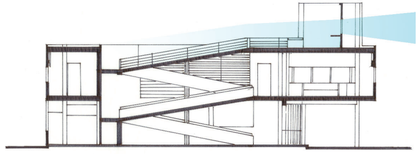


Diagrammatic Plan

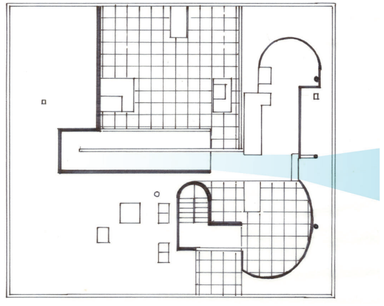
REF. 2 © Netherlands Embassy Berlin/Christian Richters

Embassy of the Netherlands, Berlin
Rem Koolhaas/OMA

The Embassy of the Netherlands perfectly frames the TV Tower of Berlin through a void in the building mass. The void penetrates the building from one end to another, letting observers see from the park, through the embassy all the way to the TV Tower at Alexander Platz. The building hence becomes a frame for an iconic building in the city of Berlin. By making such adjustment in the building mass, Koolhaas emphasizes the relevance between the building and its environment, the embassy of the Netherlands and the capital of Germany.



Diagrammatic Section



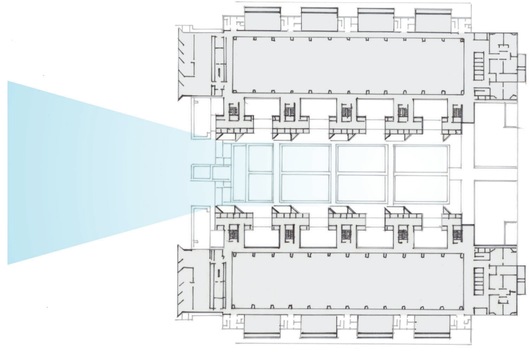
Diagrammatic Plan

REF. 3 © Villa Savoye Roof Garden/Christian Ahlskog

Villa Savoye, Poissy
Le Corbusier

At Villa Savoye's roof garden, Le Corbusier connects the interior of the building to the surrounding landscape. The window at the end of the ramp becomes an aperture that presents the horizon with increased intensity.

Diagrammatic Section

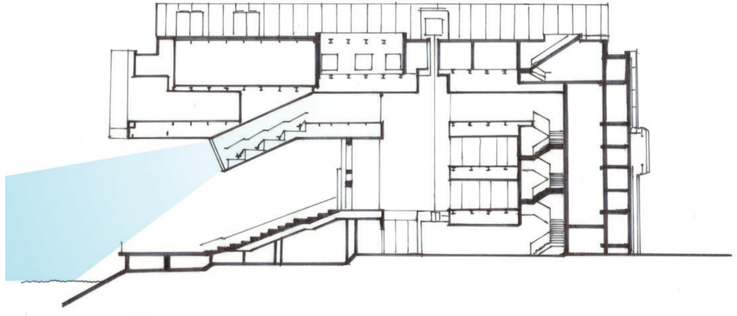


Diagrammatic Plan

REF. 4 © SD. Salk Plaza Axis 01/Naquib Hossain

Salk Institute, La Jolla
Louis I. Kahn

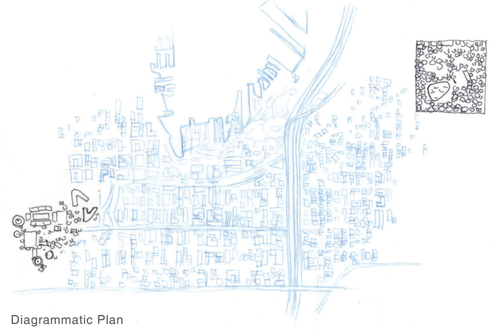
At Salk Institute, Kahn invites the vastness of the Pacific Ocean into his building. The plaza becomes a horizon lined with vertical elements. One centered stream of water flowes towards the ocean, seemingly uniting the waters of ocean and stream.



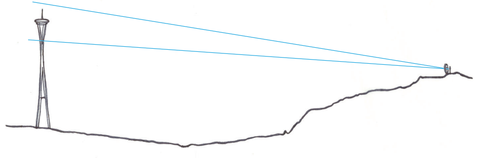
Diagrammatic Section

Institute of Contemporary Art, Boston
Diller Scofidio + Renfro

The Institute of Contemporary Art sits right on the waterfront in the Boston harbor. The media room leans toward the water like an open box. The inclination toward the water surface emphasizes its location and creates a sense of suspense.



Diagrammatic Plan



Diagrammatic Section

REF. 5 © Black Sun/Peter Alfred Hess

Black Sun, Seattle
Isamu Noguchi

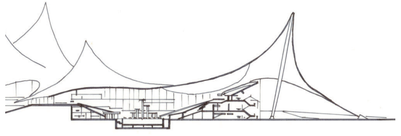
The Black Sun by the artist Noguchi is an example of a sculpture that frames an object in the field which makes a spectacular view. Standing by the Asian Art Museum, looking through the granite sculpture, the downtown area of Seattle disappears, leaving only the Space Needle left in the field of view.

Particularities of Swimming

REF. 6 © Sum Sim Reg '10/Tim Jarnvik

Louise Hansson - Swedish Olympian

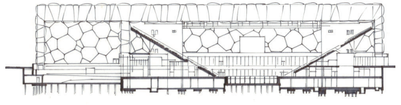
This thesis attempts to focus on moments that are crucial in the sport of swimming. Rather than designing for a perfect view of the field of swimmers with the best possible viewing angles, this aquatic center attempts to amplify highly specific moments of the sport.

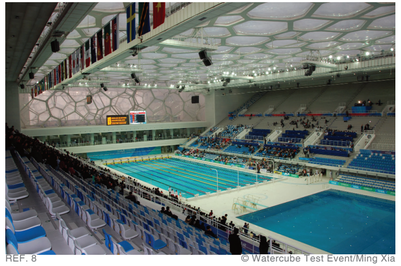


REF. 7 © Munich Olympic Swimming Pool/Jimmy Baikovicius

Olympia Schwimmhalle, Munich
Behnisch & Partner

The Olympia Schwimmhalle in Munich has remained attractive to the public after the 1972 Olympics, most likely due to its unusual tent roof structure, its central location and high level of approachability. Remarkable is the reduction of 7500 spectator seats during the Olympic Games to the present 1500.

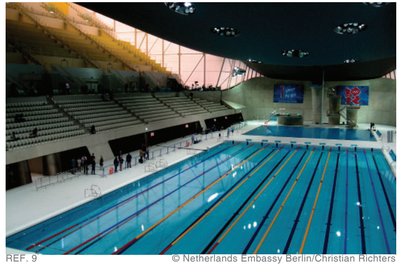




REF. 8 © Watercube Test Event/Ming Xia

Beijing National Aquatics Center, Beijing
PTW Architects

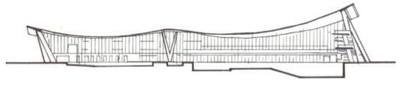
The Water Cube in Beijing was structurally and functionally very successful. Light levels are good, the energy costs are comparatively low, and the pool is excellent for racing. It has an even depth of 10' which makes it rather unique. The deep water makes the pool faster than other shallower pools. The water cube struggles to stay operational due to the cost of operating a facility of such size. It has lately converted parts into a water park and will soon convert again into a curling arena. Despite its struggles, it remains one of the best upkept facility from the 2008 Olympics.



REF. 9 © Netherlands Embassy Berlin/Christian Richters

London Aquatics Centre, London
Zaha Hadid

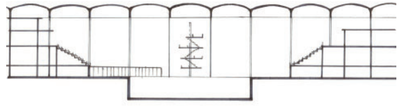
The London Aquatics Center has a beautiful and unique shape. Similar to the Munich pool, the expandable seating from 17,500 seats during the Olympics, the arena's present seating is 2,800. This ability to convert has made the pool sustainable for the city and possible to maintain after the 2012 London Olympics. The seating design did however receive critique for a less inclusive environment as the upper seats on either side did not have visual contact with one another.



REF. 10 © Grandview Heights Aquatic Centre/City of Surrey

Grandview Heights Aquatic Centre, Surrey
HCMA Architecture + Design

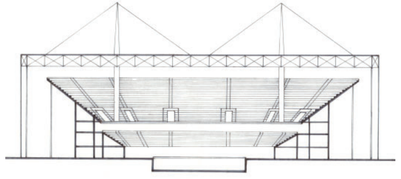
The Grandview Heights Aquatic Centre was not designed as a big arena for competitive swimming. However, it has a remarkable roof structure of Douglas fir. The tension members of the roof are able to span up to 188'. That is more than the length of the Olympic size pool hosted underneath the roof. By spanning the long way over the pool, the roof allows for unobstructed views of the surroundings on either side of the pool. Furthermore, the structure is inherently a guide for back strokers looking up into the strips of Douglas fir to stay in straight lines.



© Eriksdalsbadet ready for the 2010 World Cup leg in Stockholm/Lis i Jakupsstovu
REF. 11

Eriksdalsbadet, Stockholm
Björn Thynberger

Compared to Olympic proportions, Eriksdalsbadet in Stockholm is a humble arena. It is however the national arena for Swedish swimming. It strikes a great balance in between spacious design for the swimmer and a compact, lively atmosphere for the audience. The spectators are close enough to the action and the stands leave enough room for the swimmers and their auxiliary activities.



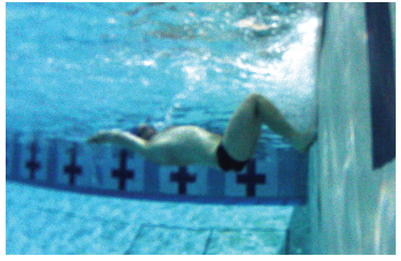
© Rio 2016 Olympics - Swimming 6 August evening session/Sander van Ginkel
REF. 12

Olympic Aquatics Stadium, Rio

Despite many shortcomings, the Olympic pool in the Rio de Janeiro offered a great displaying a view of the field of swimmers. Spectators are watching the athletes with the regular inclined view that is the standard in these large arenas.

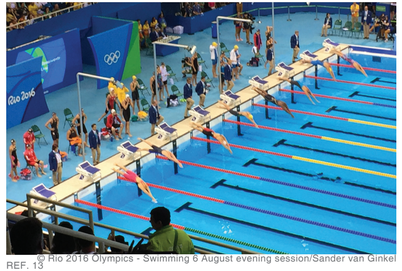
The Approaching Swimmer

Looking at a TV screening of swimming, there are a lot of intriguing angles from which a camera can display the sport. This is not to imply that the aquatics center should copy what the camera angles from the TV, but it could certainly be a source of inspiration. One of these attractive angles is the view of an approaching swimmer. Giving an unobstructed panorama of approaching swimmers would show the symmetrical motion of swimmers in detail.



The Turn

An extraordinary moment of competitive swimming is the turn at the wall. It is of great importance in the competition and the smooth motion is a necessity. The aperture that focuses on the turn is an attempt to entice the younger generation to participate.



REF. 13 © Rio 2016 Olympics - Swimming 6 August evening session/Sander van Ginkel

The Start and the Finish

In almost any race, the most significant moments are the start and the finish. While TV cameras usually frame these moments from an elevated side view, a spectator in the arena usually will see this moment form an elevated position only.

REF. 14 © Person Swimming on Body of Water/Guduru Ajay bhargav

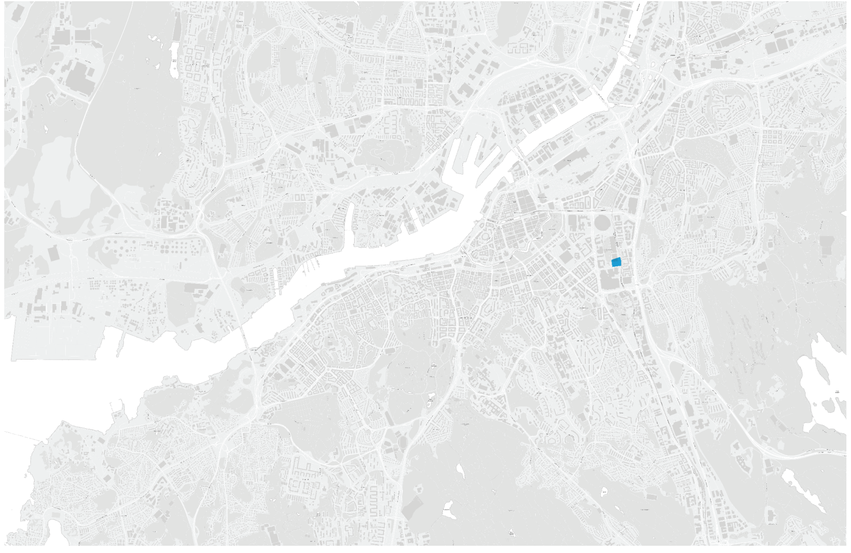
The Linearity of Lap Swimming

To exhibit swimming from a top down view, the linear organization of swimming is emphasized, together with the symmetry and balance in the strokes of the swimmer.

Contextual Considerations

Design Decisions at an Urban Scale

Sweden



Gothenburg (Göteborg)

The city of Gothenburg was founded in 1621. Based on Dutch city planning and resembles largely Jakarta, which was built around the same period.

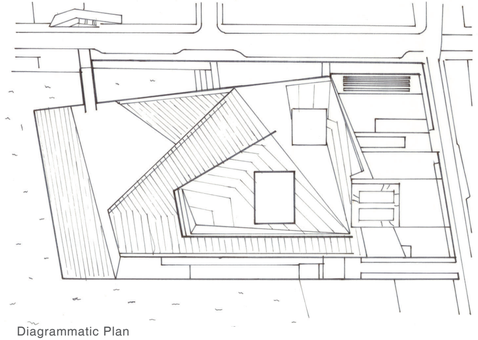
The built environment rarely stretches passed four floors, most streets are covered in cobblestone and very traditional materials are used. The river that flows through this part of Gothenburg eventually reaches the moat around the central part of the city . It establishes a connection between the city center, the sea and the site.

Just south of the site, the architectural language shifts. Geared more towards events, there is a theme park, multiple stadiums and an event space with adjacent hotels. This area is currently undergoing a planning phase for potential expansion. The stadiums are intended to grow larger and a theatre and an expanded shopping area is in the planning phase.

The above photograph show on the left the current street, Valhallagatan which is soon to be redeveloped as a pedestrian path. To the right is the current bike/pedestrian path next to the river.

Color Legend:
Event Space
Residential with Green Space
Residential without Green Space
Commercial

Diagrammatic Elevation



Diagrammatic Plan

REF. 15 © Oslo's Opera House/VisitOSLO

Oslo Opera House, Oslo
Snøhetta

A prominent, Scandinavian example of how to utilize the roof of a building to extend the city scape is the Oslo Opera House. By covering the building with a sloping roof, it allows for people to use the foot print of the building as an elevated park-like environment by the sea. The gesture is very successful and has become a destination for both tourists and locals.

Programmatic and Spatial Evaluation 1

By placing the pools as a stepped path from the hill in the back of the building to the event space, they make a natural barrier between the park and the street. They also allow for possibilities to visually connect to the river.

Programmatic and Spatial Evaluation 2

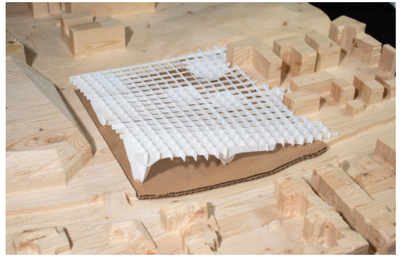
By elevating the pools and placing them adjacent to the park, they form natural, soft boundary between the building and the surroundings. Depending on the placing of the pools, they have varying levels of connections and relevance to either the park or the event space. The pools are still placed closely to the river.

Programmatic visualization in 3D

The programmatic elements begin to form relationships with the surroundings. The major competition pool belongs to the event space. The other pools have a stronger connection to the park.

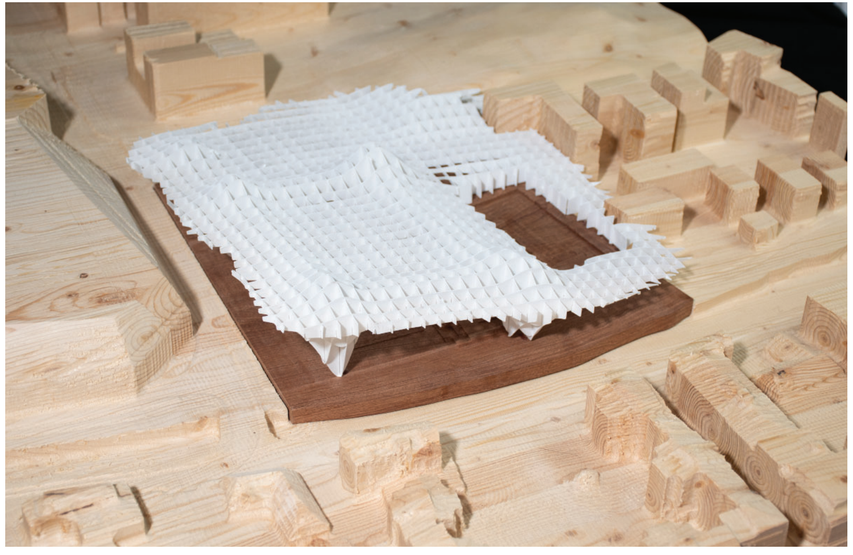
Structural Experimentation 1

Due to the size of this project, structure has played an important role. Letting structure guide the architecture, the building grows from the inside out. A structural system with a sense of direction gives the architecture another layer. The large glulam arches, mark a distance for the swimmers.



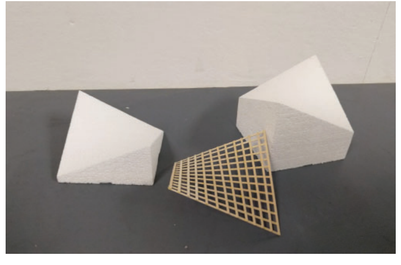
Structural Experimentation 2

The following experiment involved a bi-directional system that could both direct a path as well as mark a distance. This system also has the freedom to remain highly malleable throughout the design process.



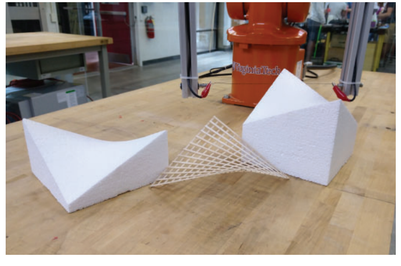
Structural Experimentation 3

Testing the possibilities of the bi-directional system. It has potential to be highly fluid which can allow for the roof to morph to desired shape both on the interior as well as the exterior. By manipulating the exterior surface of the roof, it has the potential to naturally act as a garden, with a highly manipulatable landscape. However, such system does require an excessive amount of material.



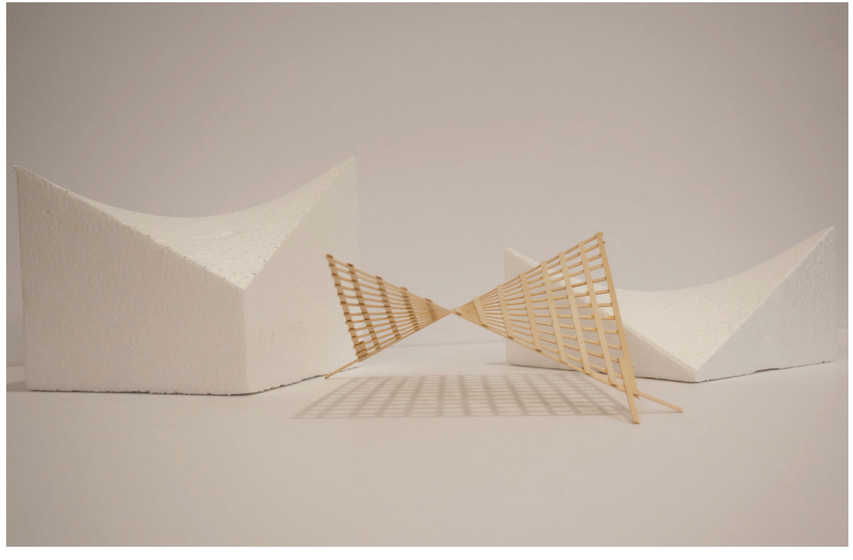
Exploring Ruled Surfaces 1

Bi-directional system, based on ruled surfaces was explored as an alternative to the grid shell structure. A hyperbolic paraboloid does not necessarily have to be bi-directional, but as a swimmer, a roof structure with two visually directional systems is appreciated.



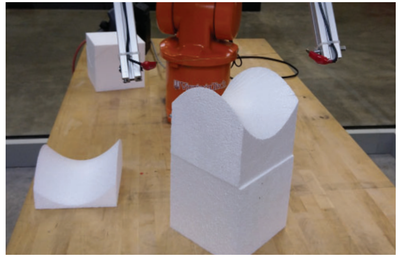
Exploring Ruled Surfaces 1

A ruled surface is constructed through an infinite amount of lines between two curves. If these curves are parallel in plan and of equal length, the perpendicular curves would also be parallel in plan, no matter the curvature of the surface. This concept became key to the roof structure. To achieve this complex surface, a hot wire cutter, mounted to a robotic arm was used to cut a foam mold. Thin slats of wood were then glued together to form the self-supporting structure of the model.



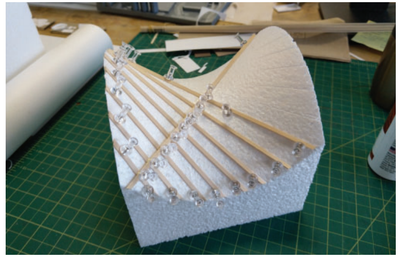
Exploring Ruled Surfaces 1

Since the hot wire cutter only could cut in a straight line, it was a good tool to use. The wood slats could easily be fitted to the form. Apart from an internal twist, the wooden slats remain straight.



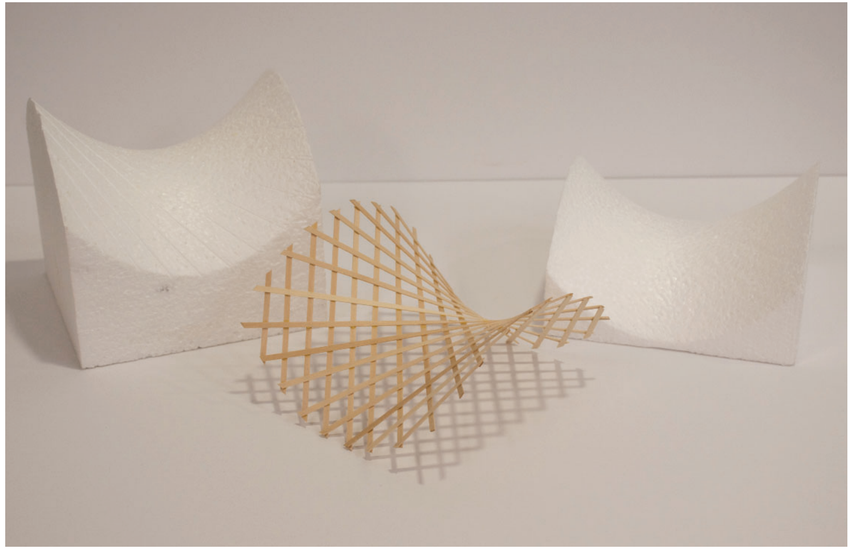
Exploring Ruled Surfaces 2

A second exploration of the hyperbolic surface involved a slightly more complex form. The same cut as in the first exploration can be performed to achieve this form, but the stock material needs to be rotated 45°.



Exploring Ruled Surfaces 2

Letting the robotic arm mark out where to lay down the wooden slats in the cut process made the gluing process easy and precise. By pinning down the wood while gluing it made the form stay stable enough to maintain its shape.



Exploring Ruled Surfaces 2

The Pringles-like shape is surprisingly simple and could be implemented as structure in the project. Noteworthy is that the cast shadow has the shape of a square. It shows the rectilinear nature of the form and is the only remnants of the stock material from which it was based upon.

A Study in Scale 1

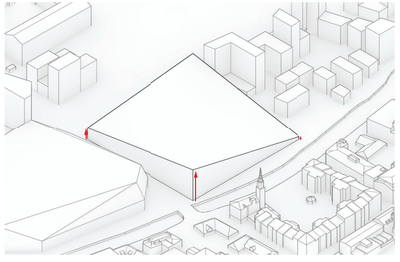
As Gothenburg is a city of rather small proportions, the project should suggestively maintain the appearance of smaller scale to match its surroundings, if possible. The first step in reducing the size of the project was to divide the form up in four segments.

A Study in Scale 2

The second step was to lower the edges that could reach out an become part of the surrounding landscape and raising those towards the street. This move facilitated the access to the roof garden. It also gives the building presence on the site.

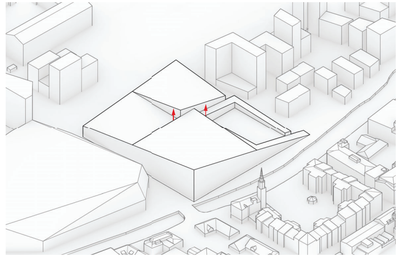
Articulation of the Form

To further break down the scale, a system of vertical fins was added around the building. The fins give structural support to the curtain wall system and adds a layer of shading. The element also becomes a playful addition to the facade as it undulates and behaves in a similar way to particles in a wave.



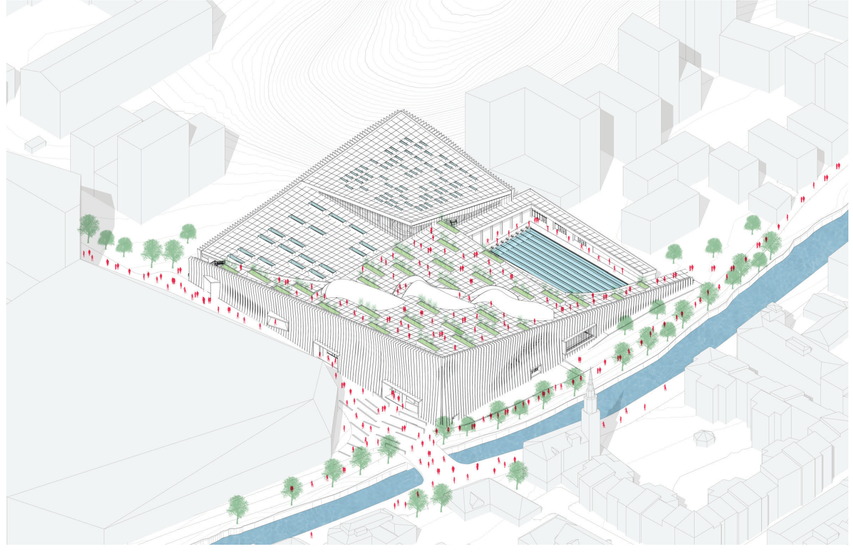
Meeting Between Event Space and Adjacent Park

To meet the busy event space, the building mass is pulled up on that side, to hold its presence at the street. At the same time, it is kept low towards the park to make an inviting gesture to the neighboring residents.



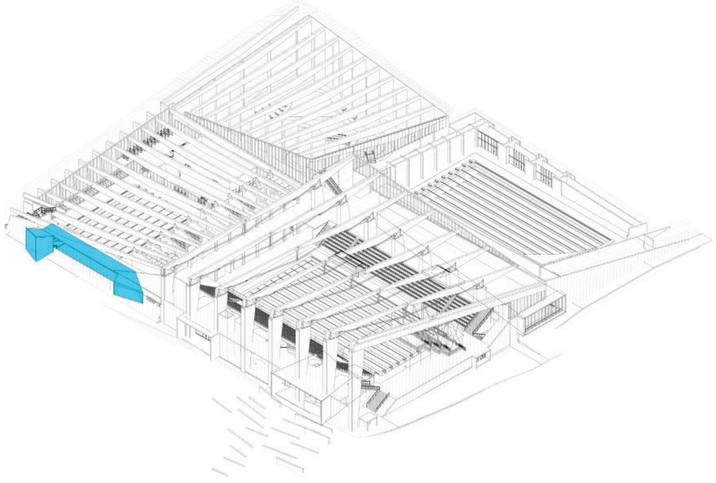
Dividing Roof According to Pools

To reflect the interior layout of pools, the roof is divided up into four segments, one to indicate each pool. While the edges are maintained for clarity of the form, the center is divided. The lowest quadrant of the roof is broken up to give room to an outdoor pool.



A Strategy for the Roof Garden

The roof garden is enhanced through three elements; skylights, planter boxes and a sculptural steel element. The skylights and planter boxes share the same proportions, but differ significantly in terms of size. The sculptural element of bent steel plates houses the windows for elevated views into the pool space.



Aperture I

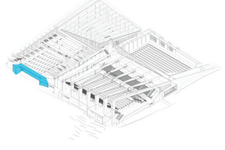
An underwater panorama

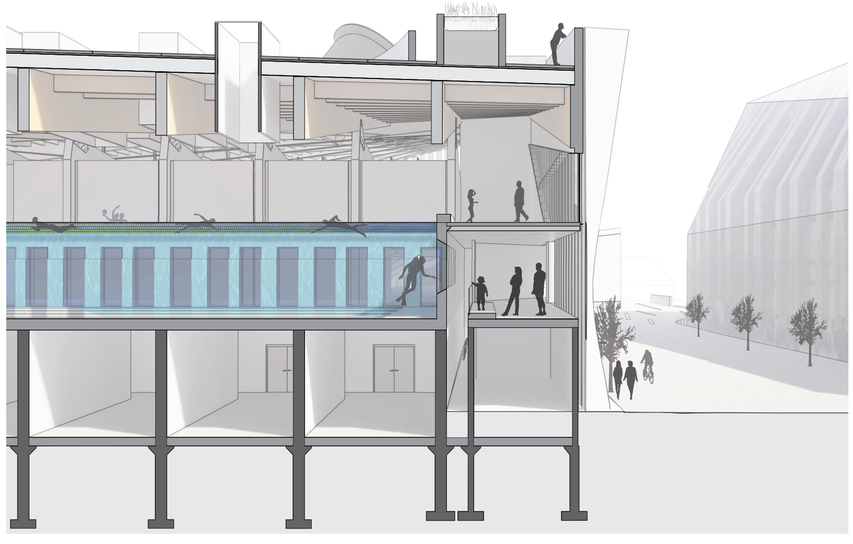
Location

Aperture I is located on the event space, right next to the new stadium. By placing the underwater panorama adjacent to the event space, the public has a more direct access to the atypical view of the sport.

An Underwater Panorama

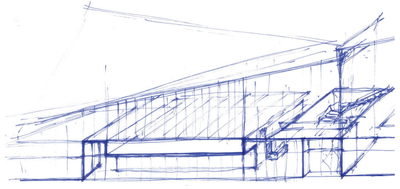
A panoramic view of the underwater world allows to observe the approaching swimmer and the motion from a front view.
Although completely alien to the sport, new possibilities for interactions between the swimmers and the general public come about.





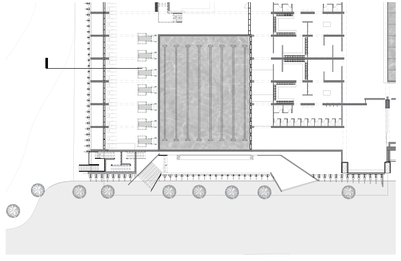
Perspectival Section

The viewing platform is elevated to match height of the pool and to facilitate a possible interaction between the swimmers and the observers. The platform is raised and pulled away from the pool window by about a meter. The window is designed to frame the panorama under water and focusing on the swimmers.

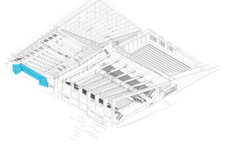


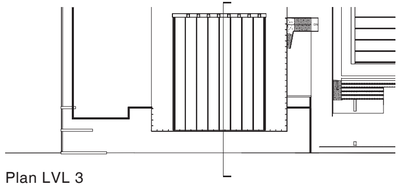
Early Sketch

An early design decision was to display swimming to the nearby street. By making the pool part of the facade and giving it a window over the street, a connection could be established between the swimmers and the pedestrians.

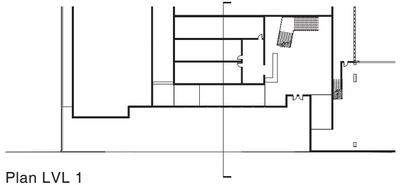


Plan LVL 2, SW Corner

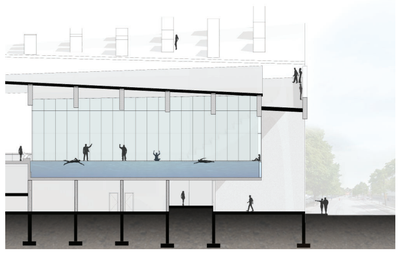




Plan LVL 3

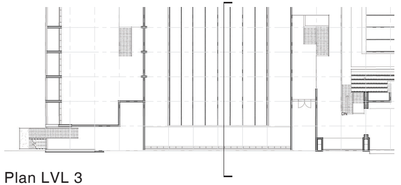


Plan LVL 1

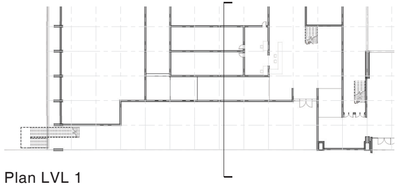


Early Section

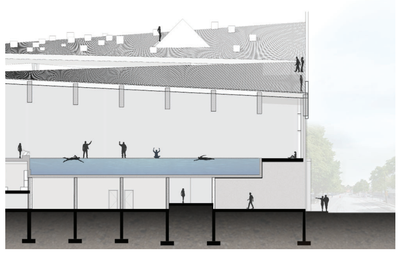
An early iteration aimed to display the swimmers through a big glass wall elevated above the street. The effect would be rather impactful, but the element of interaction would have been lost. Also, glare would preventing people to see far in to the pool.



Plan LVL 3

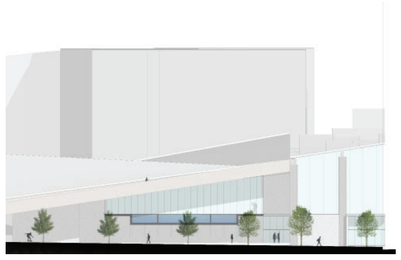


Plan LVL 1



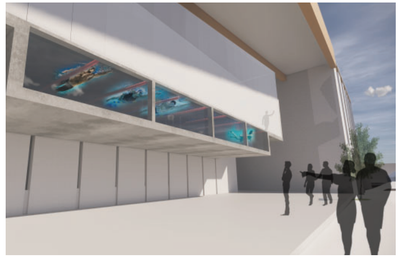
Early Section

Even with the addition of a lip protecting the window from most of the sunlight, the much brighter street environment would render the darker underwater environment in the pool almost invisible.



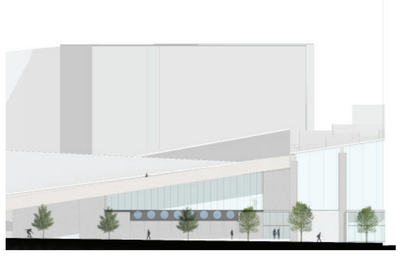
Study of Rectangular Apertures - Elevation

By using large, rectangular apertures as windows, the pool has a way of displaying large portions of the underwater environment.



Study of Circular Apertures - Perspective

The visibility into the pool is highly undermined by the unbalanced, direct sunlight. Although the large windows could give good potential views into the pool, they fall short in terms of actual visibility.

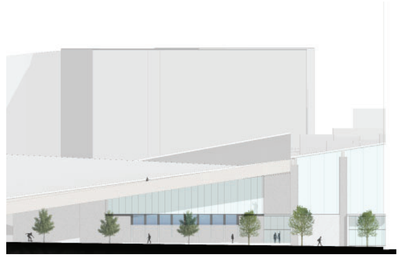


Study of Circular Apertures - Elevation

By using circular apertures as windows, the pool has a way of emphasizing each lane of swimmers.

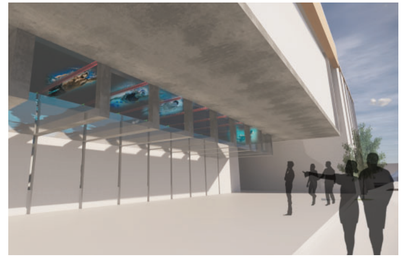
Study of Circular Apertures - Perspective

The visibility into the pool is also similarly compromised. Although the circles work well in terms of emphasizing each lane, the come across as alien to the remaining building.



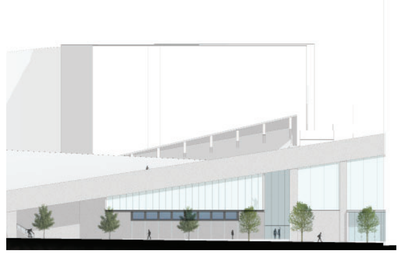
Study of Beams - Elevation

In an attempt to remove as much opaque material as possible, the pool was studied as a series of beams with inlays of acrylic panels.



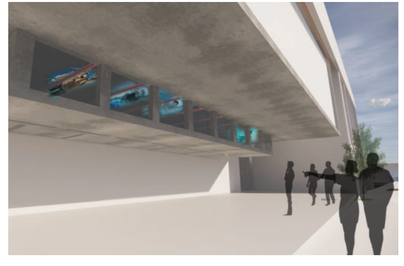
Study of Beams - Perspective

On top of a high likelyhood of leakage, the arrangement of the apertures does not help the visibility into the pool much.



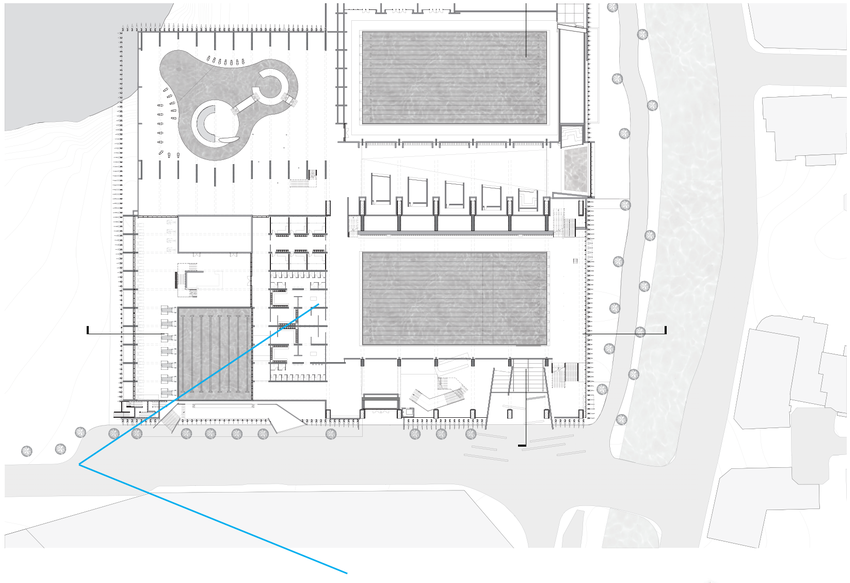
Study of Punched Windows - Elevation

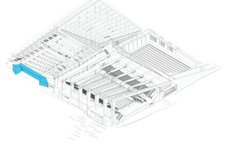
Punched holes in the concrete base for the pool was an alternative solution to the beams with inlayed sheets of acrylic.

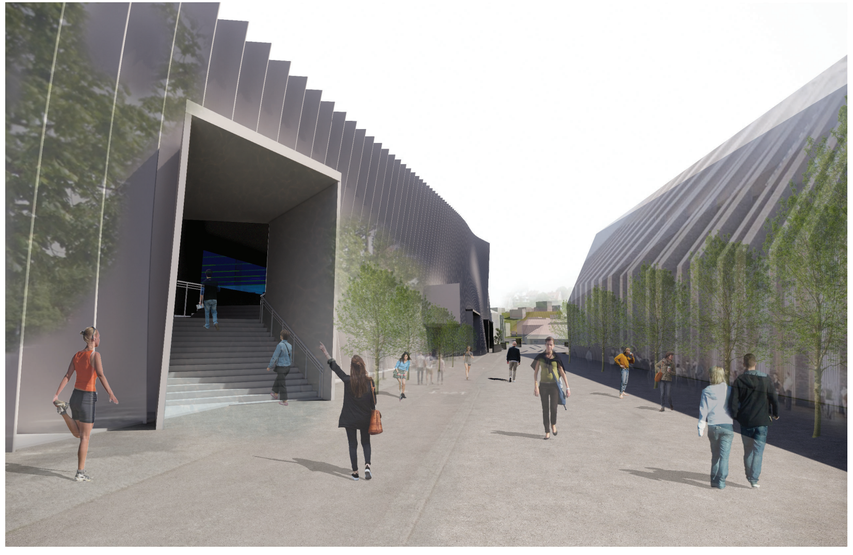


Study of Punched Windows - Perspective

Although less likely as a subject for leakage, it does not solve the problem of glare and unbalanced light levels.

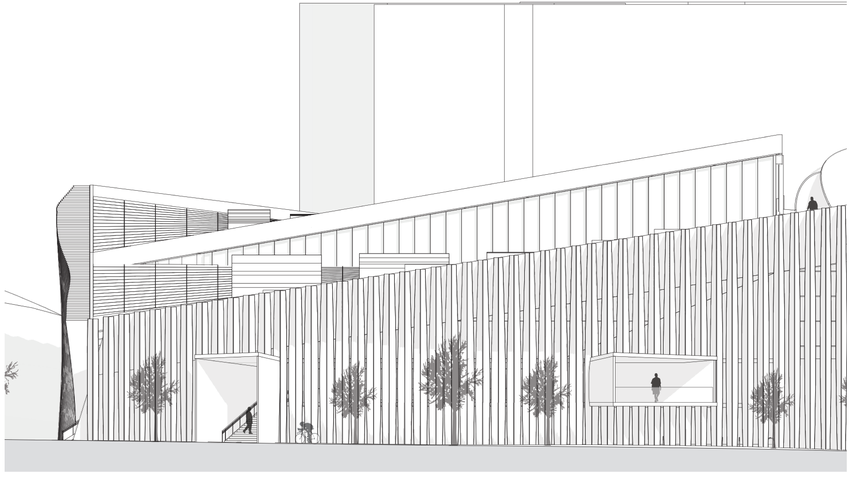






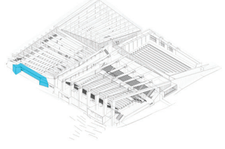
Approaching the Building

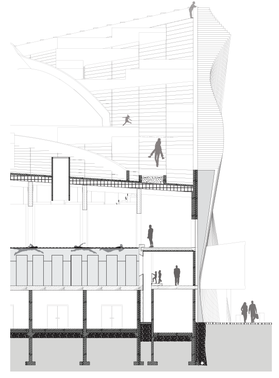
The big opening through the skin is an attempt to create an interest and pull people in into a space with low light levels to avoid glare. The strategy was to shade the window with a drapery-like skin.



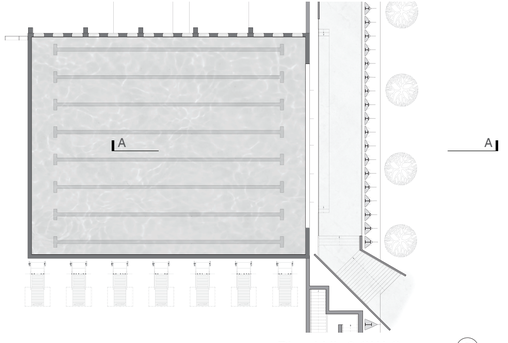
South Elevation, SW Corner

0 5m 10m 20m



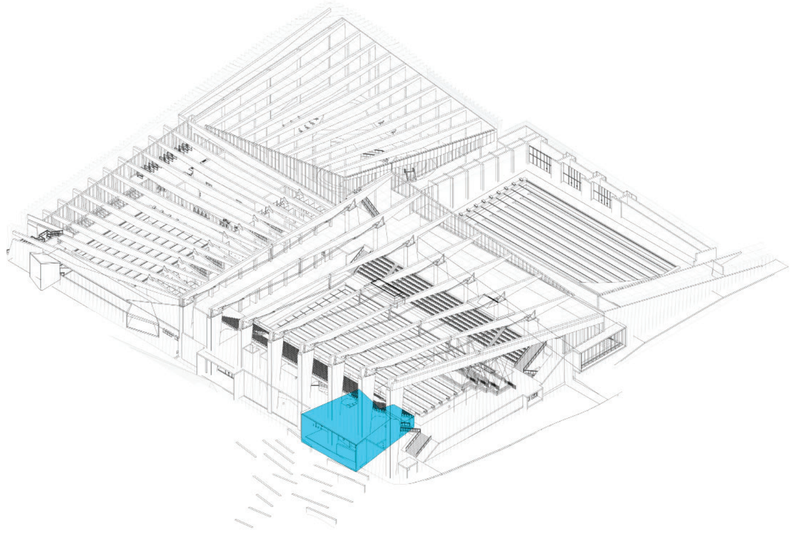


Section A



Plan LVL 2 SW Corner

0 5m 10m 20m

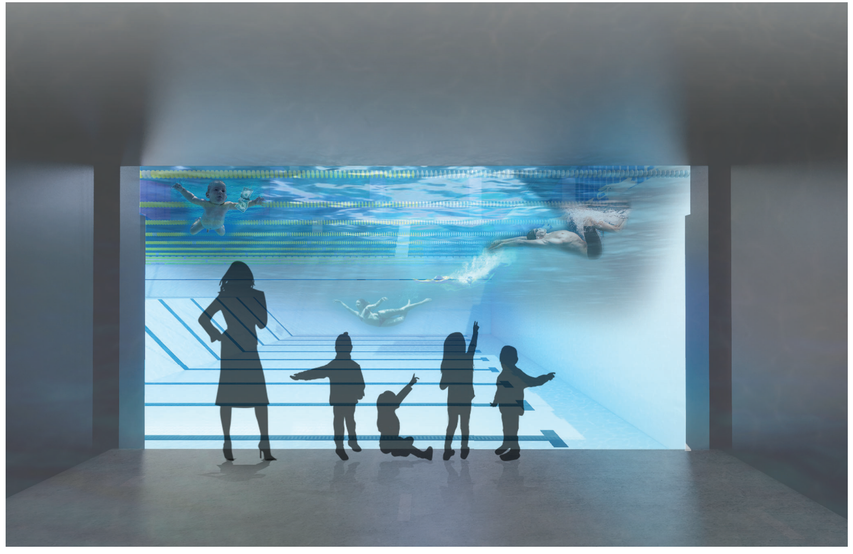


Aperture II

The Turn

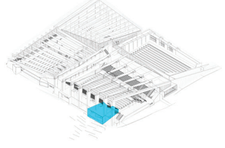
Location

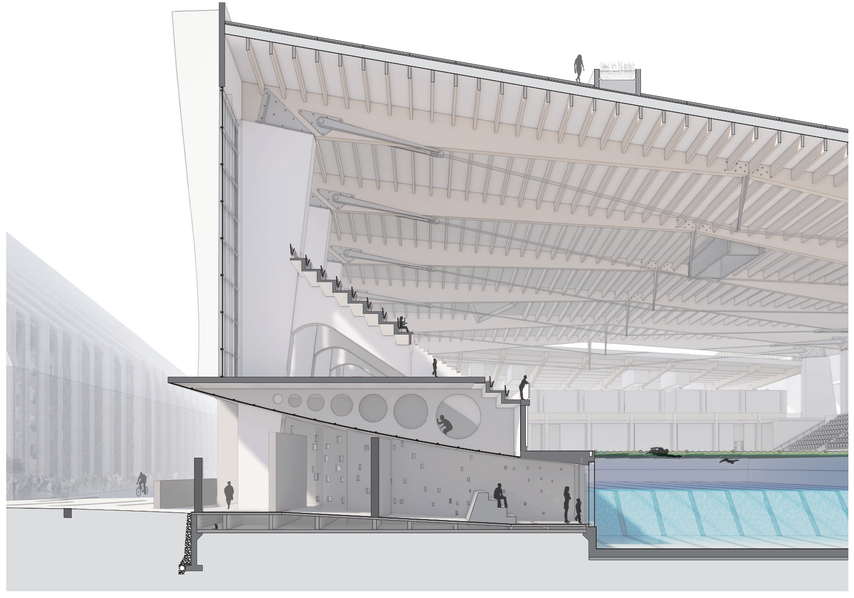
Aperture II is located further down the event space, right next to the new stadium and the river. By placing the underwater window adjacent to the event space, the public has a more direct access to the atypical view of the sport. This aperture is also part of the entrance sequence.



The Motion at the Wall

The second aperture emphasizes the motion at the wall. In a race, when a swimmer reaches the wall it is either for a start, a turn or a finish. Either of those moments are exciting to watch which makes this position ideal for observing swimming as a sport of action.



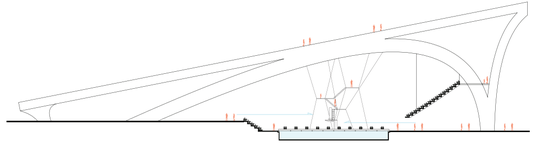


Perspectival Section

The large walls encountered upon entering Moment II blocks the light to provide the best experience possible by the window. The window is 30cm thick sheet of acrylic mounted in the reinforced high dense concrete foundation.

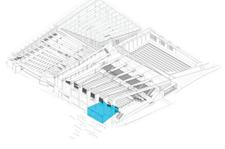
Building the Pool for Visibility

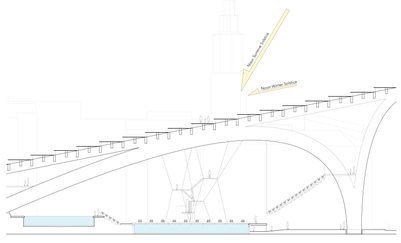
By elevating the stands and the ground on the other side of the stands, the swimmers become more visible to the public. This is instrumental in order to putting swimming on display.



Building the Pool for Visibility

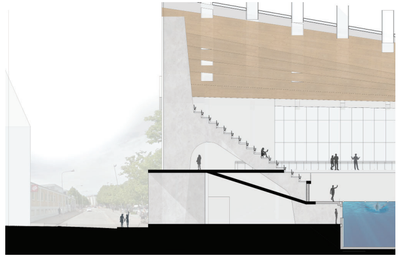
The structure above the pool conforms to this idea of visibility. By suspending portions of the elements in the arena, the ground floor is freed up to allow for good visual connections and circulation.





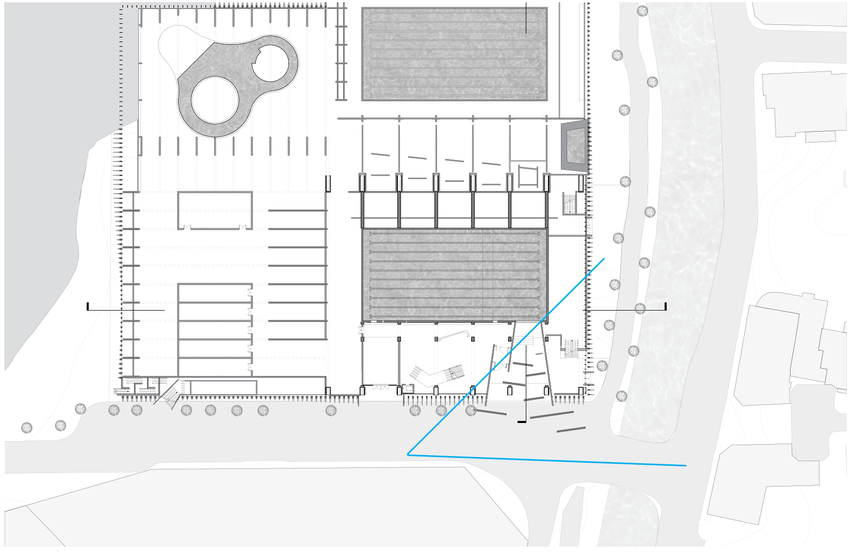
Building the Pool for Visibility Underwater

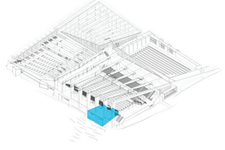
Following a similar logic, of giving certain views of the swimmer back to the public, an underwater view is provided to the street.

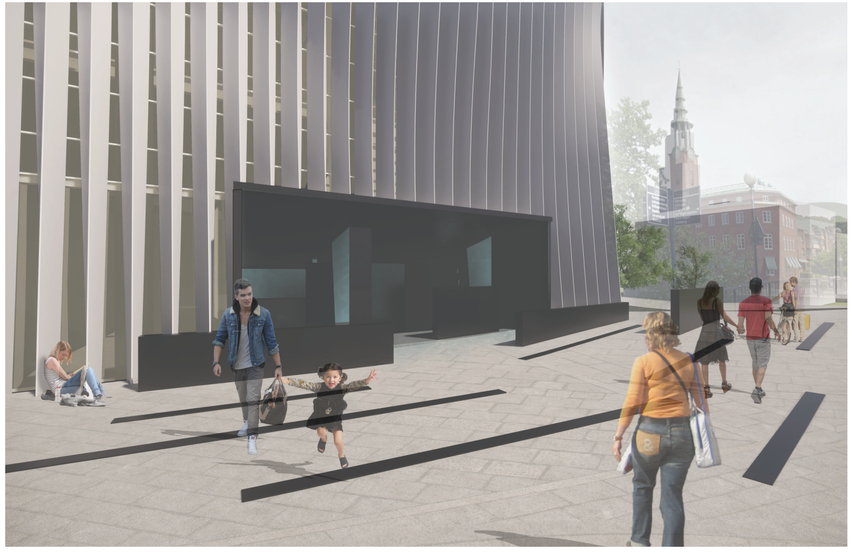


Building the Pool for Visibility Underwater

To make this view effective, the pool requires a close proximity to the adjacent street. To achieve this close relationship, the roof structure had to be redesigned. While still providing good views, the stands are pushed close to the envelope of the building.

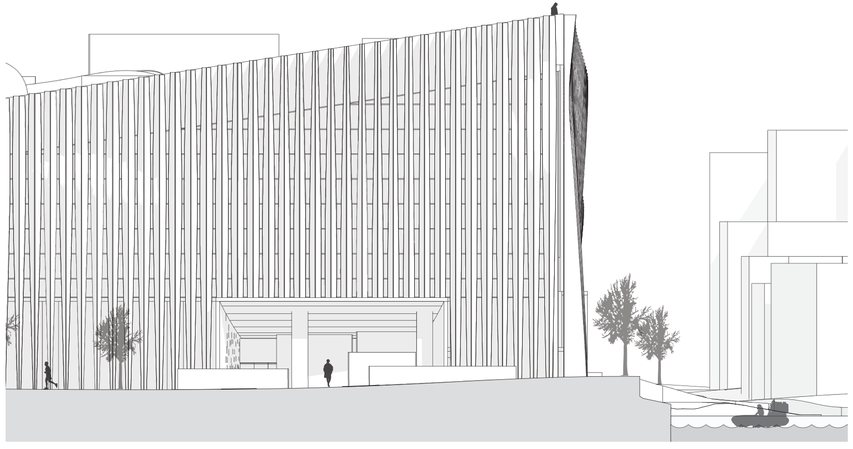






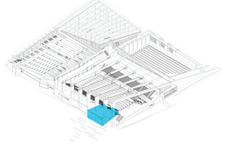
Entering

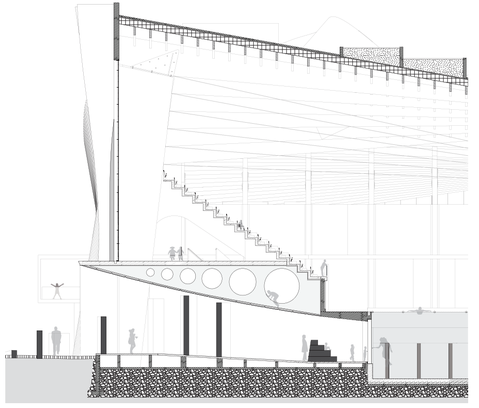
The entrance protrudes through the skin. Some of the light filtered through the pool water is reflected by the polished walls and is visible to the street. The marking in the pavement is the rippling effect of the walls stretching out into the street to call attention to the moment.



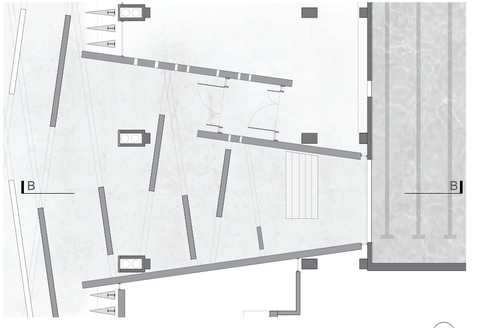
South Elevation, SE Corner

0 5m 10m 20m



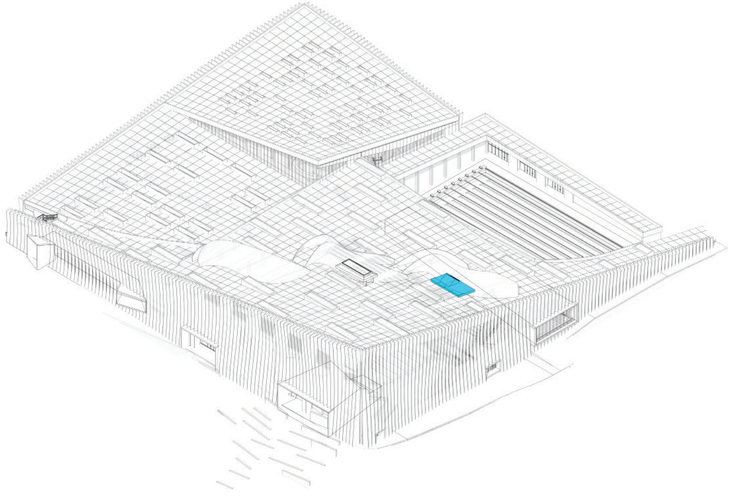


Section B



Plan LVL 1 SE Corner

0 5m 10m 20m

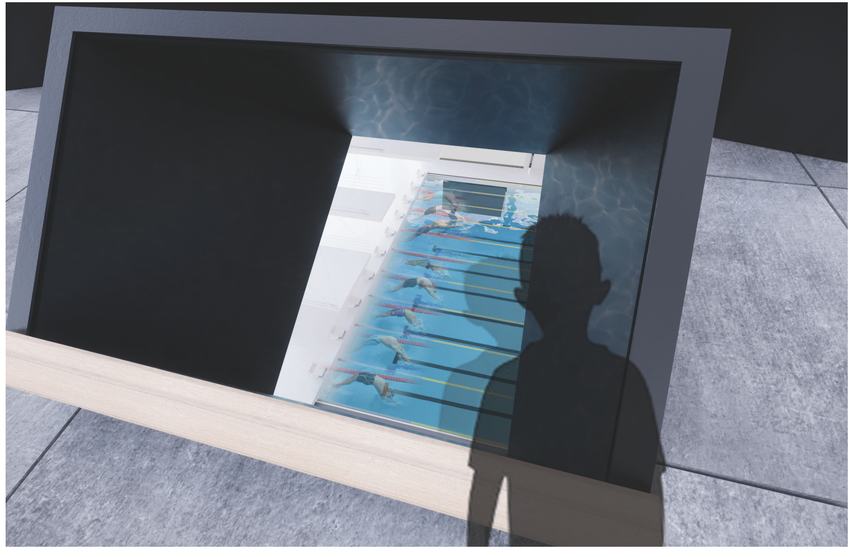


Location

When entering the roof from the north. Only a couple of meters from the opening between the steel plate covers, the window aims to capture the attention of its visitors early on.

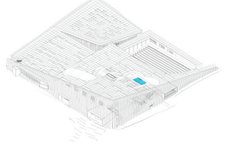
Aperture III

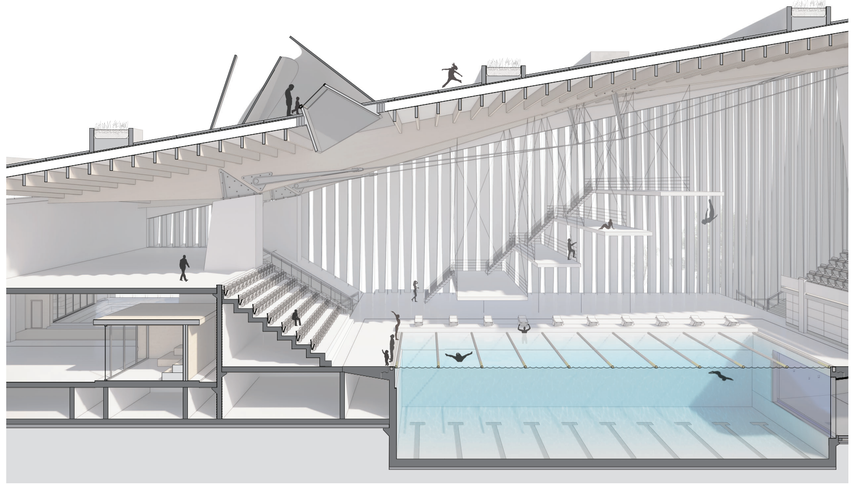
Focusing on the Start



The Start and The Finish

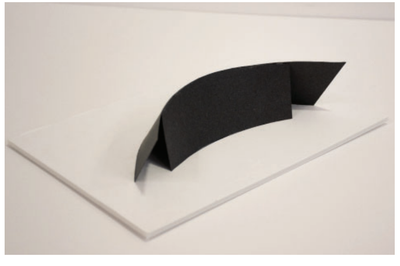
The best way to frame the view of the start and the finish is from an elevated side view. From that point of view, the starting or finishing field can be clearly observed.





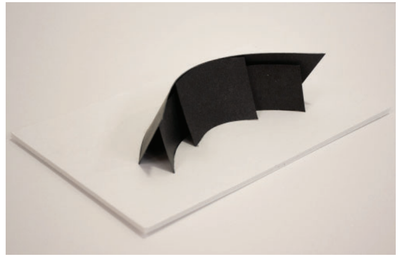
Perspectival Section

The window offers good views into the pool, especially over the diving area. The glass is angled to be perpendicular to lane four and five, which is typically where the fastest swimmers are seeded. The window becomes the aperture, or portal between the exterior environment and the pool area.



Study in Engaging Covers 1

To engage the public and to make the roof garden more dynamic, bent steel plates are used for covers of the windows into the pool.



Study in Engaging Covers 2

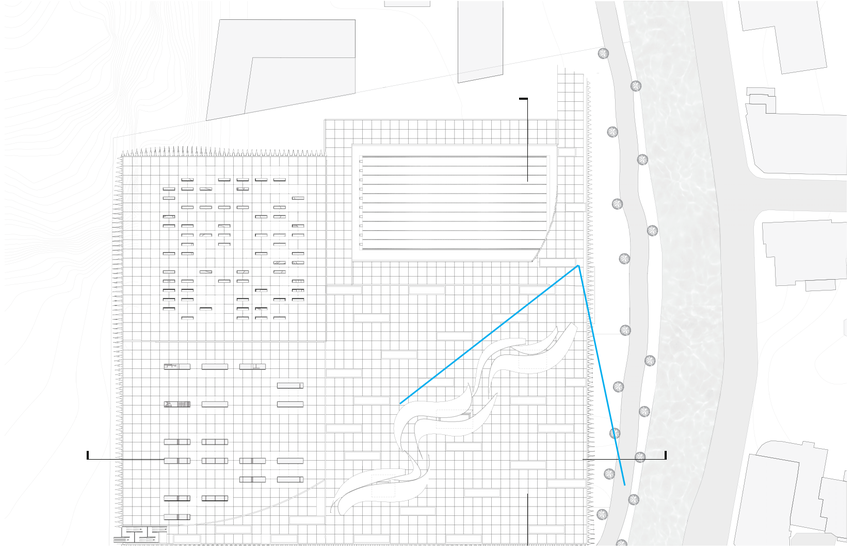
To ensure the dynamic character of these elements, the steel plates are divided up and overlapping. Multiple entrances are provided into the shaded, cave-like environment.

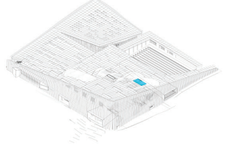
Geometry of the Window

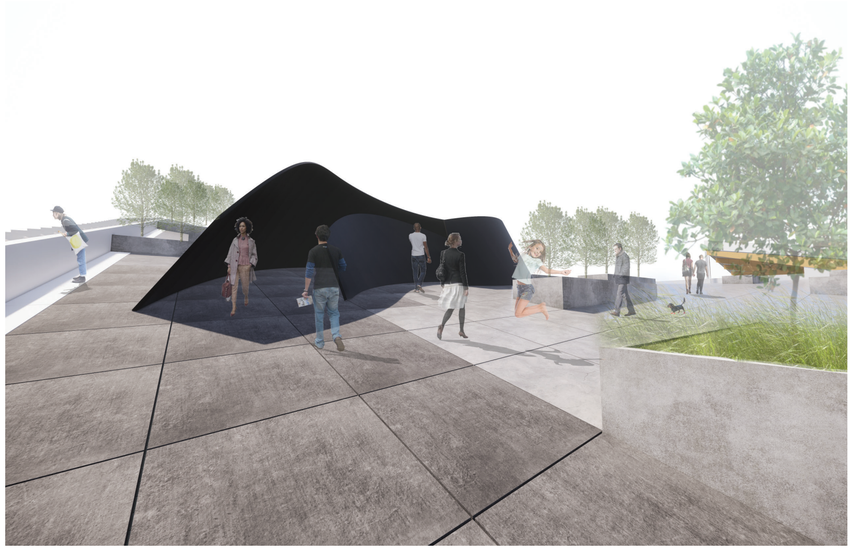
Aperture III has the advantage of indirect sunlight. The view is conducted from north to south which allows the window a lot of freedom in terms of its geometric configuration.

Exposing the Structure

An early consideration was to expose the structure through the roof apertures. The exercise to reveal the nature of the building turned out less successful as the structural elements came in competition with the view.

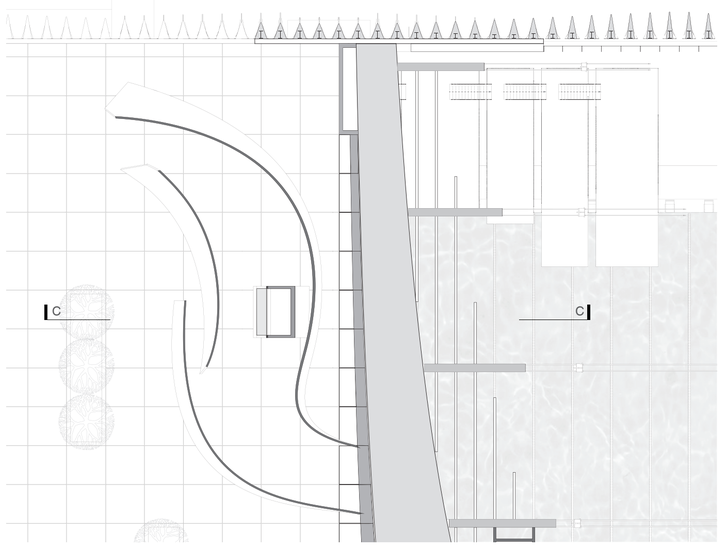






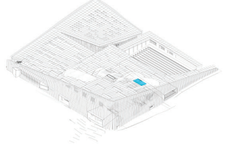
Entering the Roof Garden

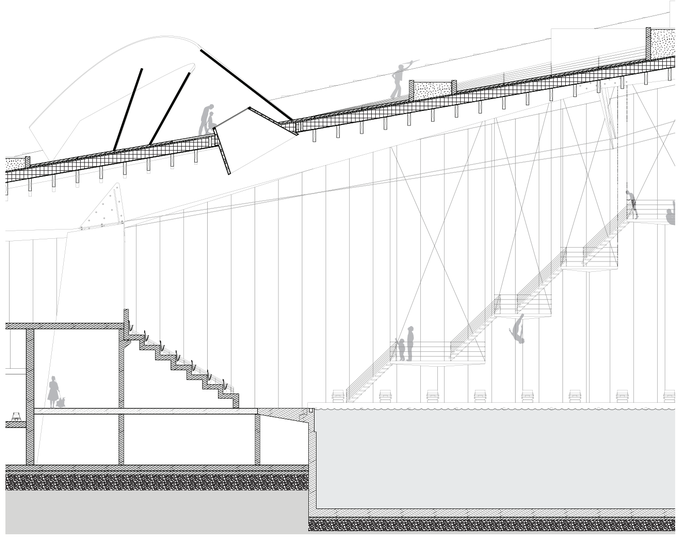
The sculpture of bent steel plates sits mounted over the concrete panels on the roof. It shelters the window into the pool area and mitigates most of the glare. The roof garden uses the placement of planter boxes to break up the scale of the large open roof scape into smaller, more intimate spaces.



Roof Plan, Middle of East Side

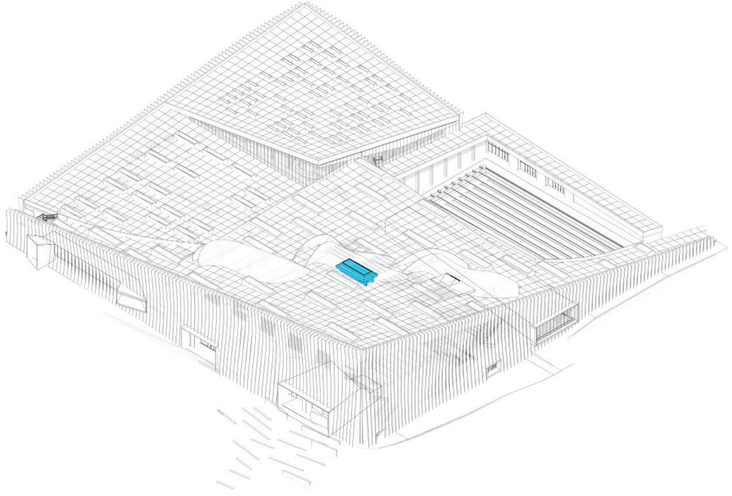
0 2.5m 5m 10m





Section C

0 2.5m 5m 10m

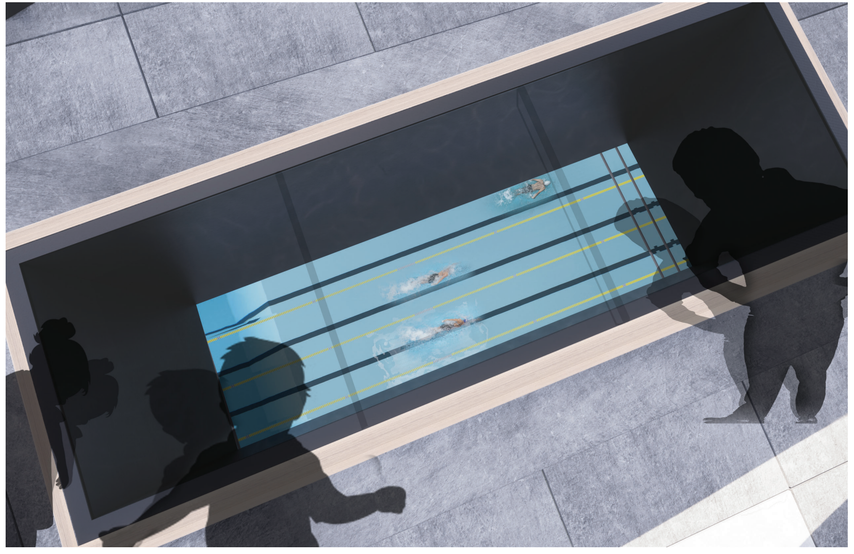


Location

Located at the center of the roof, the vertically focused window is also placed right above the center of the pool.

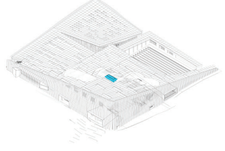
Aperture IV

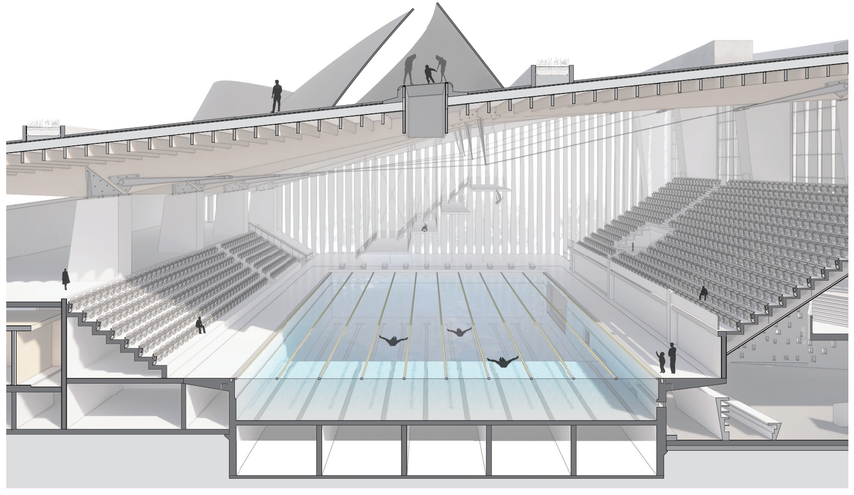
The Linearity of Swimming



The Motion at the Wall

Aperture IV focuses on the linear aspect of swimming. Pool swimming, by nature is a linear activity. To reach longer than 50m the swimmers must go back and forth. To travel a minimum distance, the swimmers stay as straight as possible. The symmetry of the swimmer, the balance of their strokes can clearly be seen and will undoubtedly be amplified from this view.



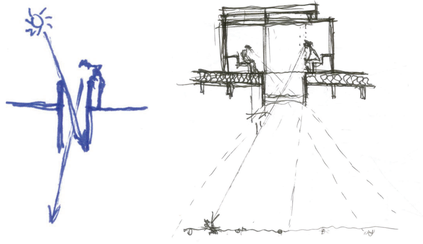


Perspectival Section

Moment IV is located right above the center of the pool. This allows for the frame to match the perimeter of the pool well. Depending on the position of the viewer, all the competing lanes (middle eight) can be seen from the window.

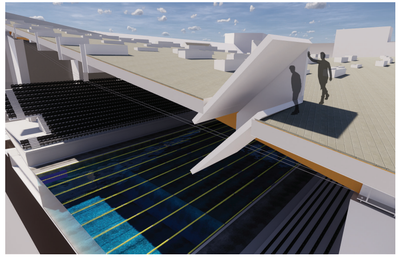
Building the Frame

The location of Gothenburg lends itself well for interesting configurations of skylights. By basically providing a box with the ratio of 21:4:8, direct natural light does not penetrate through the aperture.



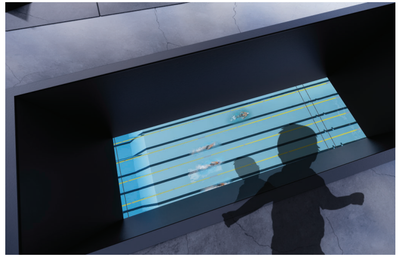
Visibility Through the Frame

Since direct rays cannot penetrate through such a deep vertical shaft, competitive swimmers will not be disturbed high contrast sunlight effects. To remove glare, a hood could help to keep the space around the aperture dark.



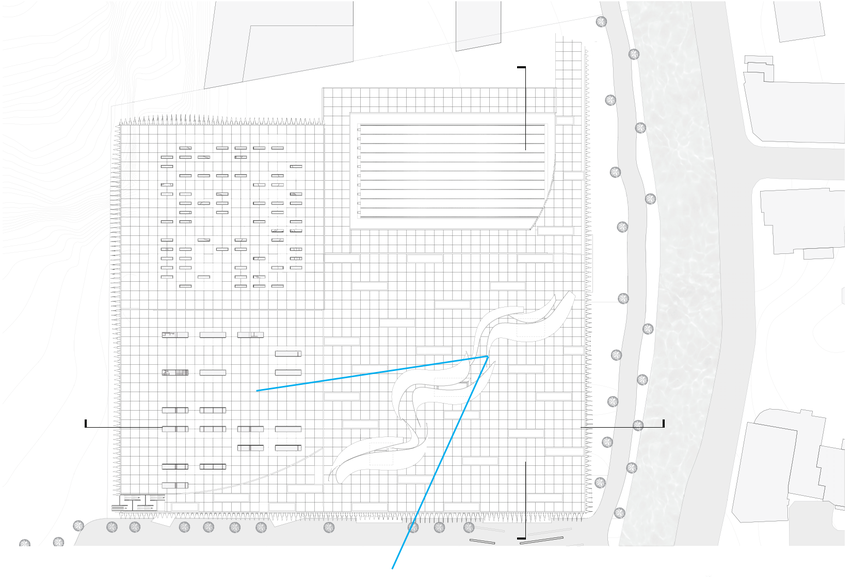
The Angle of the Box

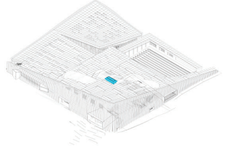
Experimenting where the box should ultimately be located and in what angle it should be placed for best effect.

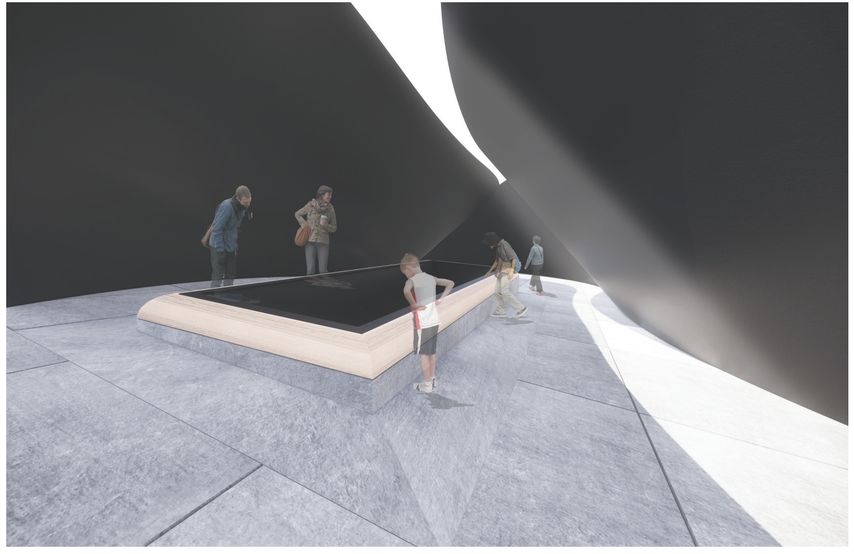


A Vertical Aperture in the Floor

To establish the best vertical focus onto the swimmers, the frame was located in the center of the roof, framing a vertical view in the floor.

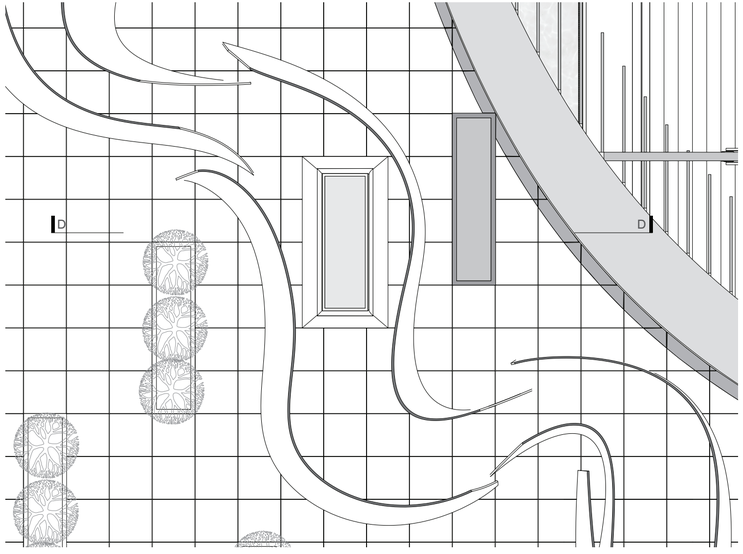






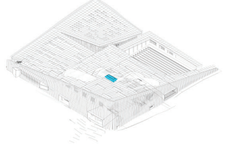
Arriving at the Window

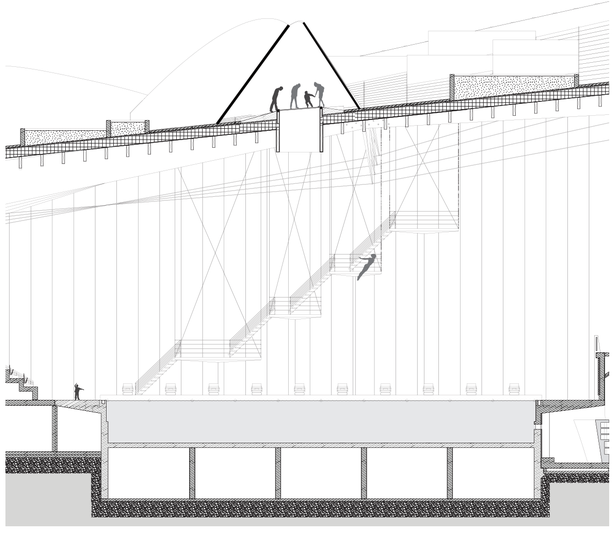
The window is lined with wood to give visitors a warm surface to touch. The glass is intended to be structural to provide a walking surface.



Roof Plan, Center of Main Roof

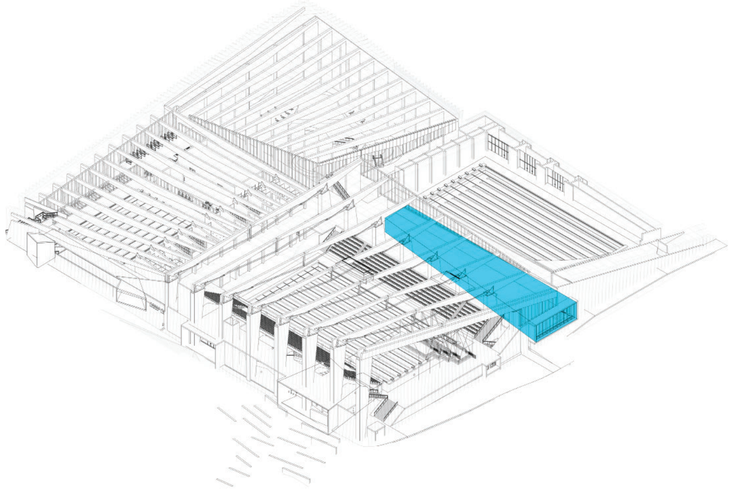
0 2.5m 5m 10m





Section D

0 2.5m 5m 10m



Location

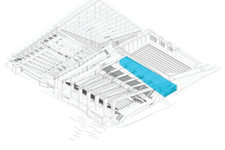
Instead of focusing on the swimming, Aperture V is an exception as it offers a framed view of the river from the inside.

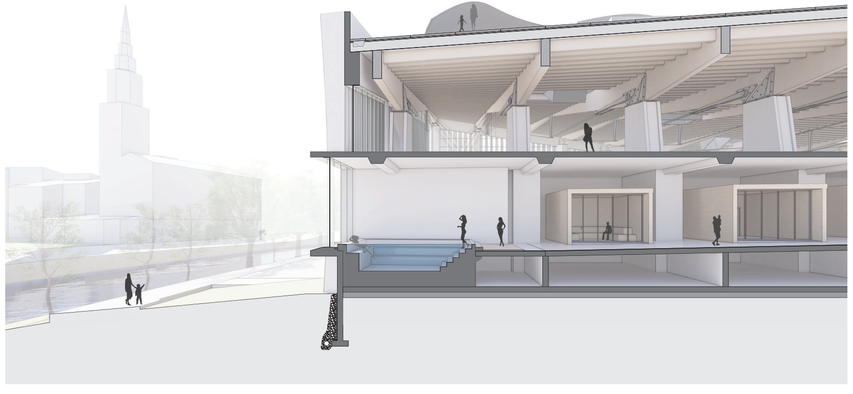
Aperture V

A Relationship to the Surroundings

A Sauna Adjacent to the River

The common position of a sauna is to put it in the center of an aquatic center. To placeon the perimeter offers an immediate connection to the surrounding city.



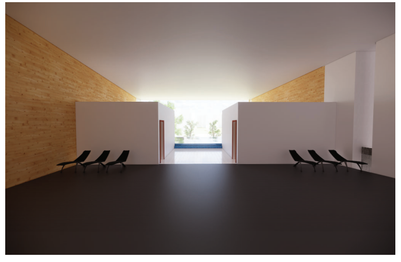


Perspectival Section

By elevating the window just above head height, the space mitigates the possible discomfort of being observed in lighter clothing. It also allows the swimmers to look above the people outside onto the surroundings with an unobstructed view.

Gathering Around the Pool

An early idea was to arrange spaces around the pool for gathering. Spaces such as saunas and decks would be provided to host people.

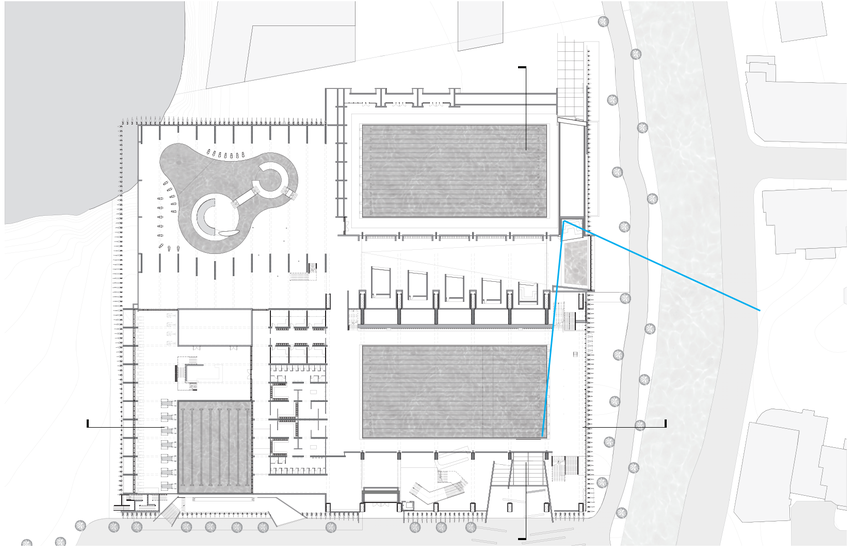


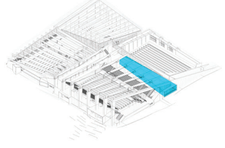
Hinting at the View

The view between the saunas and the pool. Giving a hint at the view, the arrangement of vertical planes call attention to the aperture without completely revealing it.

Establishing Contact Through Water

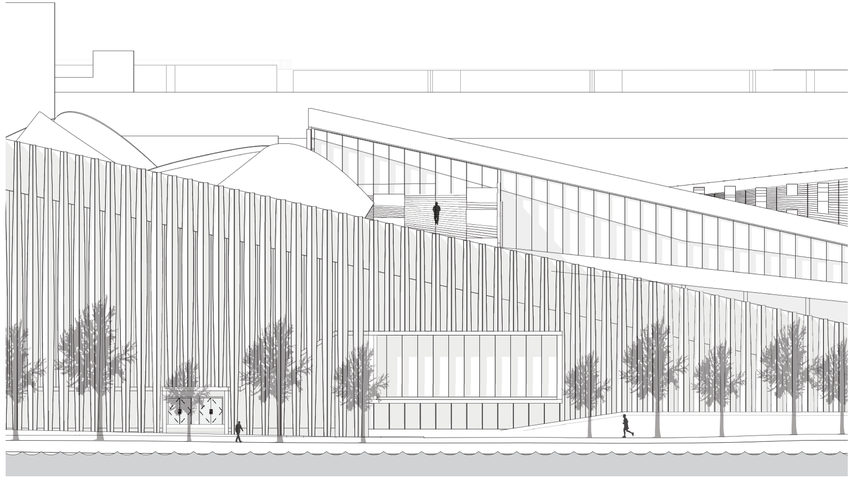
An early iteration of the sauna angled towards Gothenburg. Although the view is appealing, the sauna should ideally be pushed back a bit to allow for a better view approaching it.





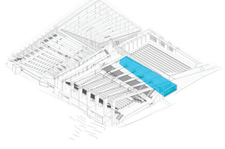
Looking out the Dry Sauna

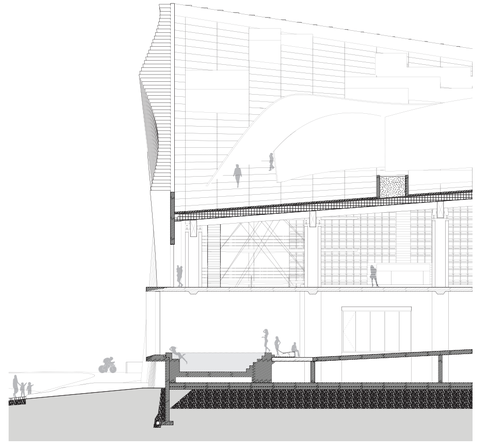
Through a set of windows, the Sauna is connected to the infinity pool, the river and the nearby neighborhood. The most private space of the complex is connected to the surroundings through this visual bridge.



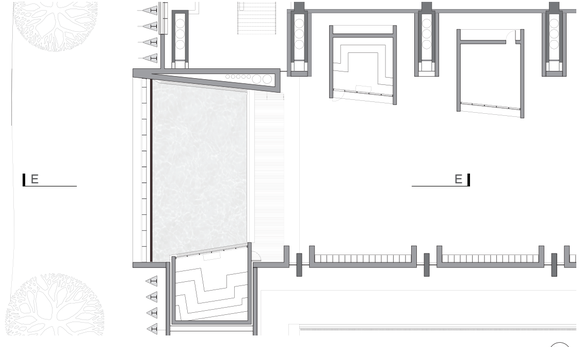
East Elevation, Middle Portion

0 2.5m 5m 10m





Section E

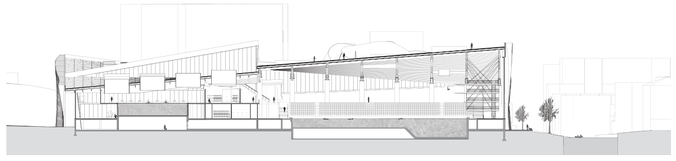


Plan LVL 2 Middle of East Side

0 2.5m 5m 10m

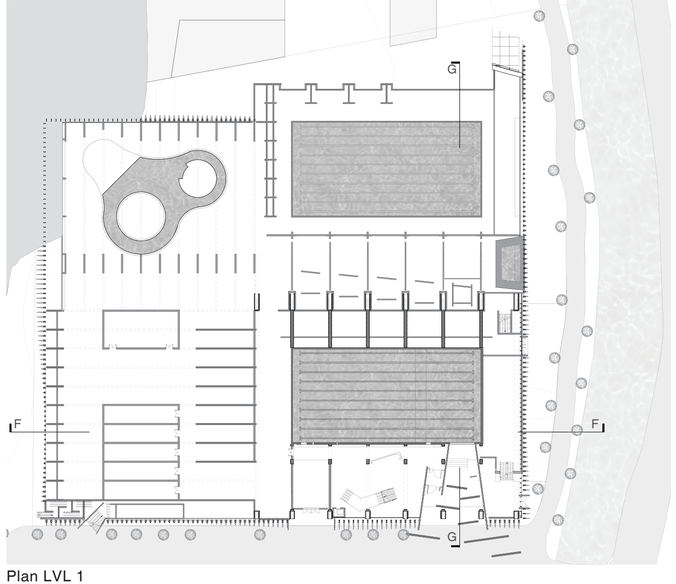
Drawings

The entire complex at a glance



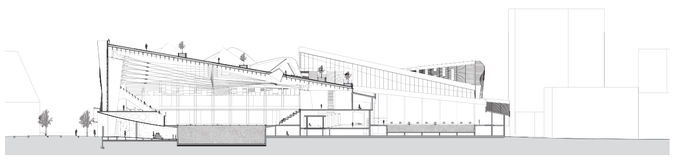
Section F

0 10m 20m 40m



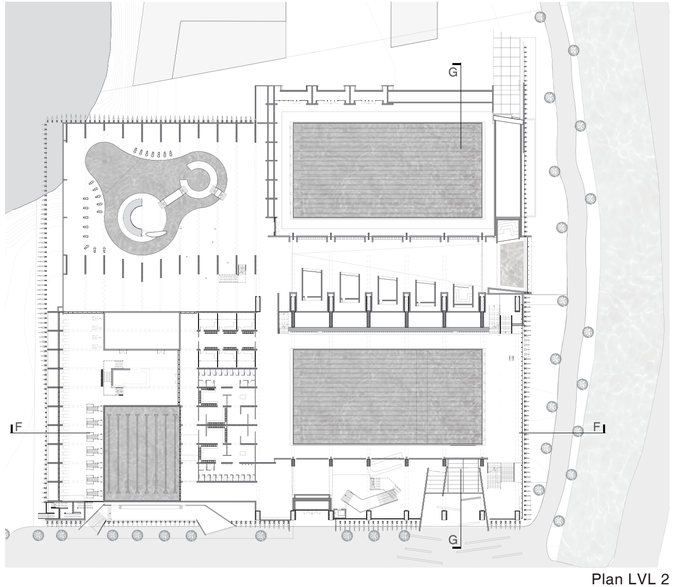
Plan LVL 1

0 10m 20m 40m



Section G

0 10m 20m 40m

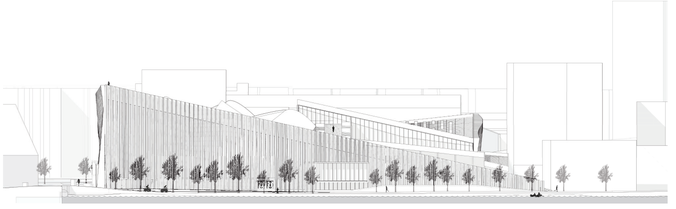


Plan LVL 2

0 10m 20m 40m

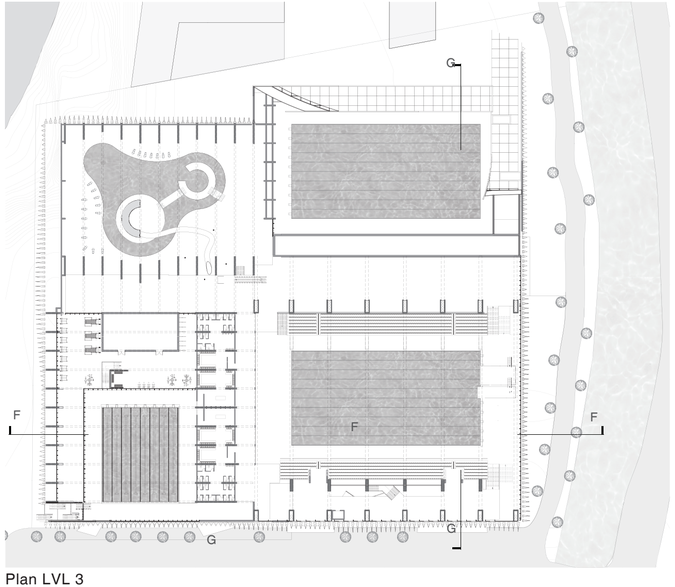
South Elevation

0 10m 20m 40m



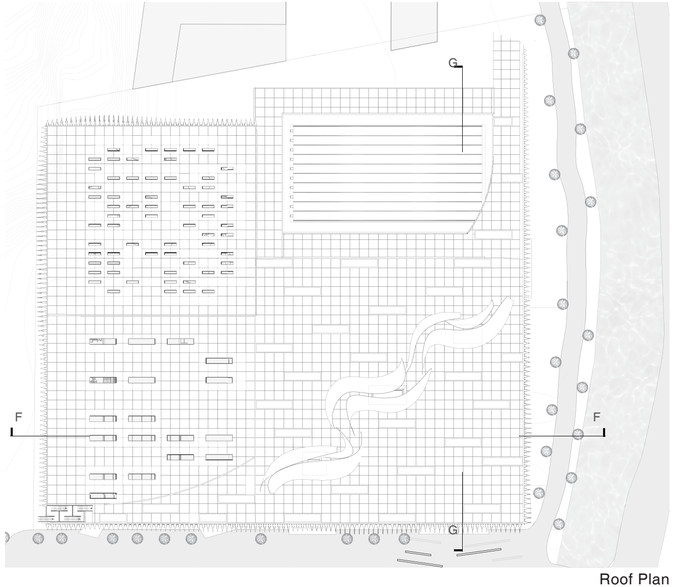
East Elevation

0 10m 20m 40m



Plan LVL 3

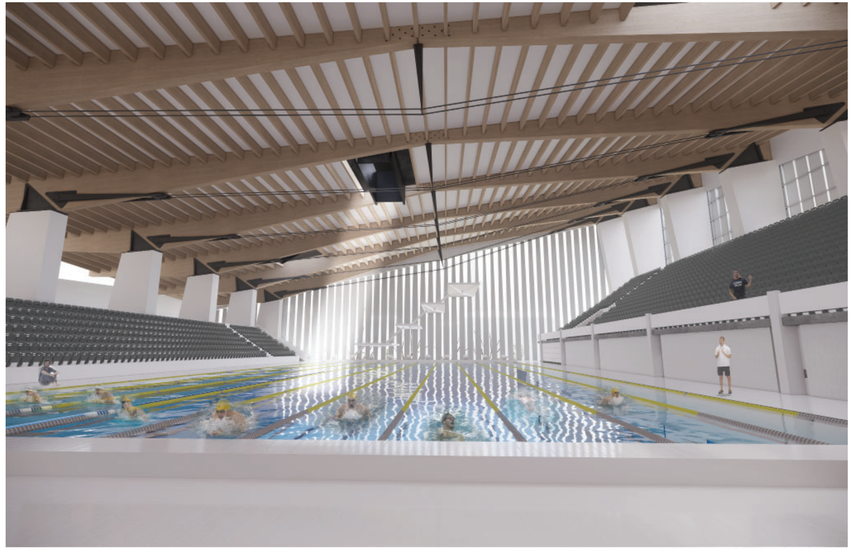
0 10m 20m 40m



Roof Plan

0 10m 20m 40m

Conclusion



Conclusion

By carefully selecting and framing moments of swimming, architecture can perhaps help to amplify the sport. While the special apertures are the driving force for the architectural thesis, the architecture's relationship to its surrounding, is equally important. It indicates that architecture does not necessarily have to be appreciated as an object, a thing of mass. Rather, it can be a framework that establishes a new setting for observation. In a healthy symbiosis between architecture as a staged frame and an object of importance, a new reality is created for that object and its observer.

References

Books

Balmond, Cecil, et al. Informal. Prestel, 2010.

Boddy, Trevor, and Ron Keenberg. Pools Aquatic Architecture: Hughes Condon Marler Architects. ORO Editions, 2013.

Chaslin François, and Höfer Cándida. The Dutch Embassy in Berlin by OMA-Rem Koolhaas. Nai Publishers, 2004.

Medvedow, Jill. Diller Scofidio Renfro: Institute of Contemporary Art (ICA), Boston. Polígrafa Ediciones, 2011.

Websites

“Olympic Pools: Where Are They Now? (Part Five).” Swimming World News, 20 Aug. 2015, www.swimmingworldmagazine.com/news/olympic-pools-where-are-they-now-part-five/.

“Olympic Pools: Where Are They Now? (Part Three).” Swimming World News, 29 July 2014, www.swimmingworldmagazine.com/news/olympic-pools-where-are-they-now-part-three/.

Images

Ref. 1: Sweat, Ryan. “NAIA Nationals 2017”. 2017. JPEG
[permission granted by Ryan Sweat]

Ref. 2: Richters, Christian. *Netherlands Embassy Berlin*. 2004. Office for Metropolitan Architecture’s Official Website. JPEG. May 2019. https://images-oma-eu.freetls.fastly.net/20150804044255-715-v7i0/1600.jpg
[permission granted by OMA]

Ref. 3: Ahlskog, Christian. *Villa Savoye Roof Garden*. 2012. Flickr. JPEG. May 2019. https://www.flickr.com/photos/22669220@N07/8538291623
[used under Attribution-NonCommercial-ShareAlike 2.0 Generic (CC BY-NC-SA 2.0)]

Ref. 4: Hossain, Naquib. *SD. Salk Plaza Axis 01*. 2008. Flickr. JPEG. May 2019. https://www.flickr.com/photos/naq/2337744981
[used under Attribution-ShareAlike 2.0 Generic (CC BY-SA 2.0)]

Ref. 5: Alfred Hess, Peter. *Black Sun*. 2015. Flickr. JPEG. May 2019. https://www.flickr.com/photos/peterhess/16941021851
[used under Attribution 2.0 Generic (CC BY 2.0)]

Ref. 6: Jarnvik, Tim. “Sum Sim Reg ‘10”. 2010. JPEG
[Permission granted by Tim Jarnvik]

Ref. 7: Baikovicius, Jimmy. *Munich Olympic Swimming Pool*. 2011. Flickr. JPEG. May 2019. https://www.flickr.com/photos/jikatu/6301409380
[used under Attribution-ShareAlike 2.0 Generic (CC BY-SA 2.0)]

Ref. 8: Xia, Ming. *Watercube Test Event*. 2008. Flickr. JPEG. May 2019. https://www.flickr.com/photos/xiaming/2287232047/in/album-72057594106897220/
[used under Attribution-NonCommercial-ShareAlike 2.0 Generic (CC BY-NC-SA 2.0)]

Ref. 9: Black, Matthew. *London Aquatics Centre*. 2011. Flickr. JPEG. May 2019. https://www.flickr.com/photos/thematthewblack/6950591618/in/photolist-bAcAJw-jSmbBw-cHfETS-dbnJau-mWuyu3-cHUwPA-cE7n3Y-bkBYbw-oKPEmF-pvysNd-cL1rjf-bqjDH1-cA4NbC-PVgQWX-pg6wcP-dUktNH-d93uaj-cyvcdC-d8P61j-cUeyRj-pg6P2m-cQMhd1-cQdbWS-aCpkpH-pCSt4K-bAkWDX-bCkTdC-cE6XVh-aM2KvT-6anE3n-bkzBuj-cE7QUw-U9Kuzu-cQMgKL-p2o4vU-cE7dUE-cyvmfh-cUcXzy-VU3wN9-cUcXgY-d92Ek5-pxyVU1-brG68Q-pg7hqh-dbq8v1-UmLkNs-d3e6F1-p2nMAr-bWgKFB-cGDkZs
[used under Attribution-NonCommercial-ShareAlike 2.0 Generic (CC BY-NC-SA 2.0)]

Ref. 10: City of Surrey. *Grandview Heights Aquatic Centre*. City of Surrey Culture & Recreation. JPEG. May 2019. https://www.surrey.ca/images/cos-master/pageImages/GrandviewHeightsAquaticCentre.jpg

Ref. 11: Jákupsstovu, Lis í. *Eriksdalsbadet ready for the 2010 World Cup leg in Stockholm*. 2010. Flickr. JPEG. May 2019. https://www.flickr.com/photos/morshus/5151289419
[used under Attribution-NonCommercial-NoDerivs 2.0 Generic (CC BY-NC-ND 2.0)]

Ref. 12: van Ginkel, Sander. *Rio 2016 Olympics - Swimming 6 August evening session*. 2016. Flickr. JPEG. May 2019. https://www.flickr.com/photos/139991533@N04/29069201612
[used under Attribution-ShareAlike 2.0 Generic (CC BY-SA 2.0)]

Ref. 13: van Ginkel, Sander. *Rio 2016 Olympics - Swimming 6 August evening session*. 2016. Flickr. JPEG. May 2019. https://www.flickr.com/photos/139991533@N04/29069204582
[used under Attribution-ShareAlike 2.0 Generic (CC BY-SA 2.0)]

Ref. 14: Ajay bhargav, Guduru. *Person Swimming on Body of Water*. 2019. Pexels. JPEG. May 2019. https://www.pexels.com/photo/person-swimming-on-body-of-water-863988/
[public domain]

Ref. 15: VisitOSLO. *Oslo’s Opera House*. 2008. Flickr. JPEG. May 2019. https://www.flickr.com/photos/visitoslo/5555503102
[used under Attribution 2.0 Generic (CC BY 2.0)]

Images belong to author unless otherwise noted