Part 3: Synthesis

Introduction

In this chapter, the intentions for technology in design are expressed. A material pallet, summary of the proposed structure along with four main structural languages shape the technical resolution of the design that was discussed in chapter 2. Various precedent studies further enforce the resolution of technology-related decisions. Lastly, the role of sustainability in sports architecture is discussed along with its impact on technical design decisions.

In the research proposal of this mini-dissertation, the connection between sport and architecture was made evident by comparing both to a form of spatial organisation and expression (Cleary, 2017). The commonalities exist in that both sport and architecture generally have a frame - be it formal or informal, permanent or temporary - and within this frame, a performance by or experience of the user. The merging of the frame and the performance it accommodates is what transforms generic space into ‘place’ (Cleary, 2017). Noting that the frame impacts the performance (hence, architecture can impact the athletic performance of an athlete), it is vital that this frame needs to be clearly defined. Generally, the frame in sport exists as the field of play itself: the boundaries of the soccer pitch, the painted line on a tennis court or the carefully demarcated lane-lines of a swimming pool. In architecture, this frame can be extended past merely the field of play, encompassing the surrounding and supporting spaces that house and accommodate this field of play and the athletes within it as well. This architectural frame becomes defined through its *structure*, *materiality*, *form* and *technological functionality*. Ideally, these aspects should work together in harmony to create pleasant and, ultimately, athletic performance enhancing experiences for the athletes and other users.

Figure 114: The current TuksAquatics Complex (Slechter, 2021)

Intentions for technology in design

The second portion of the original research question states: “How can the design of sports architecture be improved to benefit and enhance the performance of the professional athletes it serves?” Relating this to the architectural issue of *functionality* being favoured over *experience* in sports design, it becomes clear that the frame of sports architecture cannot be a generic formal, structural, material or technological solution. Instead sports venue designers must merge technological thinking with experiential design intentions to ensure that the athletic performance enhancing potential of sports architecture is maximised.

In order to achieve this, the design is divided into four main *design languages* that guide the technological, formal and structural resolution of the larger sports venue. These four languages are based on previously discussed principles of environmental psychology in design that enhances the experience and performance of the user (figure 115).

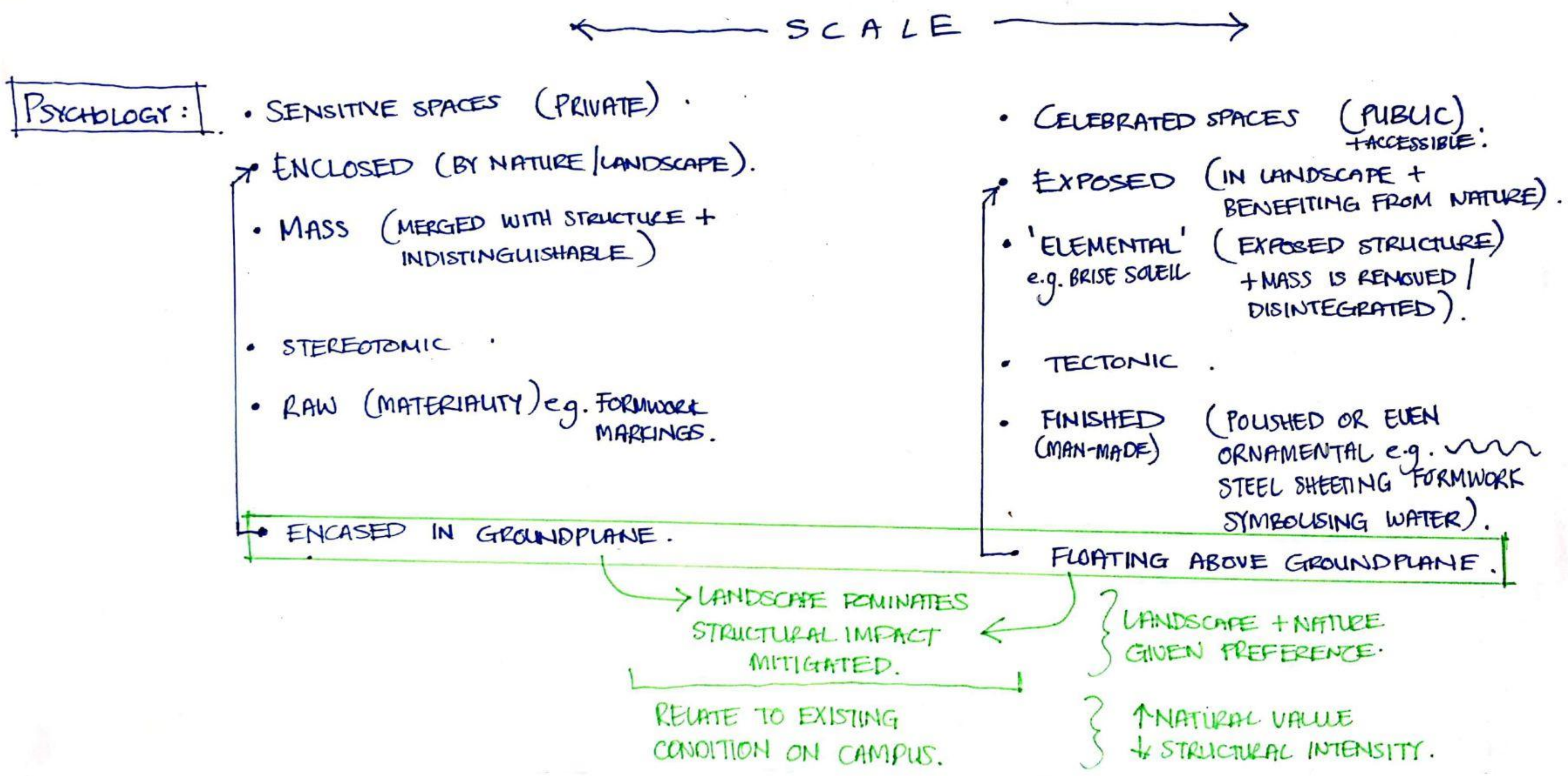


Figure 115: Scale of structural languages in terms of previous psychological findings Author, 2021)

The materiality of each language is based on a response to the features of the existing building and the larger sports campus. The buildings on campus employ varying methods of construction, materiality, architectural style and form. However, an overarching theme exists in the high natural value and low structural intensity of the Hillcrest campus (figure 116). Landscape and nature are given preference over built structure - a theme that has been explored in the earliest stages of the design and that contributes to psychologically supporting environments for athletes.

The roof form acts as an extension of the existing landscape at the east of the site (figure 117). Man-made structures and functions are housed beneath the raised earth and roof. Hence, the materiality of the roof and the structures beneath and beside it differ. The roof of the arena, as a new element that belongs to the landscape, is constructed with natural materials such as timber (treated plywood that is locally sourced). Along with slanting green roofs and translucent polycarbonate, the roof mimics the light, airy and tranquil vegetation of the rest of the campus. Polycarbonate is used due to its high insulative properties that prevent condensation in the roof interior of often-humid spaces like indoor swimming pool facilities. Furthermore, the translucent light transmission allows natural daylighting without allowing too much heat gain in the interior of the arena. Green roofs also allow natural insulative properties, creating more comfortable indoor environments at the offices and consultation rooms.

On the other hand, the man-made structures below and beside the roof are constructed of typically man-made materials, related to the materials chosen for the existing building (old squash courts) and spectator stands. This includes: exposed reinforced concrete as a dominant structural material as well as yellow facebrick as a dominant infill (and sometimes structural) material. Facebrick is favoured over plastering and painting walls to relate back to the existing building as well as to reduce the maintenance that will be needed on the building in the future.

Figure 116: Low structural density on campus (Adapted from GoogleEarth, 2021)

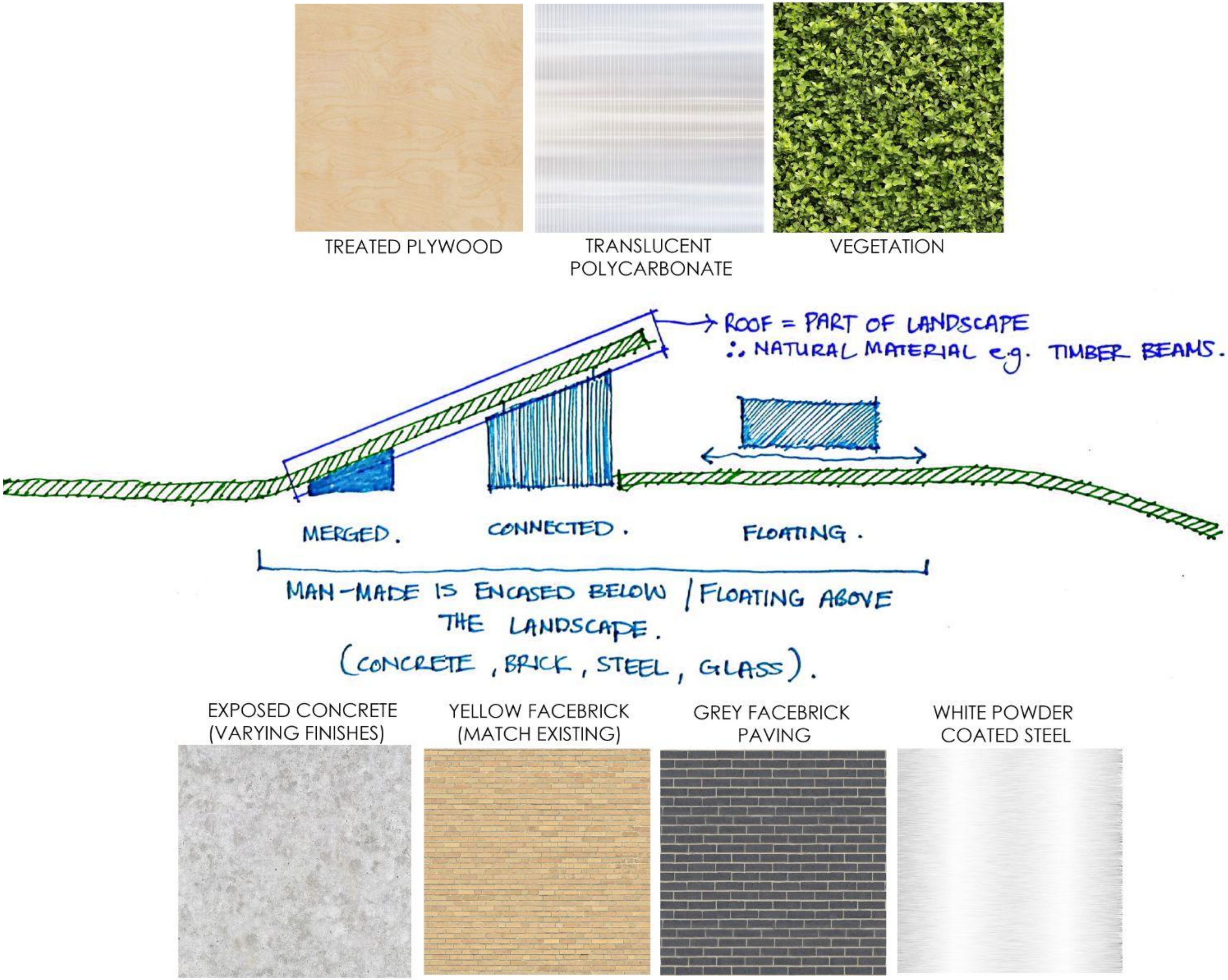


Figure 117: Materiality concept (Author, 2021)

Four Languages for technology in design

Language 1: Enclosure & extending the ground plane

Sensitive spaces in the facility, such as sports psychology and nutritionist offices and injury rehabilitation spaces are enclosed beneath the roof, creating a private and secure environment for athletes. The roof, acting as an extension of the landscape, encases the athletes in nature. The structural make-up of these spaces enhances the theme by using concrete as the dominant material. Structure, infill and even furniture are merged into a single concrete mass, giving the impression of protective spaces that are carved out of the landscape and enclosed within it. These spaces, being completely separate from the existing buildings on the opposite side of the swimming pool, take on a new design and structural language. This even translates to the treatment of the concrete at this portion of the site, where concrete formwork marks are left exposed, to give the impression of natural, unfinished carvings in the earth. The new language of spatial organization can be seen on the plan (figure 121).

As this portion of the arena is enclosed and tightly fitted beneath the landscape (and its extension into the roof), the connection between the roof structure and the concrete masses below become an important element to resolve. The intention is that the roof and landscape join seamlessly with one another so as to create a continuous landscape that stretches up and over the arena, blending the arena in with its surroundings (Seen in the iterations of figures 120-128).

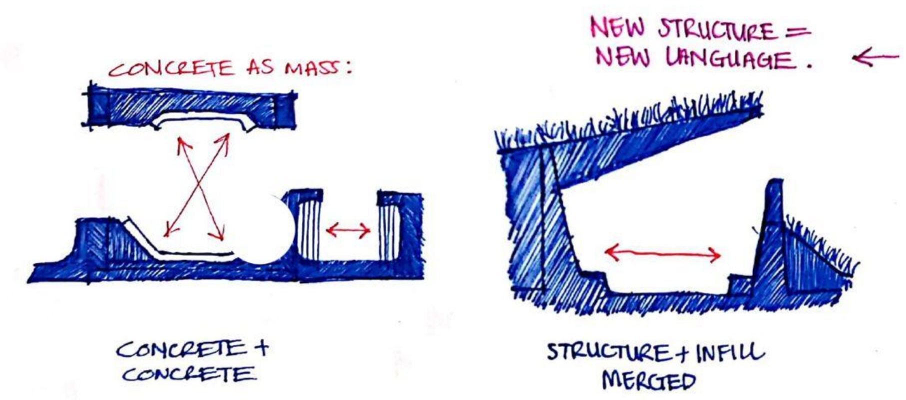


Figure 118: Language 1: Enclosure (Author, 2021)

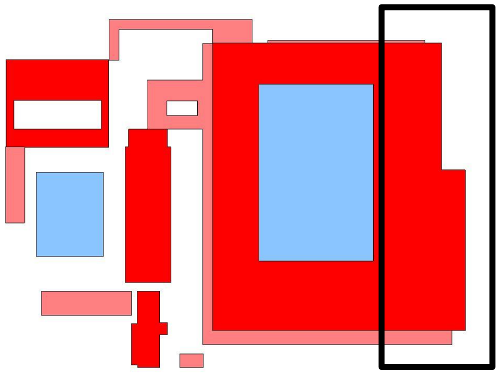


Figure 119: Supporting site diagram to show locality (Author, 2021)

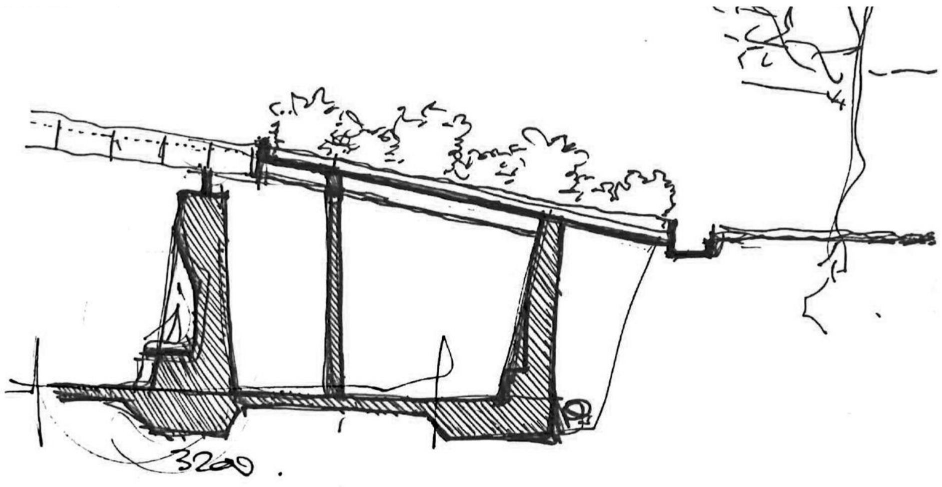


Figure 120: A seamless extension of the landscape (Author, 2021)

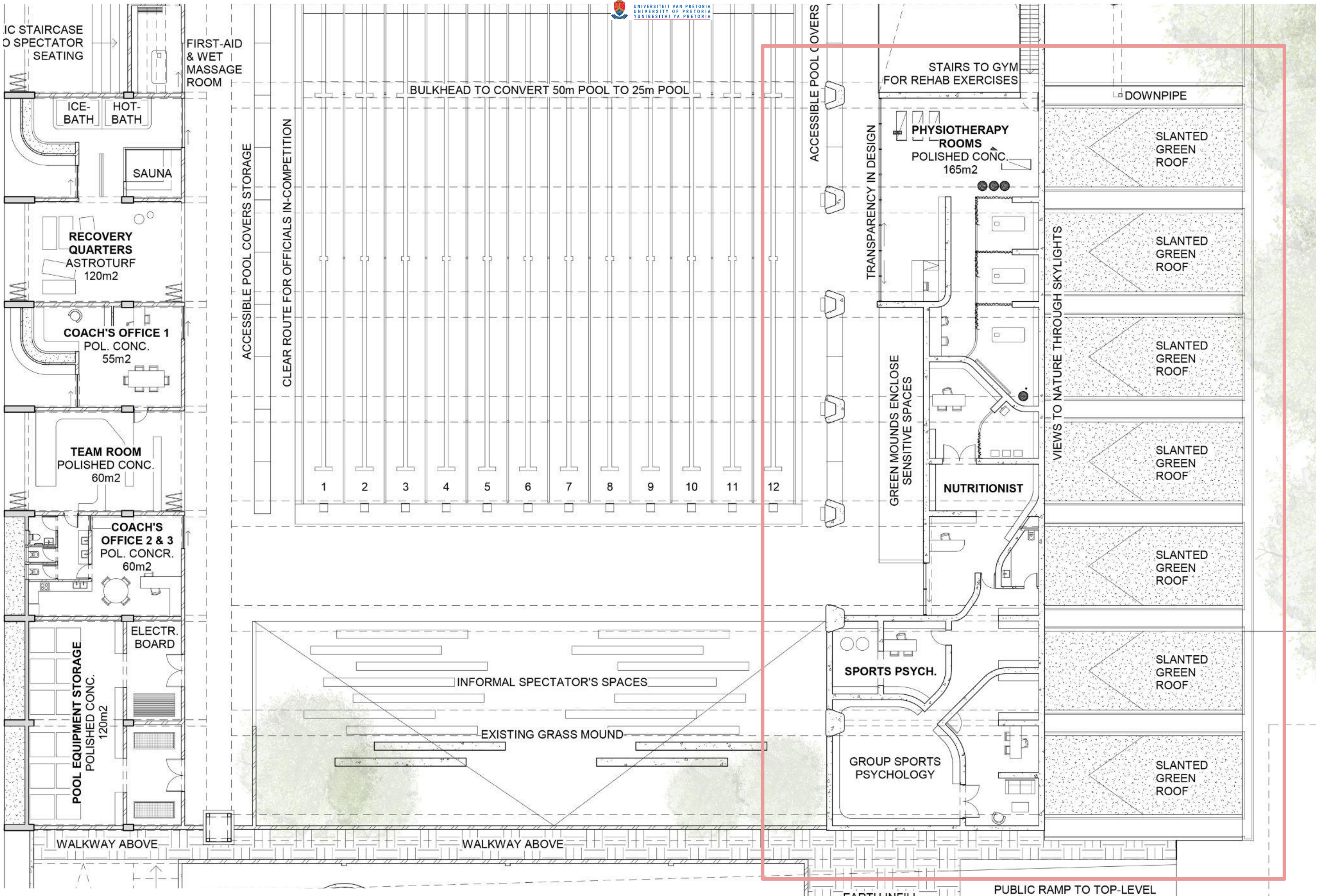


Figure 121: Callout of area on ground floor plan where language 1 was expressed (Author, 2021)

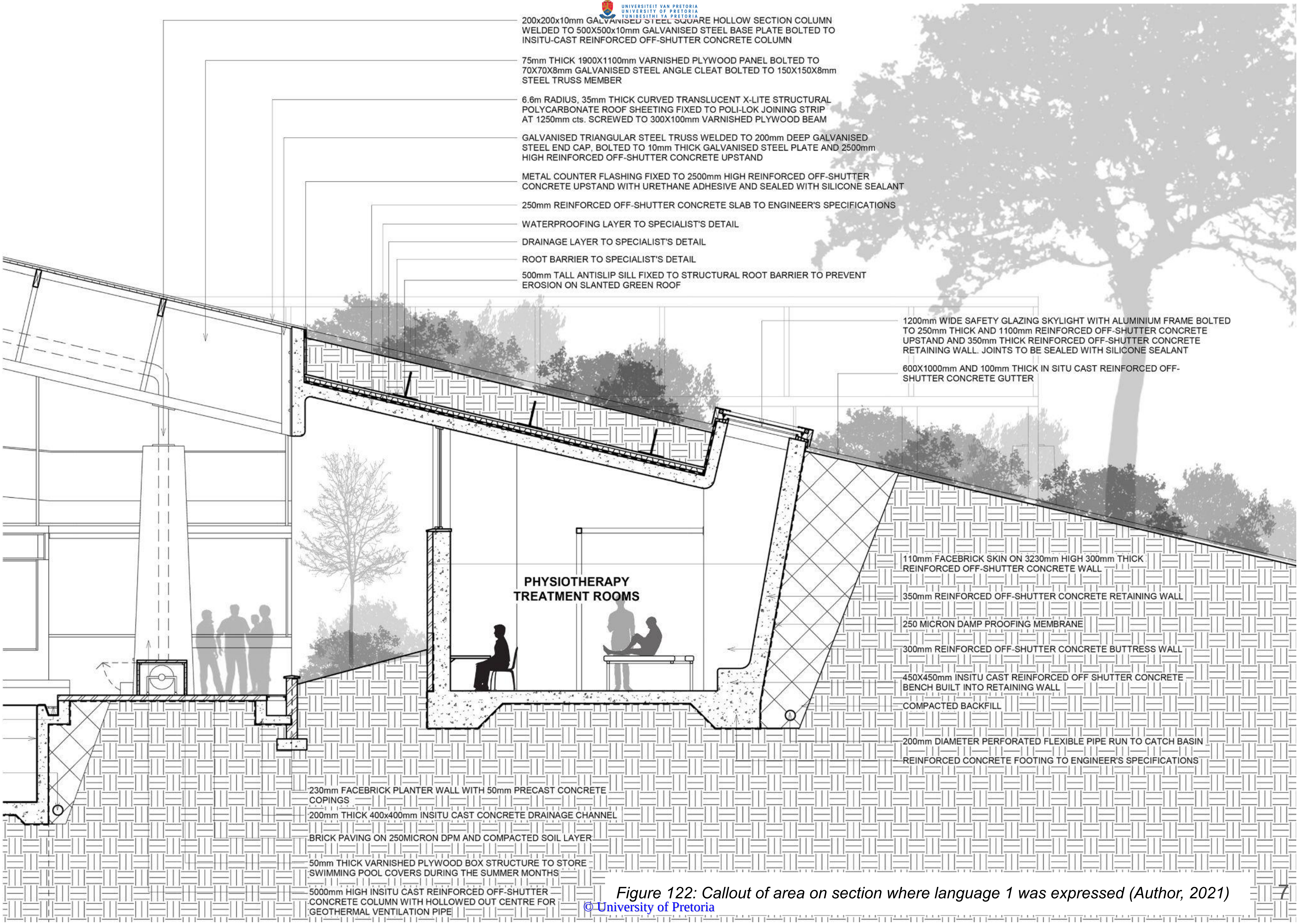


Figure 122: Callout of area on section where language 1 was expressed (Author, 2021)

DETAIL 1: CONNECTION BETWEEN ROOF, CONCRETE AND LANDSCAPE.

AIM: SHOW SEAMLESS CONNECTION + CONTINUATION OF NATURAL MATERIALITY THROUGH ONTO THE ROOF.

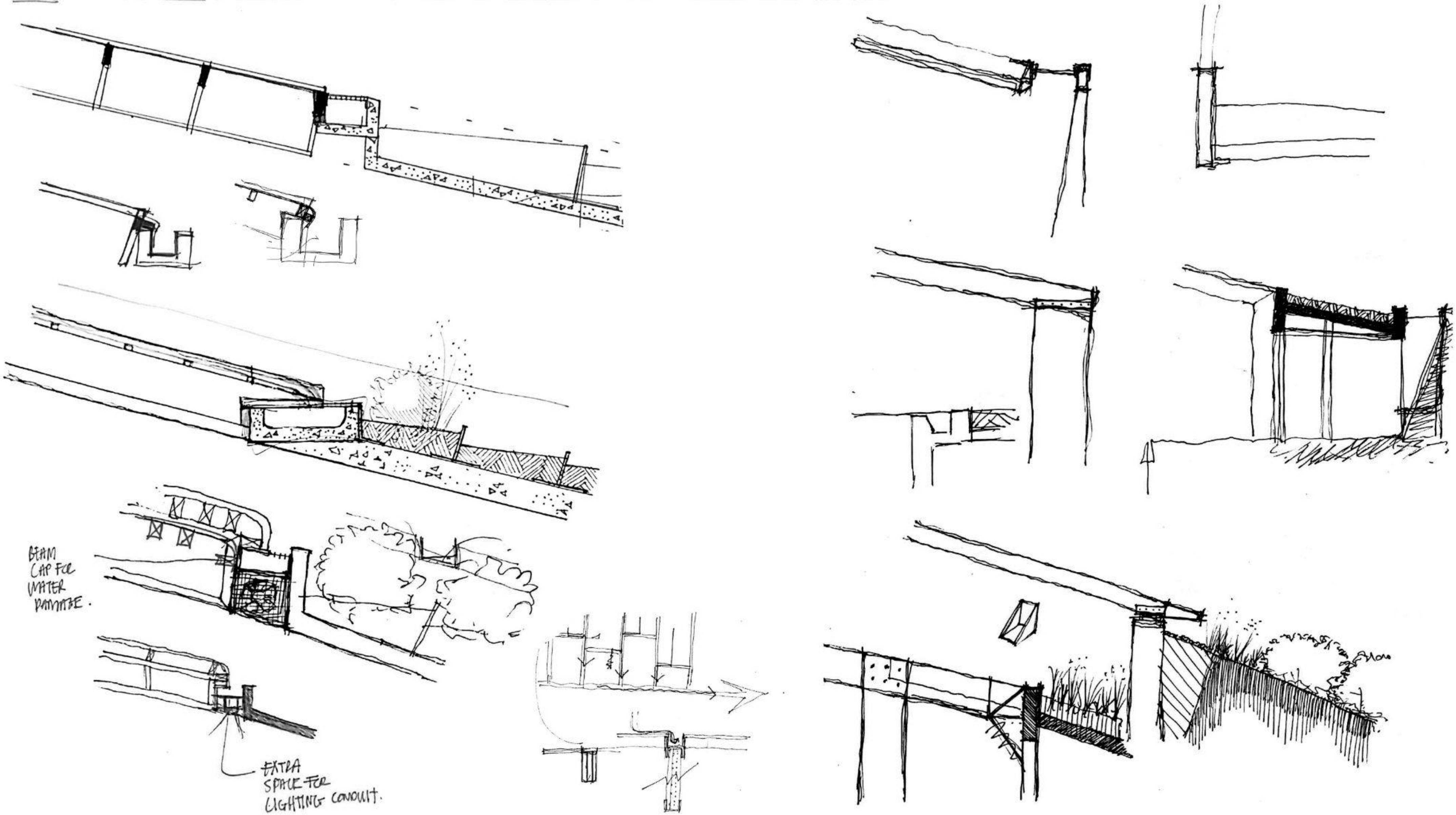


Figure 123: Iterations attempting to create a seamless connection between roof and landscape (Author, 2021)

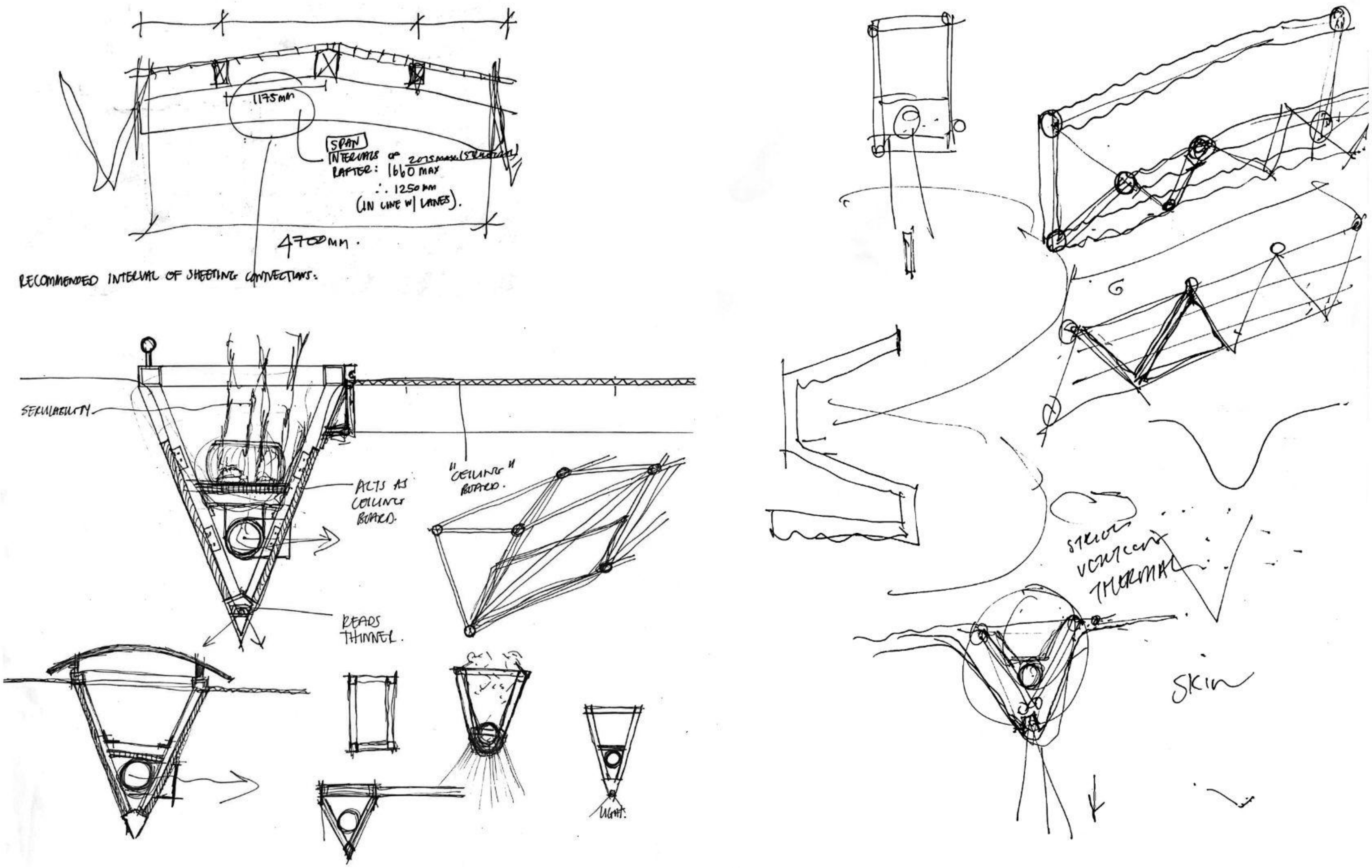


Figure 124: Iteration of the roof structure to determine how the roof and landscape will merge (Author, 2021)

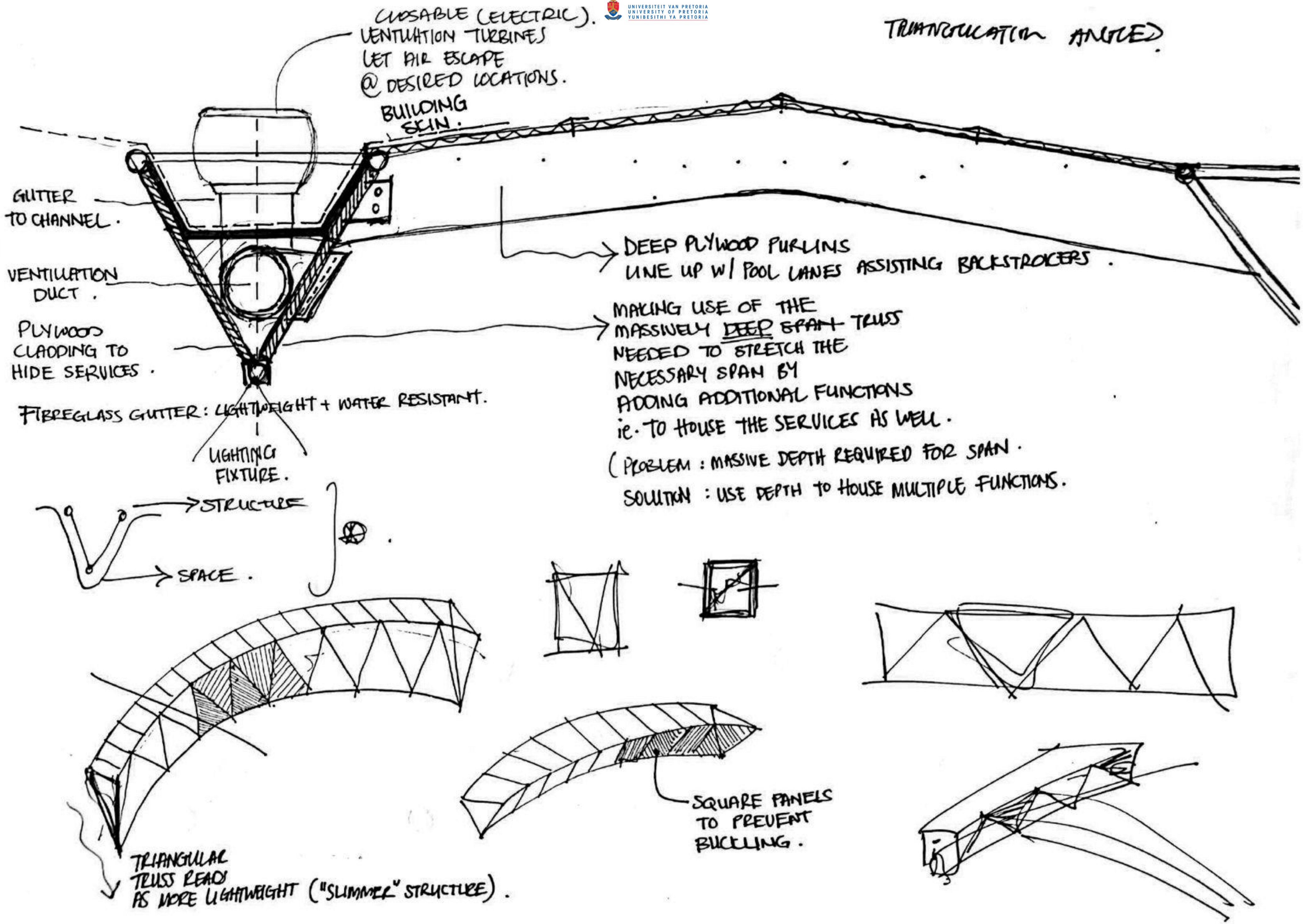


Figure 125: Iteration of the roof structure to determine how the roof and landscape will merge (Author, 2021)

1700mm WIDE AND 2200mm DEEP GALVANISED STEEL TRIANGULAR TRUSS: MAIN HORIZONTAL TRUSS MEMBERS TO BE 200X200X10mm GALVANISED STEEL SQUARE HOLLOW SECTIONS. VERTICAL TRUSS MEMBERS AND HORIZONTAL BRACING MEMBERS TO BE 150X150X8mm GALVANISED STEEL SQUARE HOLLOW SECTIONS

10mm THICK AND 600X1000mm FIBRE GLASS RAINWATER GUTTER BOLTED TO 200X200X10mm STEEL TRUSS MEMBERS AND SEALED WITH SILICONE SEALANT
note: fibre glass gutter with steel supports below allows for walkability and roof maintainance

100mm RADIUS INLET PIPE IN 1900X1100mm VARNISHED PLYWOOD PANEL SEALED WITH SILICONE SEALANT
Note: houses electrically operated mehcanical fan to re-circulate air internally

75mm THICK 1900X1100mm VARNISHED PLYWOOD PANEL BOLTED TO 70X70X8mm GALVANISED STEEL ANGLE CLEAT BOLTED TO 150X150X8mm STEEL TRUSS MEMBER

METAL FLASHING FIXED TO 600X1000mm FIBREGLASS AND REINFORCED CONCRETE GUTTER WITH URETHANE ADHESIVE AND SEALED WITH SILICONE SEALANT

METAL COUNTER FLASHING FIXED TO 2500mm HIGH REINFORCED OFF-SHUTTER CONCRETE UPSTAND WITH URETHANE ADHESIVE AND SEALED WITH SILICONE SEALANT

200x200x10mm GALVANISED STEEL SQUARE HOLLOW SECTION COLUMN WELDED TO 500X500x10mm GALVANISED STEEL BASE PLATE BOLTED TO INSITU-CAST REINFORCED OFF-SHUTTER CONCRETE COLUMN

DRAINAGE LAYER TO SPECIALIST'S DETAIL

WATERPROOFING LAYER TO SPECIALIST'S DETAIL

500mm TALL ANTISLIP SILL FIXED TO STRUCTURAL ROOT BARRIER TO PREVENT EROSION ON SLANTED GREEN ROOF

250mm THICK REINFORCED OFF-SHUTTER CONCRETE SLAB TO ENGINEER'S SPECIFICATIONS

ROOT BARRIER TO SPECIALIST'S DETAIL

5000mm HIGH INSITU CAST REINFORCED OFF-SHUTTER CONCRETE COLUMN WITH HOLLOWED OUT CENTRE FOR GEOTHERMAL VENTILLATION PIPE

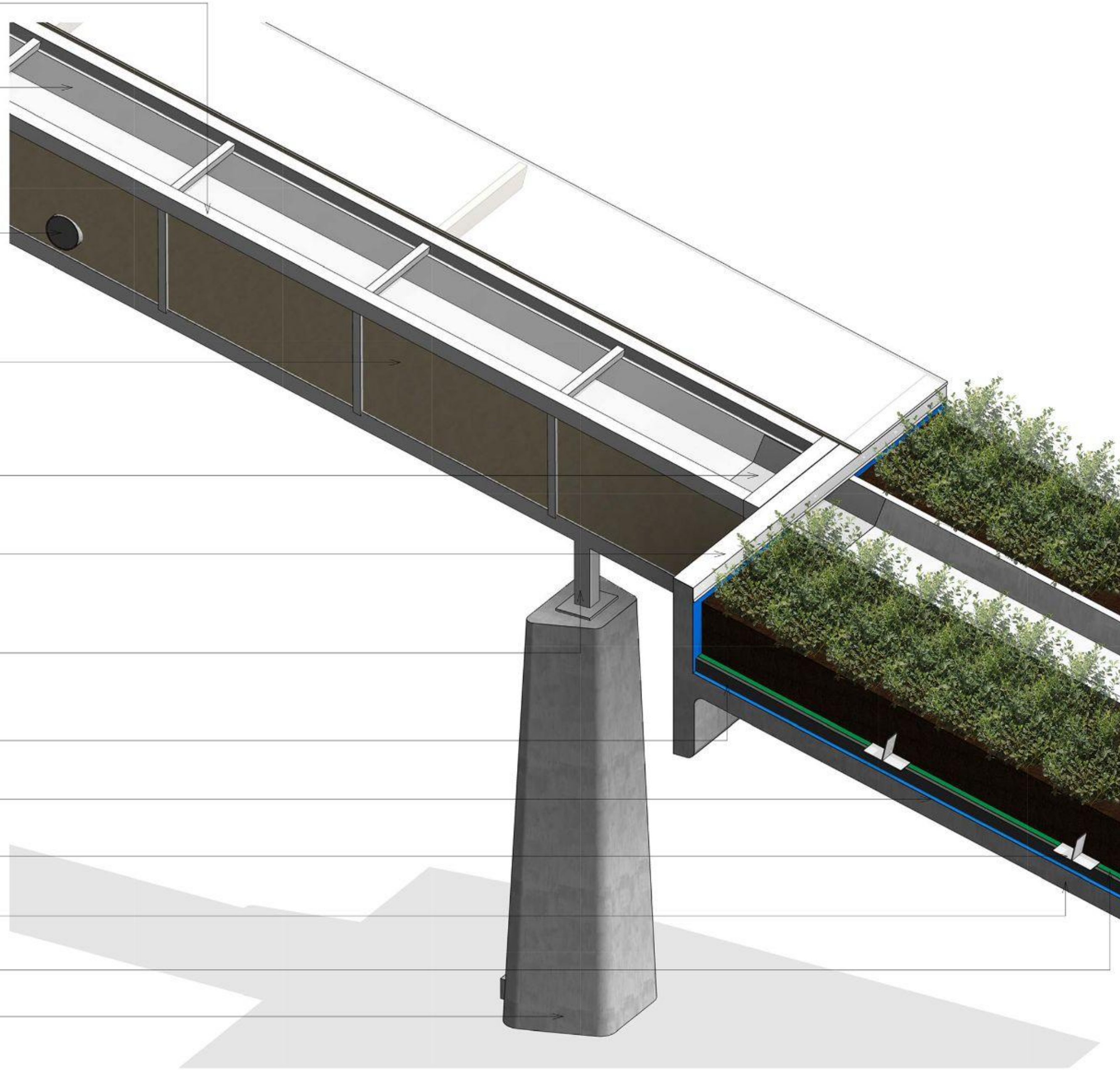


Figure 126: DETAIL A1 (Author, 2021)

Figure 127: DETAIL A2 (Author, 2021)

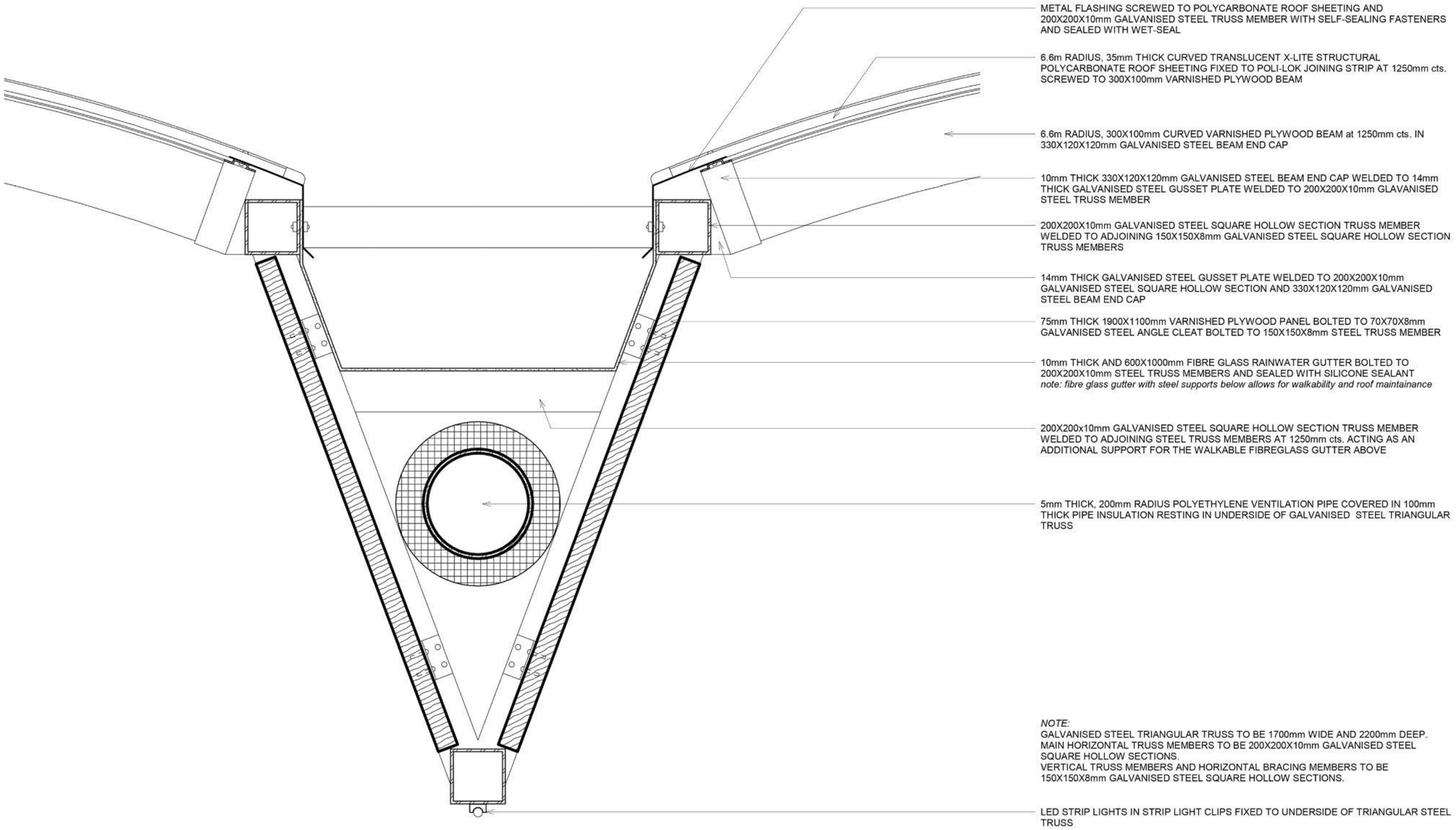


Figure 128: Cross section through triangular roof truss (Author, 2021)

Language 2: Enhancing the existing / functional

Functionality was largely favoured in the design of the existing building beneath the spectator seating. This was proven in the site analysis, showing long and narrow hallways, hidden entrances, no visibility to the field of play and no interaction between the interior and exterior spaces. The existing structural language exists as a concrete structure that supports the spectator seating above, with full-height yellow facebrick infill and partition walls that close off the internal spaces. In the proposed new language, the concrete structure remains intact as the medium for the infill, but the yellow facebrick infill is altered and redesigned to enhance the experience in the once solely functional spaces. Extensions to the concrete structure are smoothed out to relate the new additions back to the existing building and structure.

In contrast to the first *language* where structure and infill were merged, *language 2* clearly distinguishes the structure from the infill to tie in with the existing. In this sense, the construction becomes more elemental and less mass-driven - each element with an intentional purpose of enhancing the experience of the user and athlete beyond merely satisfying the program. The infill is disintegrated at certain parts where the solid, impermeable facebrick wall is replaced by a yellow facebrick brise soleil partition. This partition enhances visibility to the field of play while allowing some privacy to interior spaces. Furthermore, it helps to allow natural ventilation through the openings in the wall.

(Seen in the iterations of figures 132-136).

In the detail (figure 135-136), the existing solid, impermeable edge condition of the building is transformed into a layered threshold. The line between inside and outside is blurred (figure 131) allowing nature to be drawn in partially into the interior spaces and past the traditional solid wall. This allows athletes to benefit from the psychologically supportive properties of nature through an enhanced experience of the space. Furthermore, openable window sections surrounded by the brise soleil wall allow a lot of ventilation through these internal spaces without compromising on privacy or security.

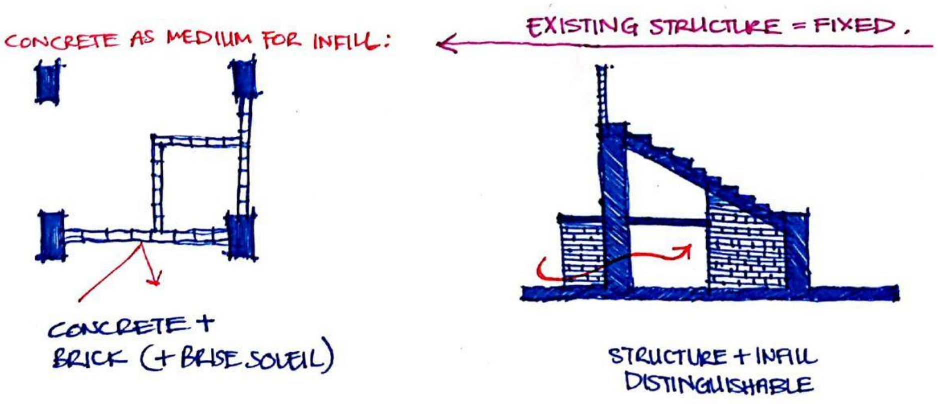


Figure 129: Language 2 (Author, 2021)

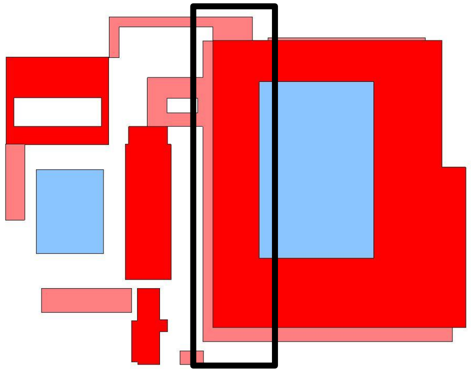


Figure 130: Supporting site diagram to show locality (Author, 2021)

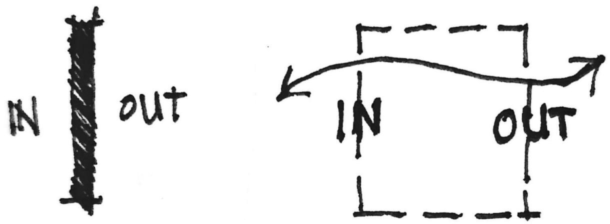


Figure 131: A layered threshold (Author, 2021)

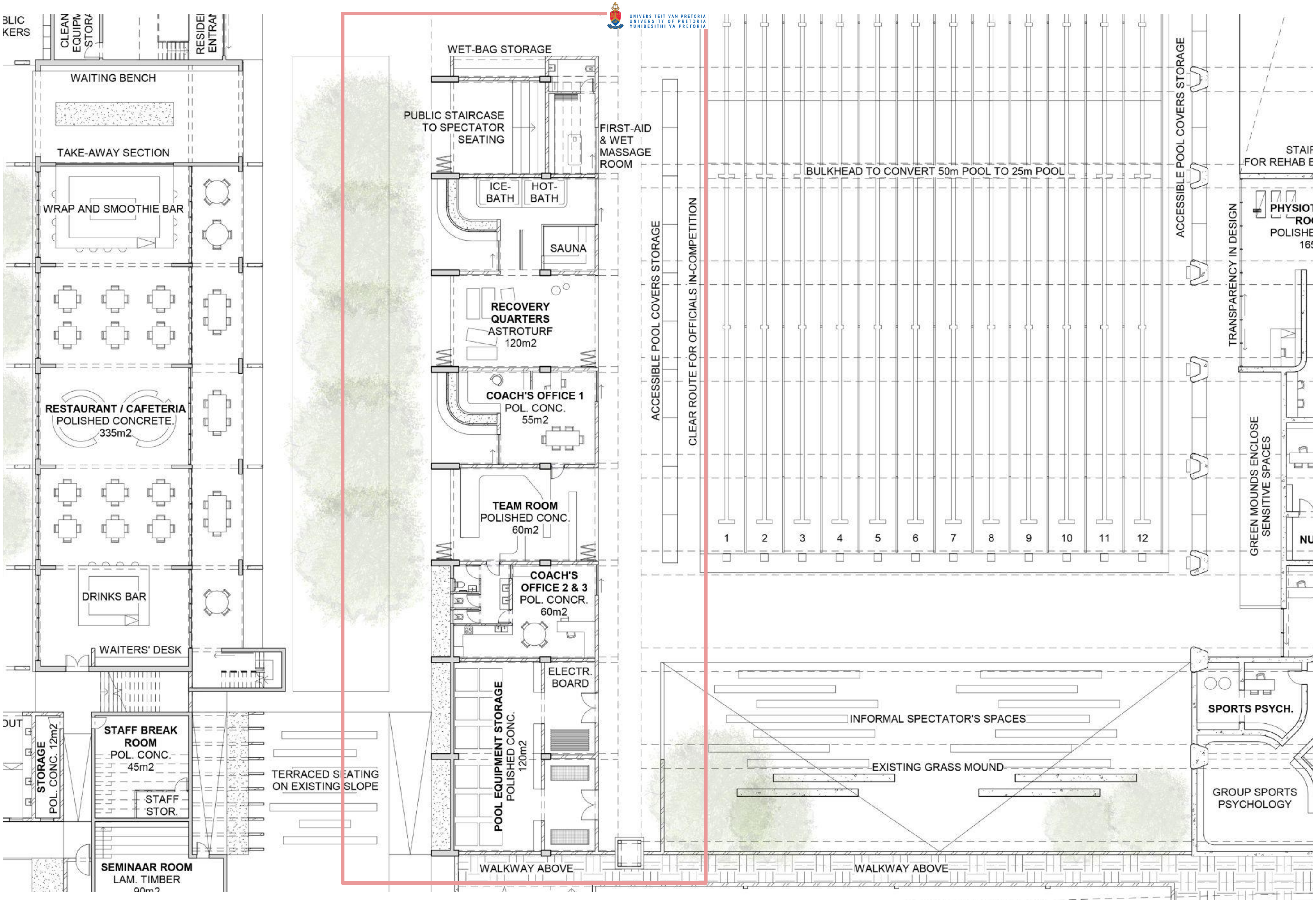


Figure 132: Callout of area on ground floor plan where language 2 was expressed (Author, 2021)

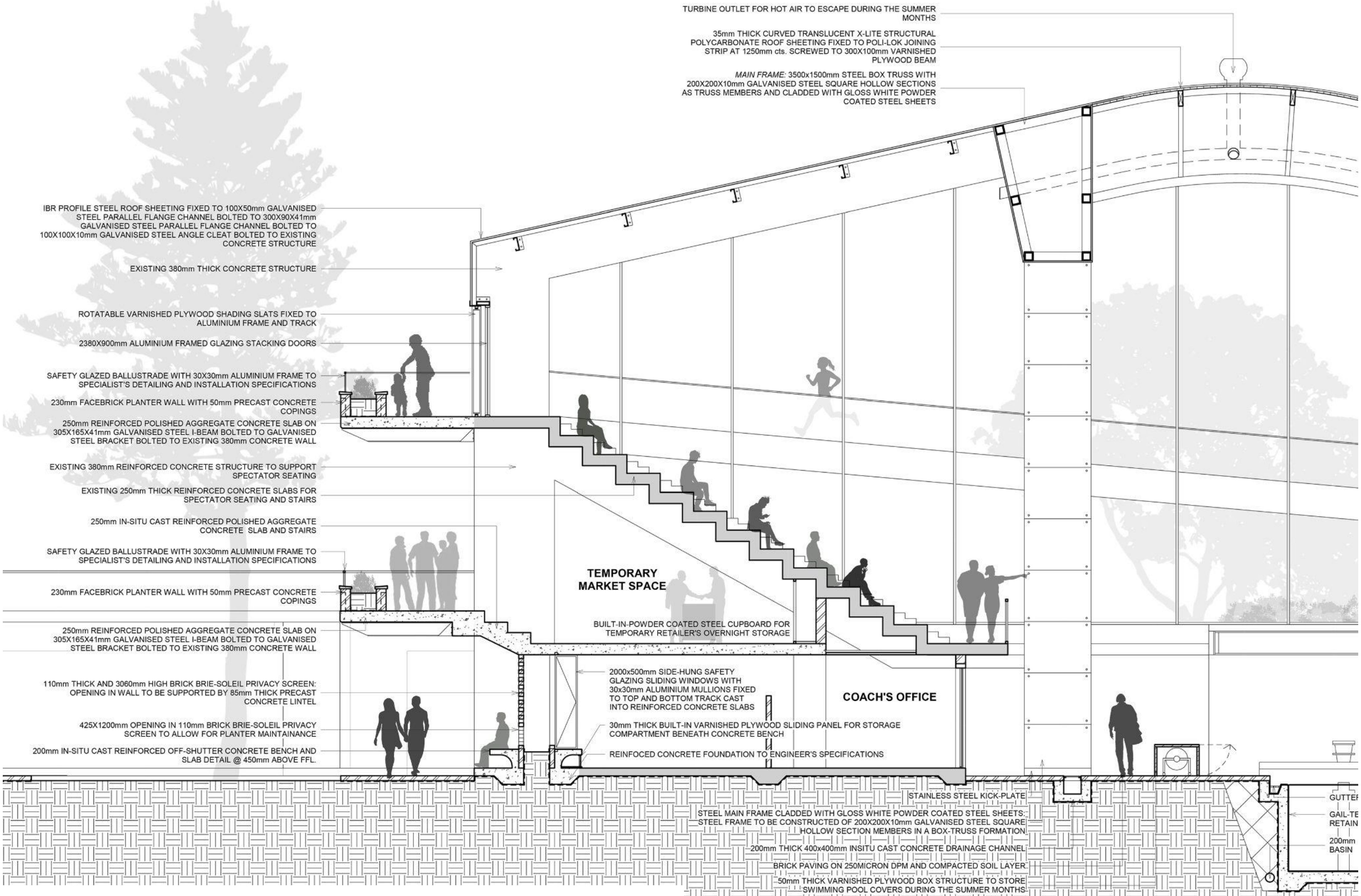


Figure 133: Callout of area on section where language 2 was expressed (Author, 2021)

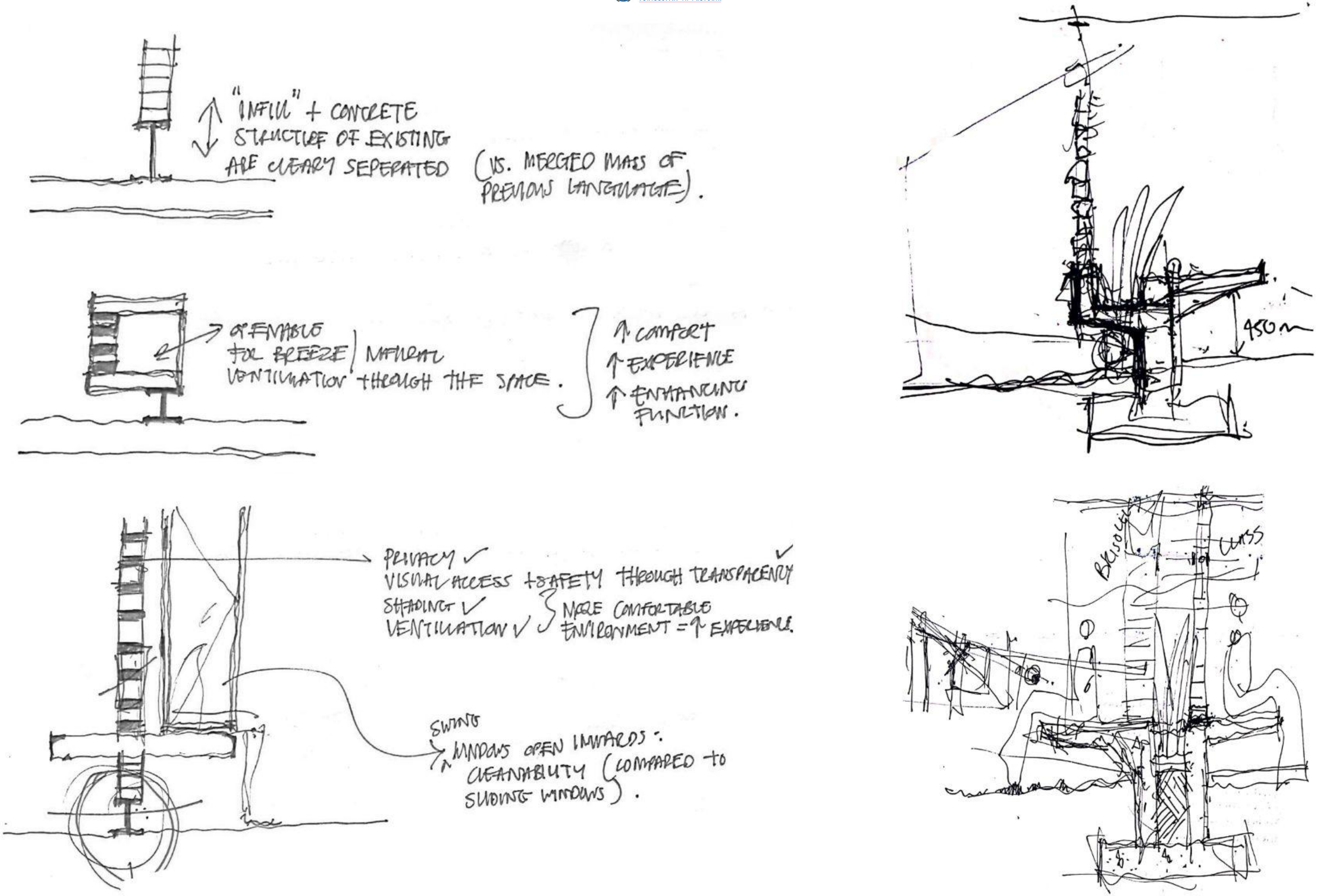


Figure 134: Iterations attempting to blur the threshold to create experientially enhanced functional spaces (Author, 2021)

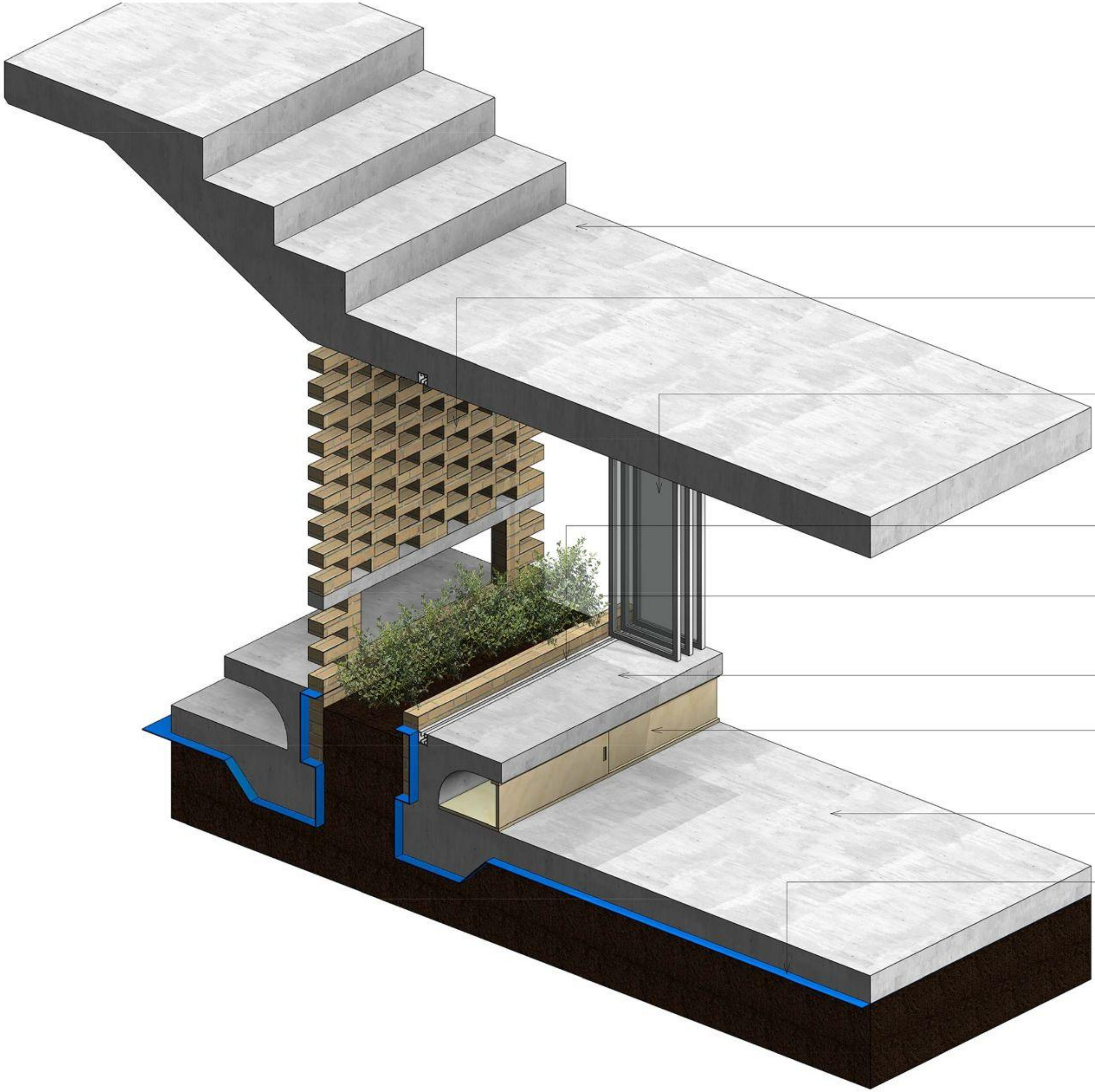


Figure 135: DETAIL B1 (Author, 2021)

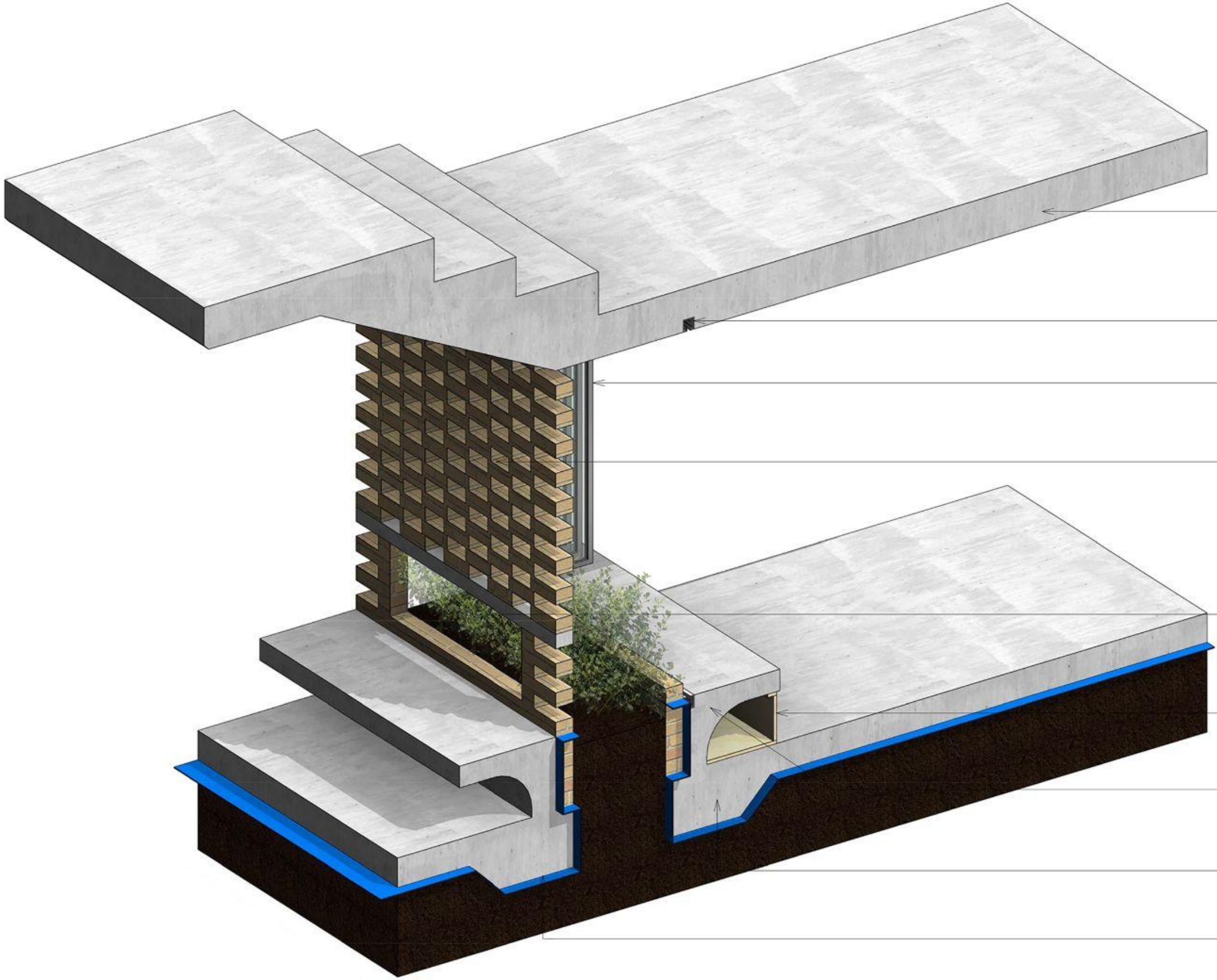


Figure 136: DETAIL B2 (Author, 2021)

Language 3: Enhancing accessibility by removing the infill

As discussed earlier, athletes' support structures - family, friends, coaches and fans - are vital to their success and performance. The site analysis showed the existing squash court building to be a solid, inaccessible mass. By removing the facebrick infill almost entirely and replacing it with openable glazing, the visual and, though controlled, physical access of the space is drastically enhanced (figure 137). Broken facebrick fragments from the demolished wall can be repurposed to fill gabion structures where the gradually sloping landscape needs to be terraced across the site. Furthermore, concrete, smoothed out and rid of its formwork marks, remains as the primary structure, but is now left exposed, isolated and almost entirely stripped of its infill, appearing fully accessible to the public. The smooth concrete is unadorned with the internal spaces being activated by the movement, activity and experience of the users: athletes and their support figures.

Due to the orientation of the existing building, protection is needed to shield the glazed facade from the western sun. Vertical treated plywood louvres supported by a steel framework that encases trees for additional shading softens the facade. The high building gradually steps down to the human-scale as one enters the building, as seen in the section (figure 140).

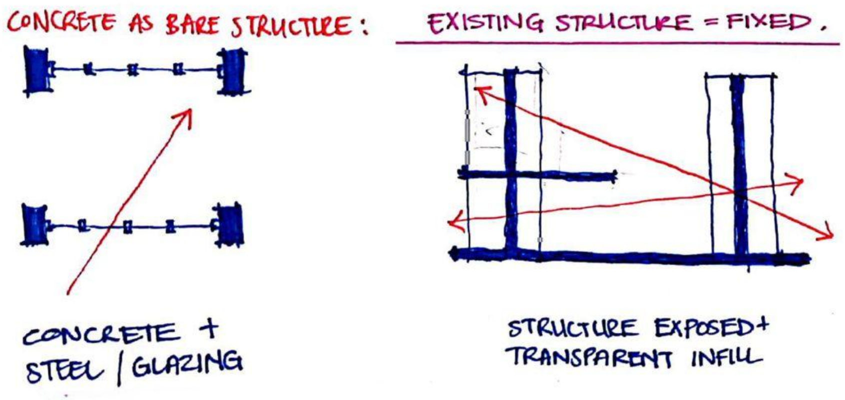


Figure 137: Language 3 (Author, 2021)

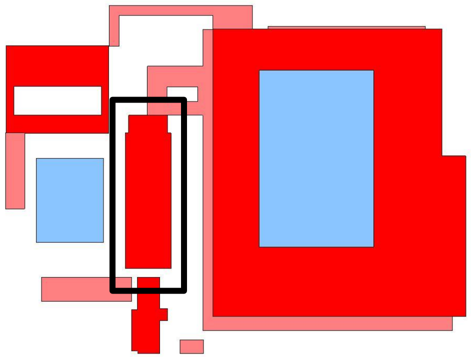


Figure 138: Supporting site plan to show locality (Author, 2021)

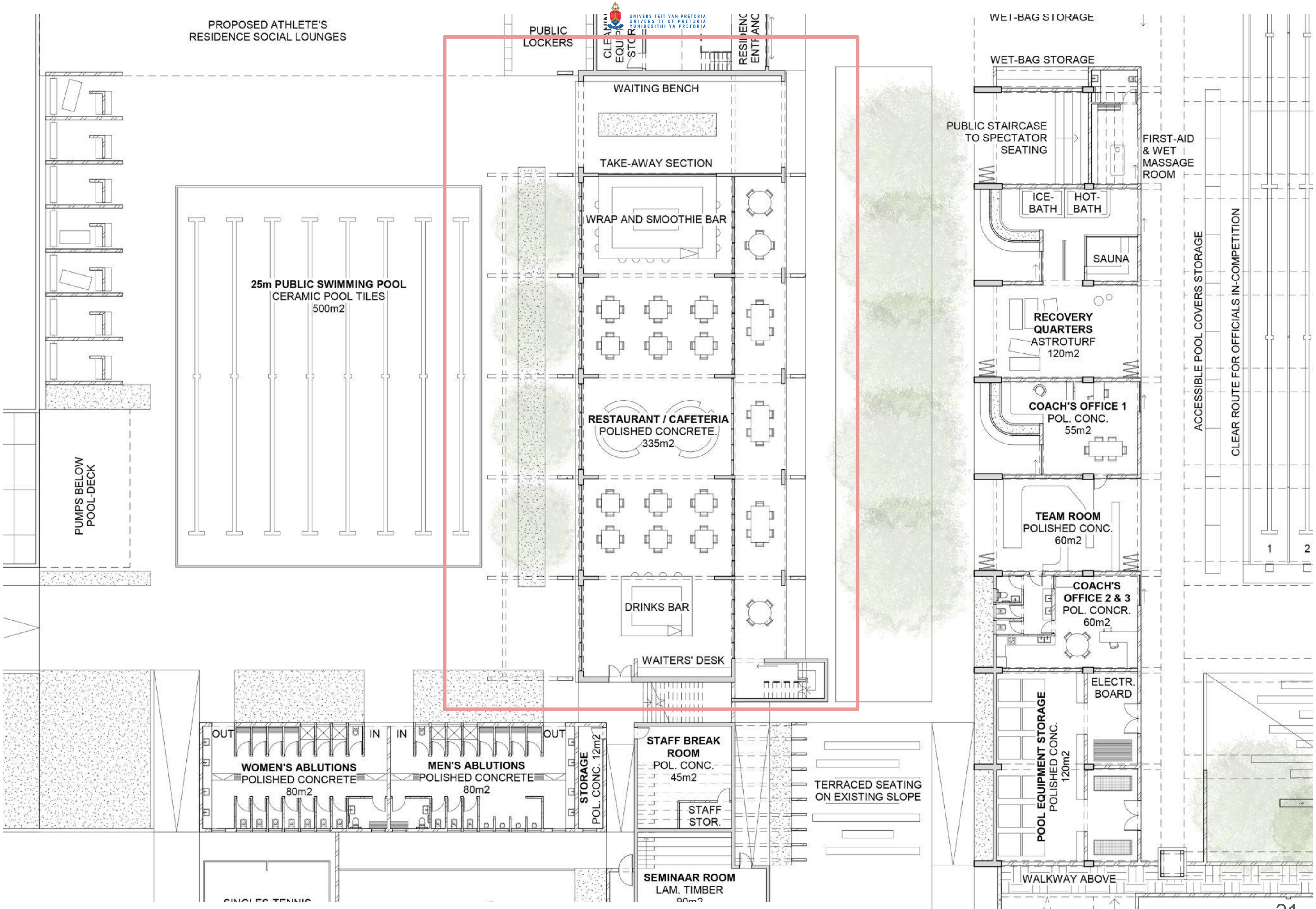


Figure 139: Callout of area on ground floor plan where language 3 was expressed. An enhanced accessibility (Author, 2021)

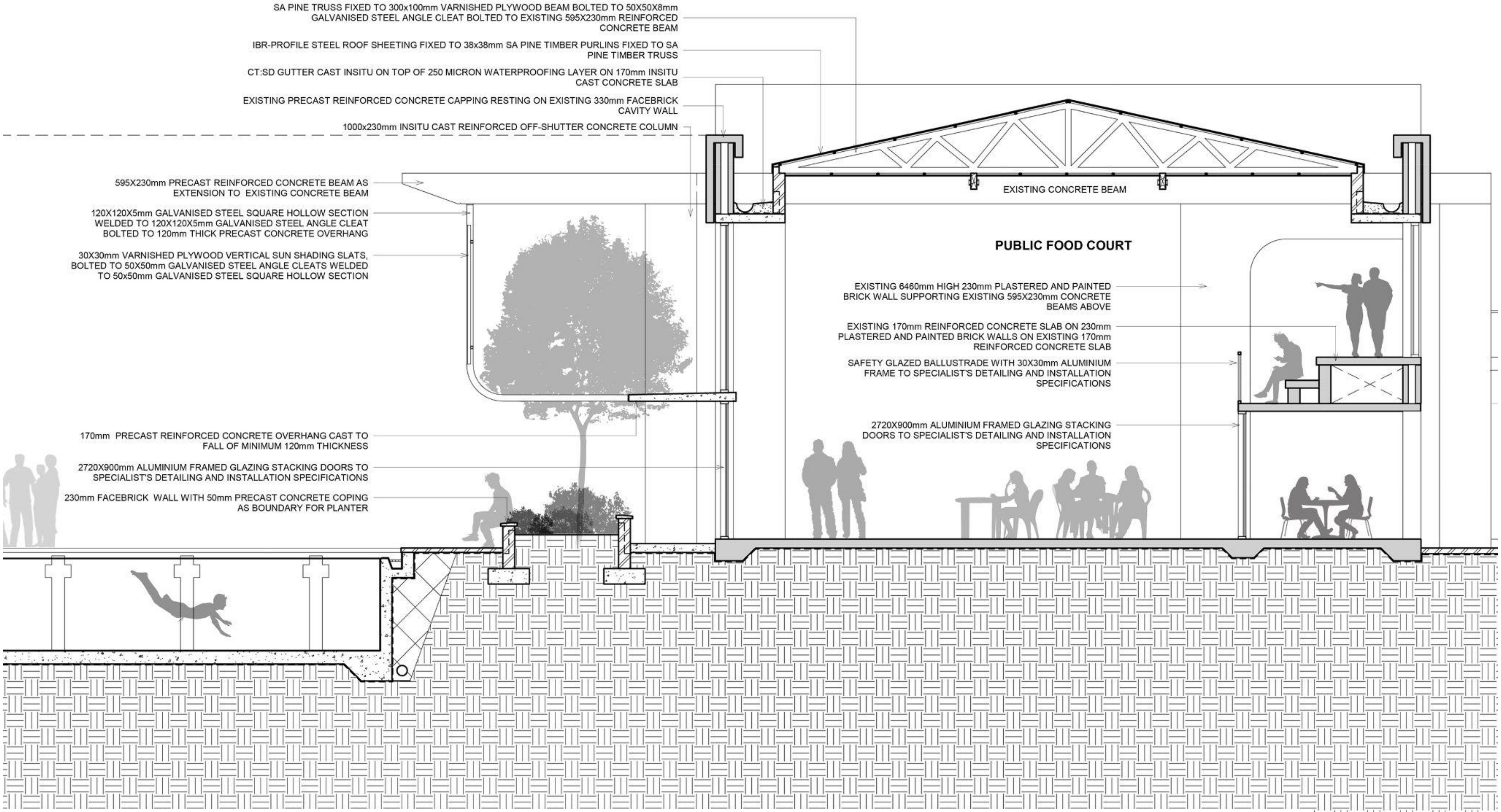


Figure 140: Callout of area on section where language 3 was expressed: Section through the food hall showing the stepped facade and shading (Author, 2021)

Language 4: Simulative environments

Language 4 is primarily used in the design and construction of the race visualisation pods that athletes use before and after their races. Athletes can use these private and intimate outdoor spaces to practice their sports psychology routines prior to or after a race. These new additions to the facility exist completely detached from the existing building, taking on their own new design and structural language. Progressing from *language 3* where the brick infill was stripped away, *language 4* uses nature and landscape as the infill to enhance the experience of the athlete in these spaces.

The concrete structure exists as secondary, keeping nature at the forefront of the design to tie the structures in with the low structural intensity of the surrounding campus. Prioritising nature as an infill also allows for the creation of a psychologically supportive environment for the athletes where they can benefit from the calming properties of nature. The concrete structure of the floor, wall and roof are now separated by steel supports, submitting to the desired openings, outward looking views and nature (figures 145-149). The seemingly floating concrete structures give the impression of a minimally invasive intervention.

Furthermore, the formwork used for the reinforced concrete partition walls is corrugated iron sheeting. This gives a rippled effect that mimics the movement of water. Through texture and form-making, athletes are immersed in a simulative environment that can psychologically aid in their race-imagery exercises before a race (figures 145-149).

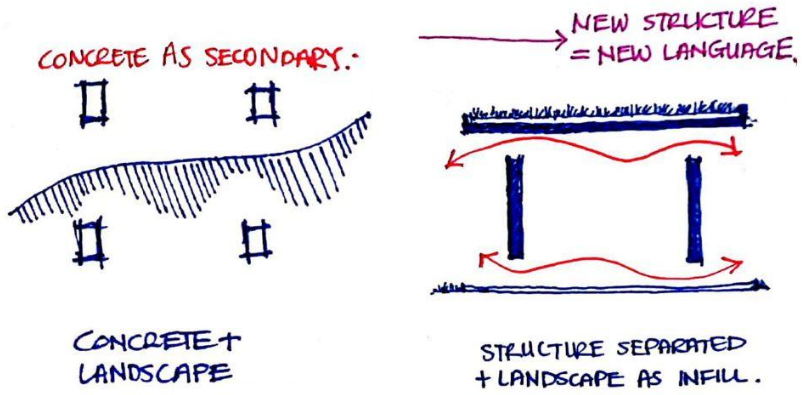


Figure 141: Language 3 (Author, 2021)

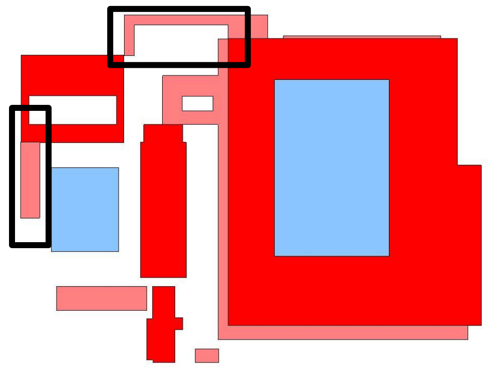


Figure 142: Supporting site plan to show locality (Author, 2021)

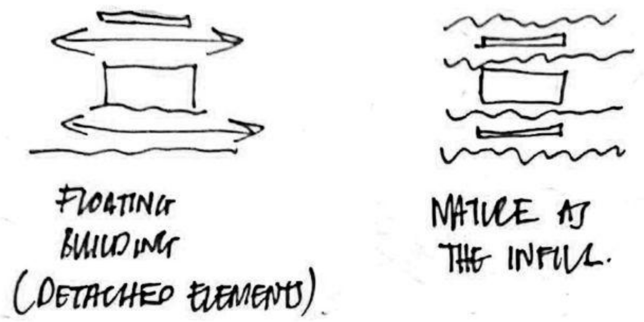


Figure 143: Separated structure and natural infill (Author, 2021)

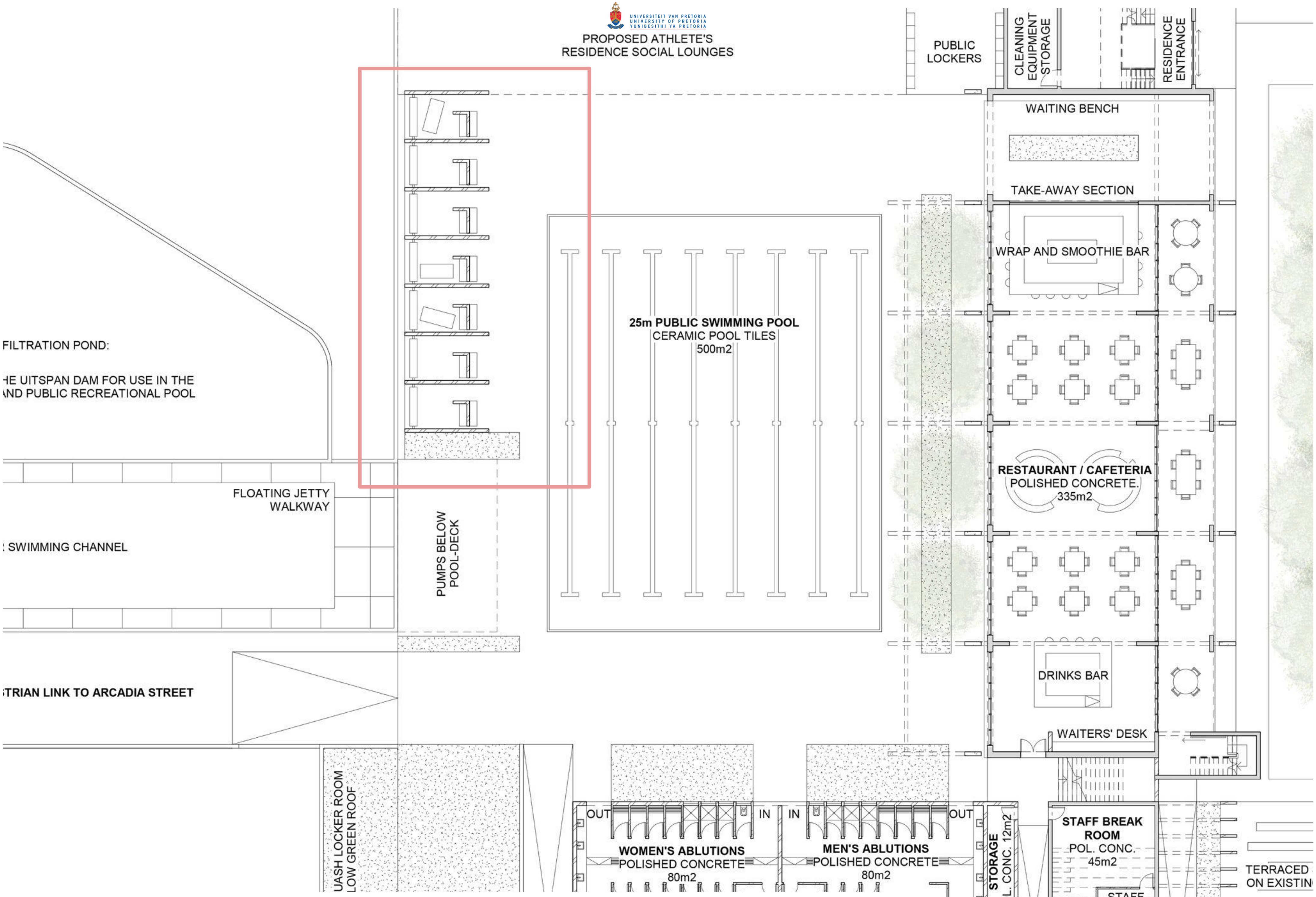


Figure 144: Callout of area on ground floor plan where language 4 was expressed: The race-visualisation pods (Author, 2021)

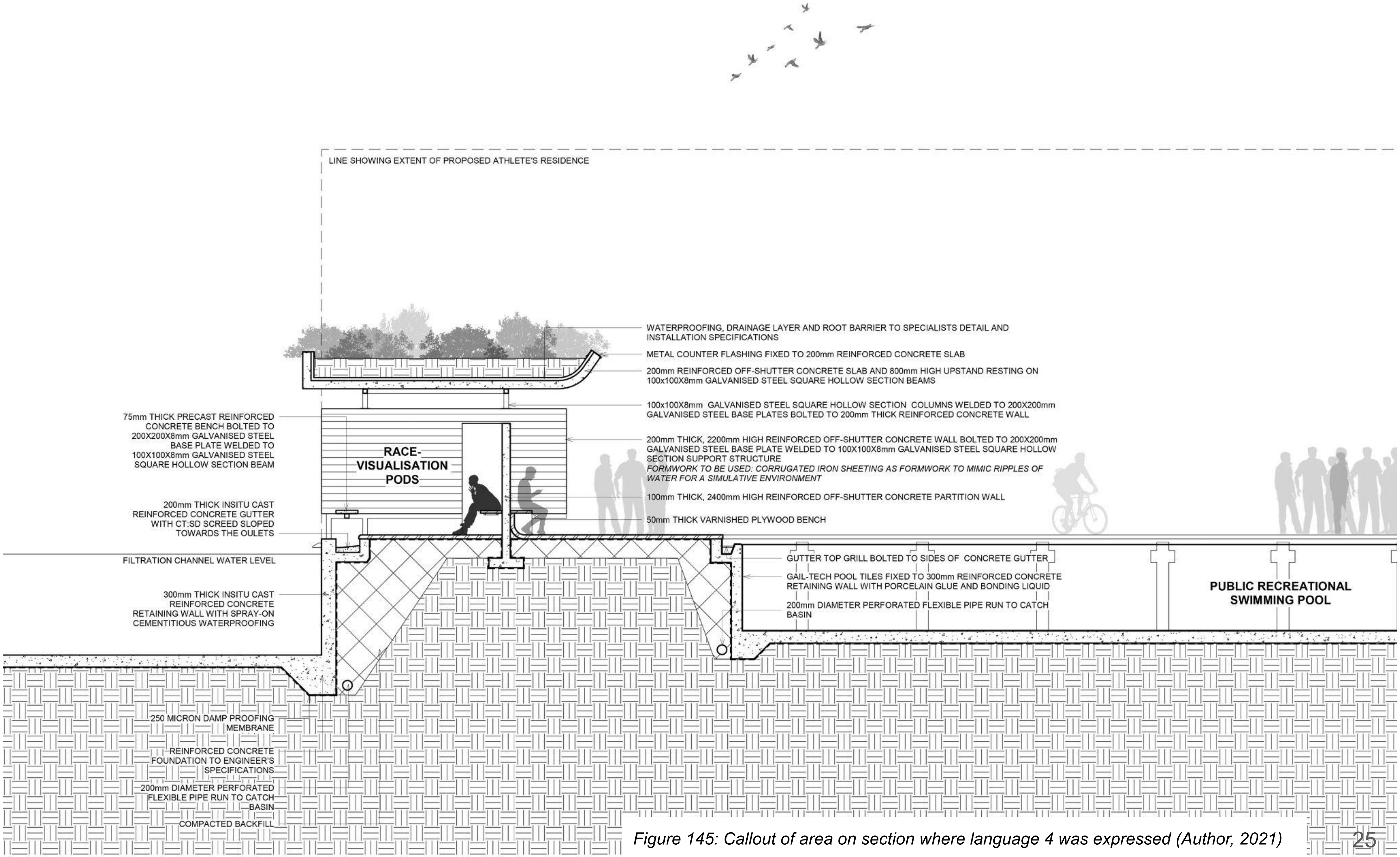


Figure 145: Callout of area on section where language 4 was expressed (Author, 2021)

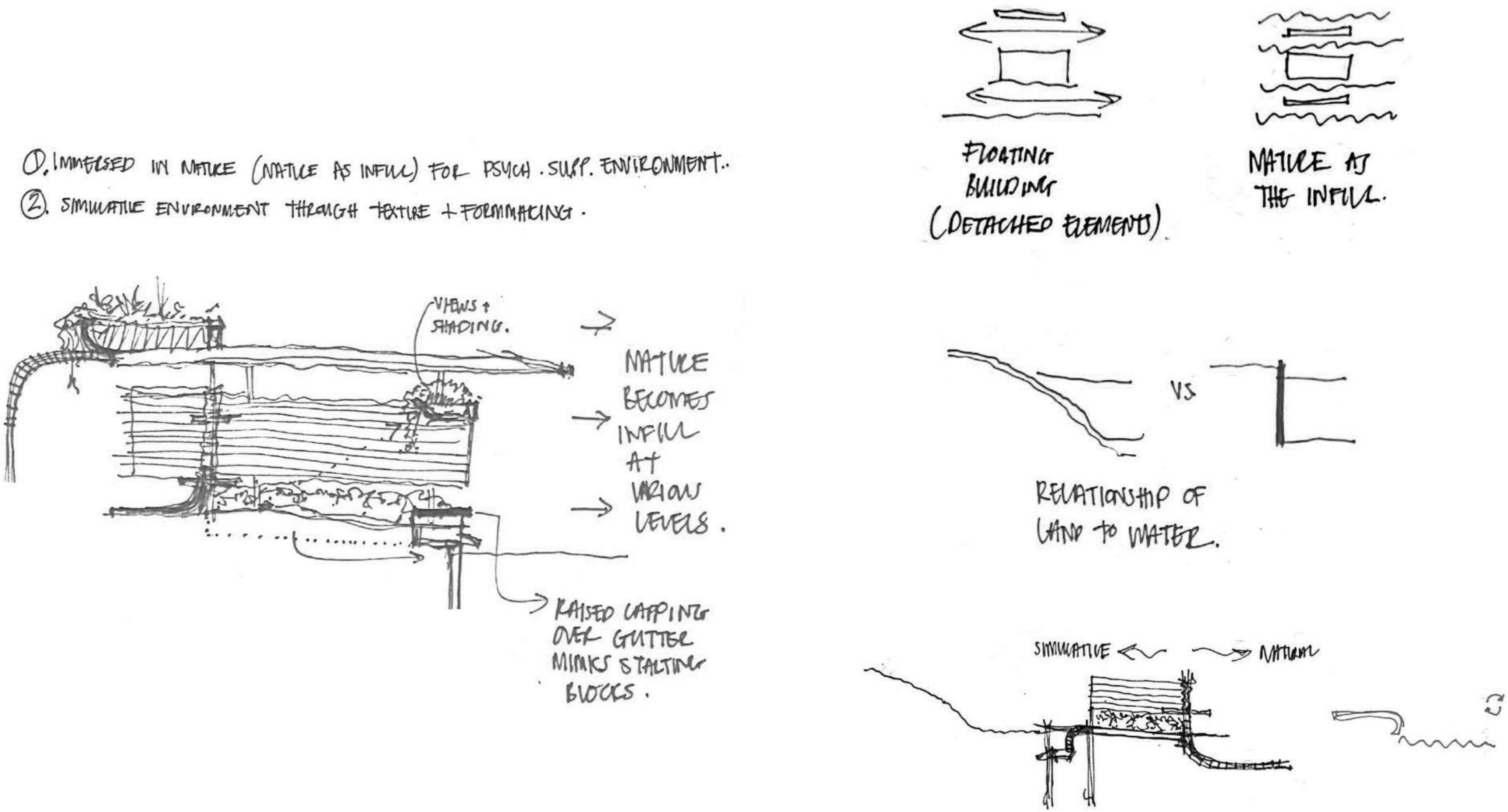


Figure 146: Iterations of detail C (Author, 2021)

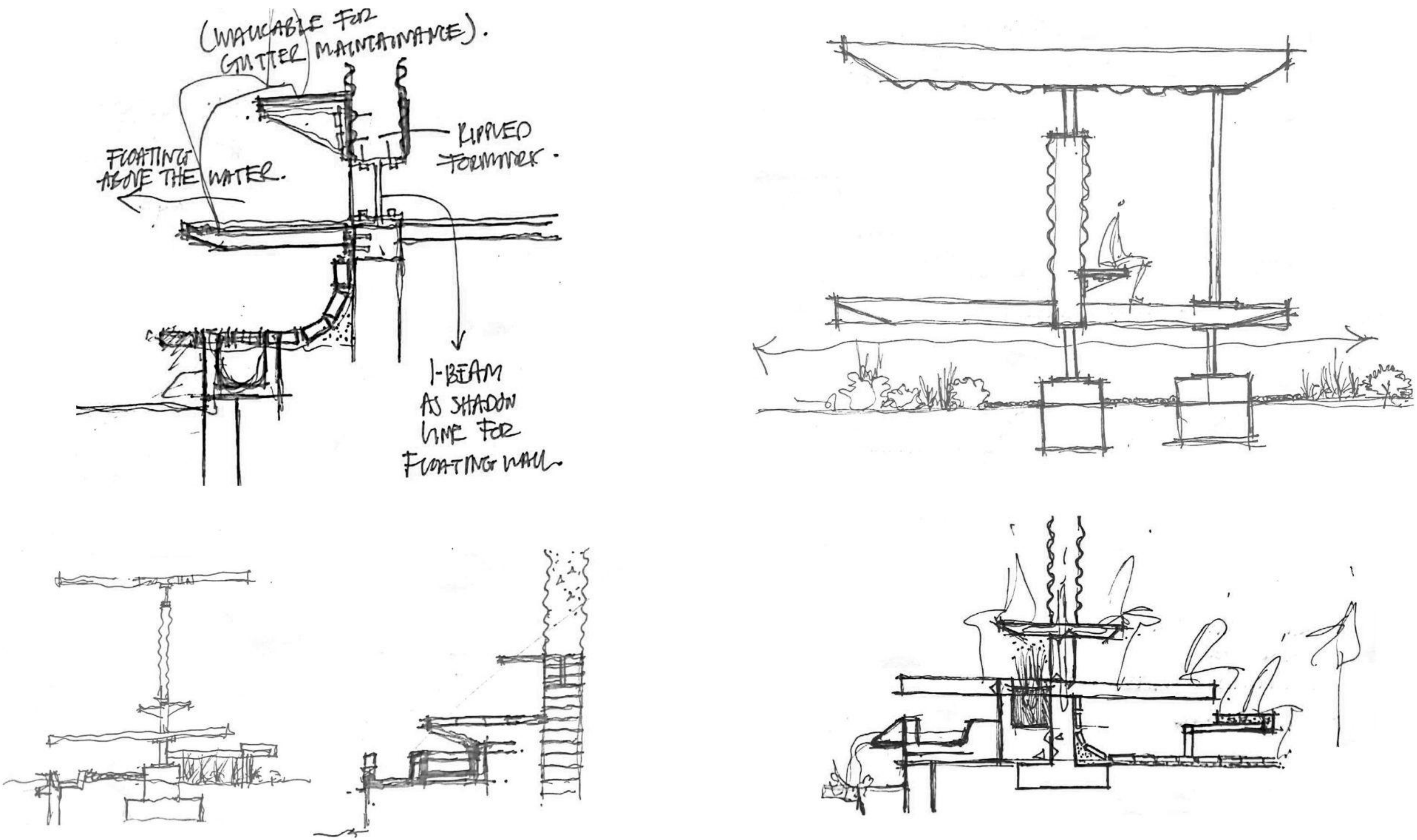


Figure 147: Iterations of detail C (Author, 2021)

Figure 148: DETAIL C1 (Author, 2021)

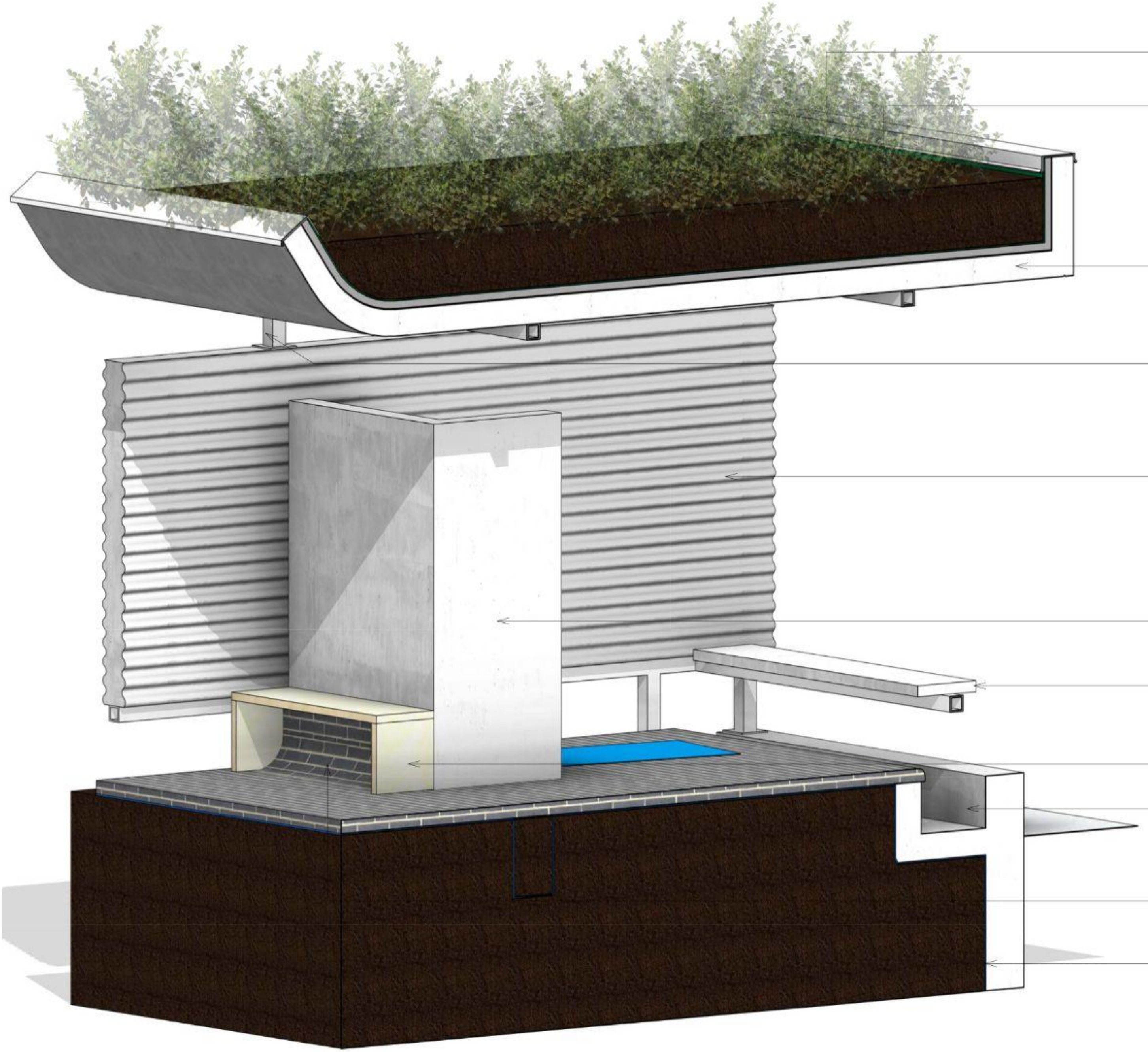


Figure 149: DETAIL C2 (Author, 2021)

Technological precedents

In terms of the roof, as a major element in the design, the span, along with the desired retractability needed to open the venue during the warmer months and close it during cooler months and competitions, created various technical challenges. Precedents were used to inform the chosen solutions:

Kengo Kuma

Due to the desired use of timber as a construction material for the roof ("the roof as an extension of the ground plane"), issues of span and material efficiency arose. Kengo Kuma does a lot of work using timber construction, however, for larger buildings, he resorts to hybrid structural systems where timer and steel are used in conjunction with one another. This creates an efficient solution where steel as the primary structure allows for the desired large spans, and timber as the secondary structure improves the general energy efficiency as well as the aesthetic of the roof. Kuma can be seen using these strategies in projects like those seen below (figures 150-153):

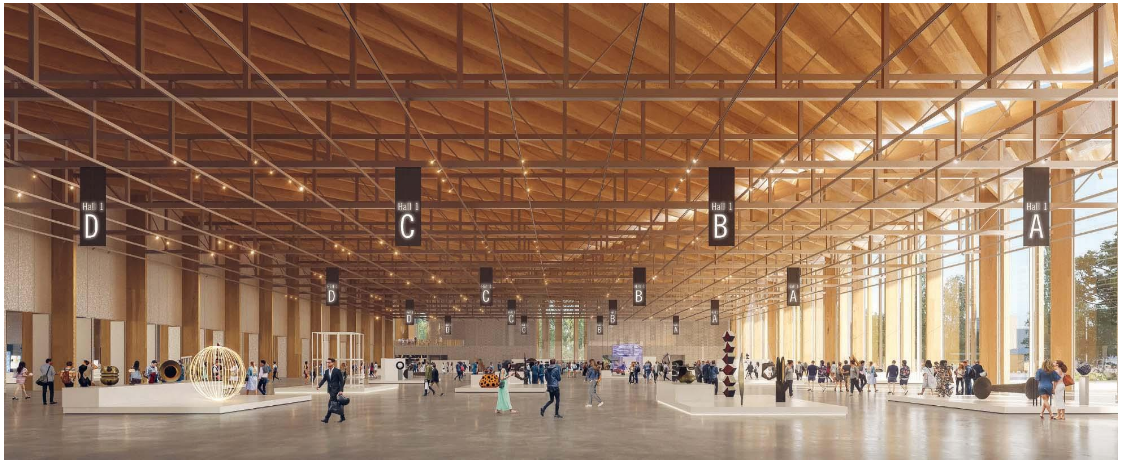


Figure 150: Exhibition Center of Strasbourg, Kuma and Associates, 2018 (arquitecturaviva, 2021)

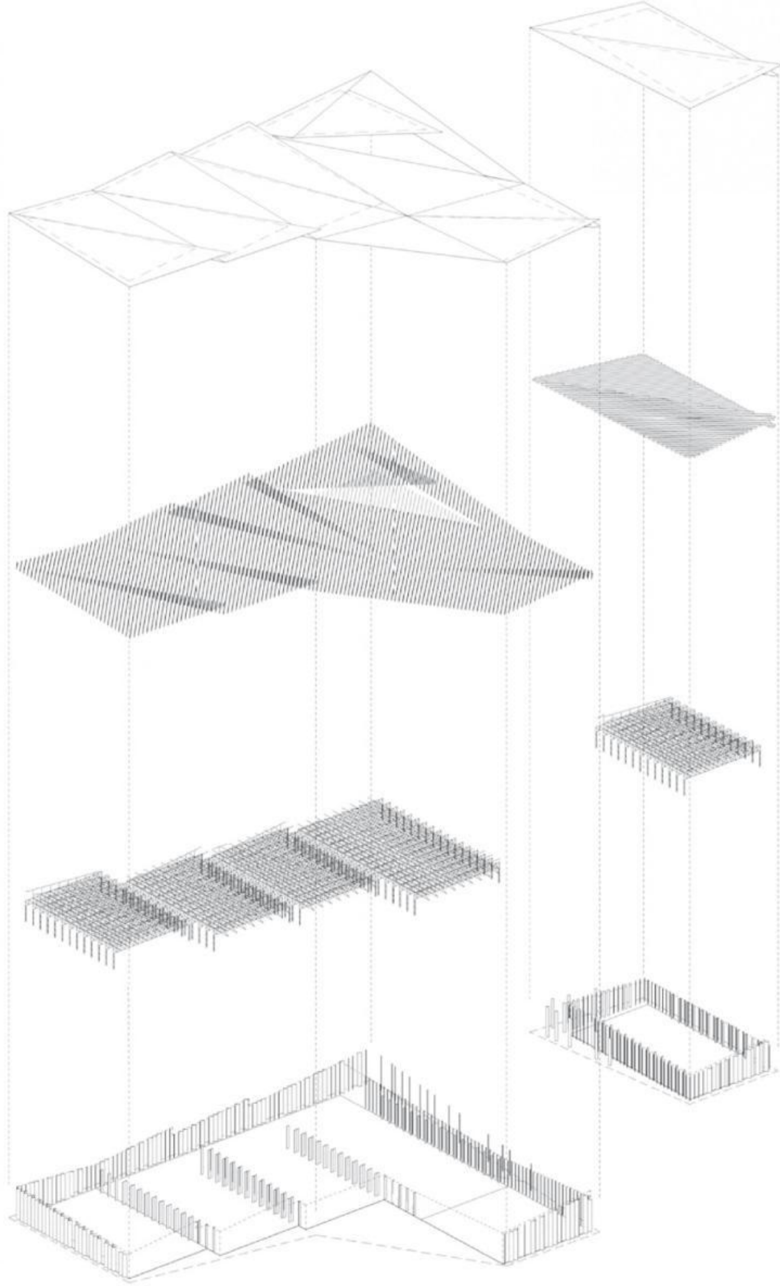


Figure 151: Exhibition Center of Strasbourg, Kuma and Associates, 2018 (arquitecturaviva, 2021)

Figure 152: Japan National Olympic Stadium, Kuma, 2016-2019 (Lynch, 2016)

Figure 153: Japan National Olympic Stadium, Kuma, 2016-2019 (Lynch, 2016)

Technological precedents (continued…)

Wimbledon Centre Court, Populous Architects, 2015

Retractable roofs have become common features in architecture. However, at larger spans like those needed to house sporting facilities, they become more challenging. The Wimbledon centre court employs a retractable roof that operates similar to a stacking door or concertina. The roofing material (translucent Tenara fabric), held by large steel trusses, stacks away to open up the space above the tennis court (McManus et. al, 2021). However, in order to reduce the amount of structure that is needed to achieve this, the retractable roof in my scheme is broken into segments; each segment running on its own set of tracks, which is fixed to the steel trusses that run across the swimming pool. This breaks up the heavy weight of the retractable members, requiring less structure and creating a better aesthetic.

Figure 154: Open view of the Wimbledon Centre Court (McManus et. al, 2021)

Figure 155: Closed view of the Wimbledon Centre Court (McManus et. al, 2021)

The need for sustainability

Relating to the first portion of the original research question of identifying how current sports architecture is failing the athletes who use it, the maintainability of sports venues proves to be a key factor. Bad design and difficult maintenance on a building detract from its sustainability, making it impossible for the sports venue to serve future generations of athletes. Waterproofing issues along with damp internal spaces with restricted ventilation prove to be large contributing factors to dilapidating swimming pool facilities, as seen in the images below (figure 156). However, moving beyond mere maintenance, international sporting organisations like the International Olympic Committee (IOC) insist that its sporting venues are designed with strict environmental sensitivity in mind (Sheard: 2001, 60-67) (figure 157).

Issues that are promoted by the IOC include: environmentally friendly construction materials such as locally sourced bricks with low embodied energy, efficient energy usage and waste management, minimising building maintenance and designing contextually sensitive buildings that are responsibly inserted into existing urban structures with the aim of improving and uplifting these structures (Twardowski: 2018, 54).

Sustainable design strongly promotes *self-sustaining* architectural principles. These include energy generation or saving measures and water harvesting (Twardowski: 2018, p.67). Self-sustaining buildings could be a potential solution to the lack of sporting facilities in South Africa - as can be seen in competitive swimming where existing facilities quickly become run-down and uninhabitable due to improper management and neglected maintenance (Imray: 2012).

Figure 156: Waterproofing issues in the existing building (Author, 2021)

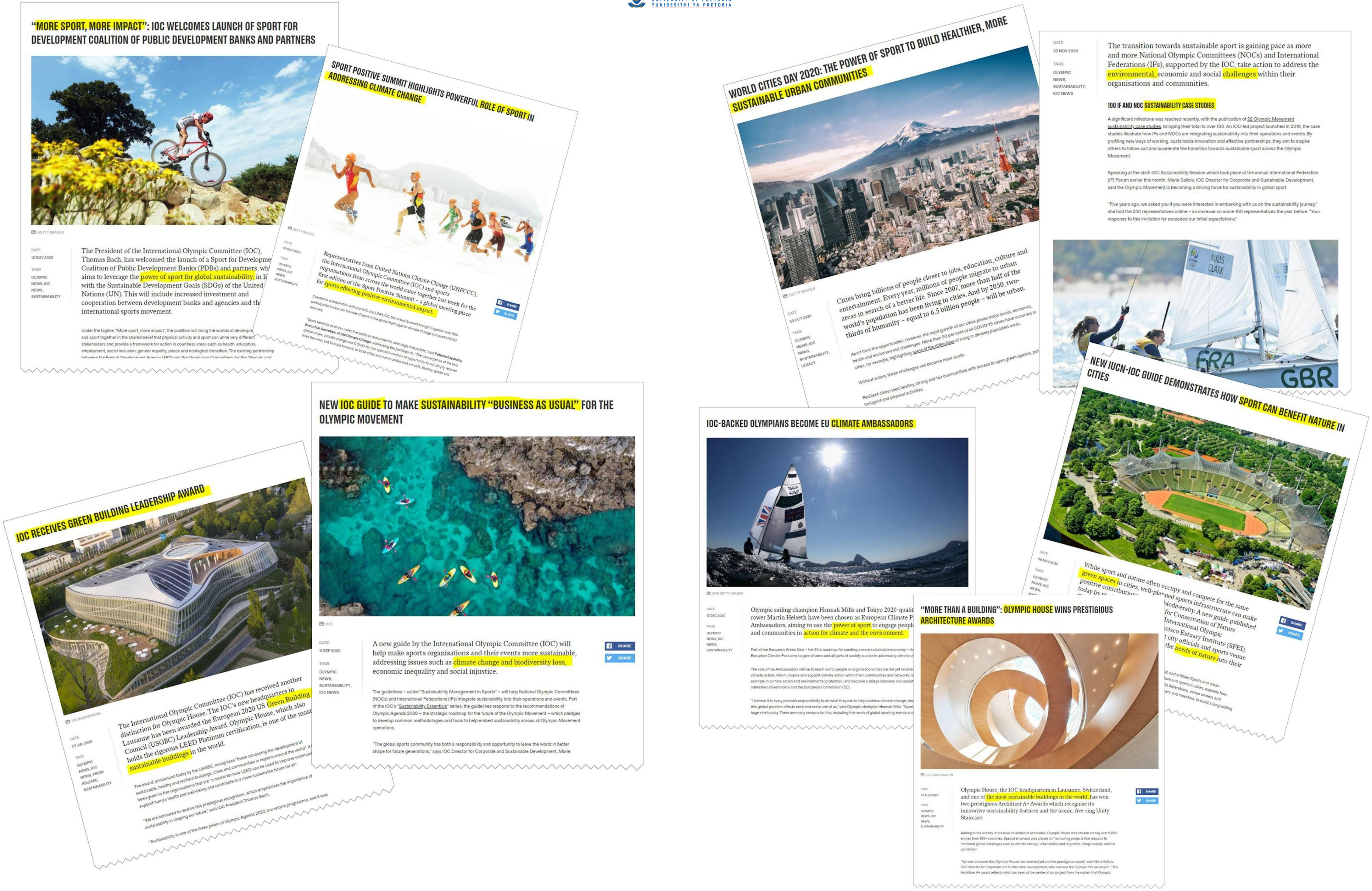


Figure 157: Articles by the IOC regarding sustainability (Adapted from IOC, 2021)

Rainwater harvesting

Making use of the extremely large surface area of the swimming arena's roof, rainwater is harvested. Rainwater collected from the roof surface, along with stormwater from the adjacent parking lot and pavements surrounding the facility are carried by stormwater channels down the natural slope of the land and towards the natural filtration channels. The filtration channel acts as a detention pond for both rainwater and filtered water from the neighbouring Uitspan dam. A pump is used to transport collected water to the ablutions and showers used by the athletes and public. This mitigates the running costs of the facility for the University. Furthermore, the water from the dam is filtered through a two-stage natural filtration process. This filtered water is used to fill up both the open water training channel as well as the 25m public recreational swimming pool, further minimizing maintenance costs for the university (figures 158-163).

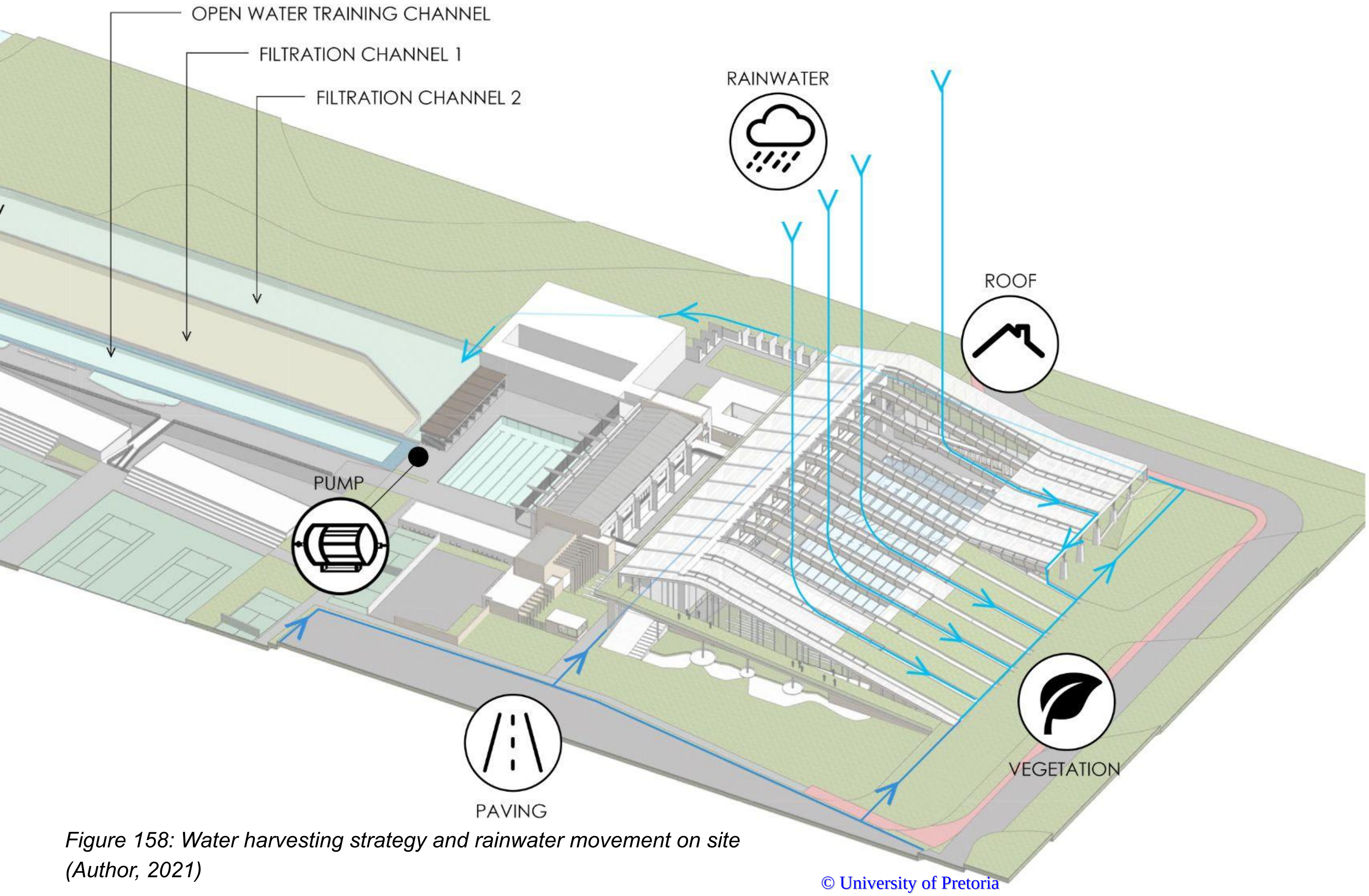


Figure 158: Water harvesting strategy and rainwater movement on site (Author, 2021)

AREA CALCULATIONS

Catchment	Area, A (m^2)	Runoff Coefficient,	
Lawn, sandy	3400	0.08	0.01
Roof	6100	0.9	0.30
Paving	7000	0.8	0.30
Veld Grass	0	0.3	0.00
Gravel	0	0.5	0.00
Slope lawn, 25%	1200	0.2	0.01
Cultivated vegetition	740	0.5	0.02
TOTAL	**18440**	3.28	**0.65**

RAINWATER YIELD CALCULATION

Month	Ave. rainfall, P (m)	Yield (m^3) (Yield = PxAxC)
January	0.154	**1843.688**
February	0.075	**897.9**
March	0.082	**981.704**
April	0.051	**610.572**
May	0.013	**155.636**
June	0.007	**83.804**
July	0.003	**35.916**
August	0.006	**71.832**
September	0.022	**263.384**
October	0.071	**850.012**
November	0.098	**1173.256**
December	0.15	**1795.8**
ANNUAL AVE.	**0.674**	**8763.504**

TOTAL YIELD

Month	Total Yield (m^3/month)
January	**1843.688**
February	**897.9**
March	**981.704**
April	**610.572**
May	**155.636**
June	**83.804**
July	**35.916**
August	**71.832**
September	**263.384**
October	**850.012**
November	**1173.256**
December	**1795.8**
ANNUAL TOTAL	**8763.504**

Figure 159: Calculating rainwater yield (Author, 2021)

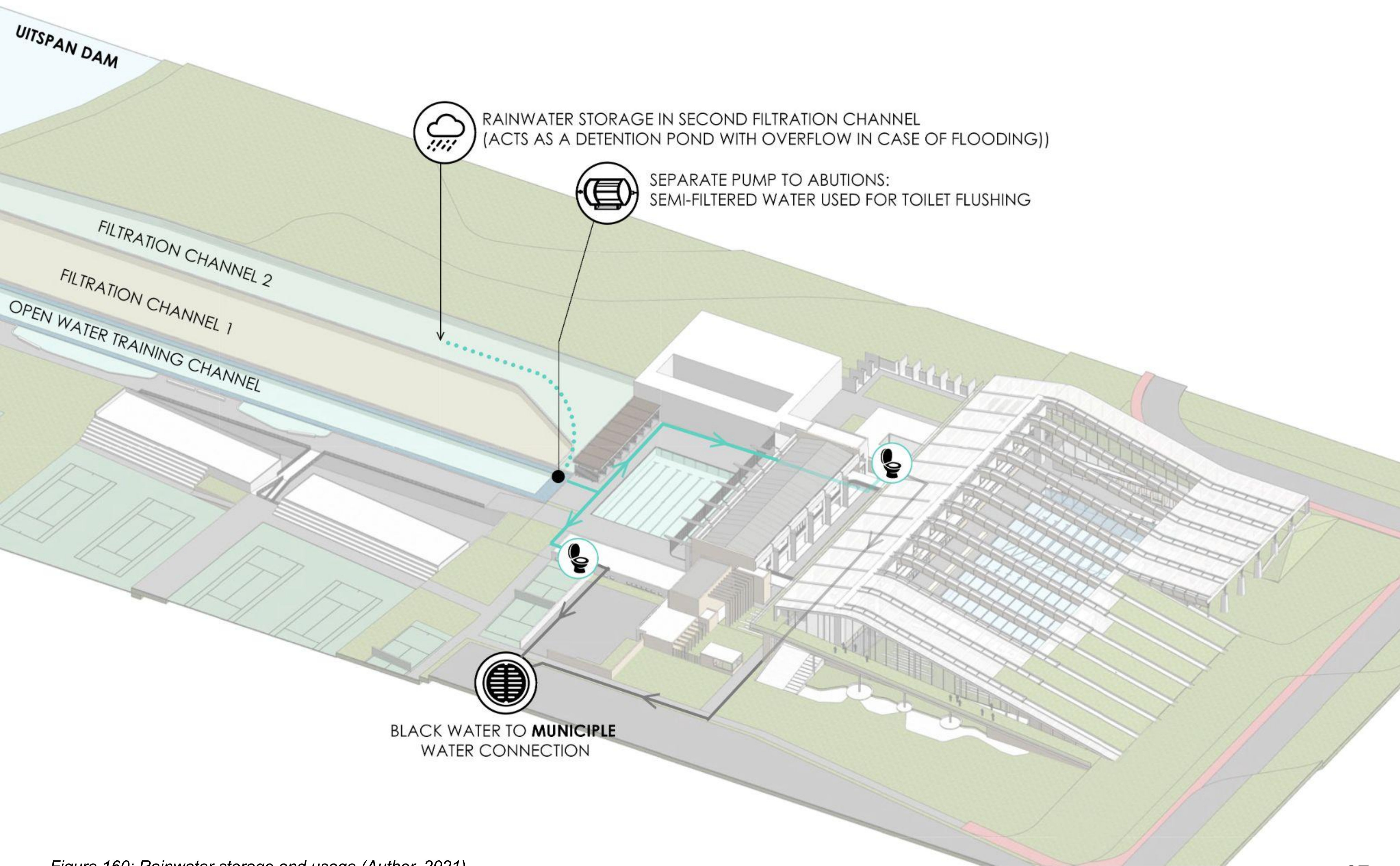


Figure 160: Rainwater storage and usage (Author, 2021)

IRRIGATION DEMAND

Month	Planting area (m^2)	Irr. depth / week (m)	Irr. depth / month (m)	Irrigation demand (m^3/month)
January	1940	0.05	0.2	388
February	1940	0.05	0.2	388
March	1940	0.05	0.2	388
April	1940	0.04	0.15	291
May	1940	0.03	0.1	194
June	1940	0.03	0.1	194
July	1940	0.03	0.1	194
August	1940	0.03	0.15	291
September	1940	0.03	0.1	194
October	1940	0.05	0.2	388
November	1940	0.05	0.2	388
December	1940	0.05	0.2	388
			ANNUAL TOTAL	3686

ALT DEMAND

Month	Entity (Persons ?)	Entity demand / day (l)	Alt demand (m^3/month)
January	500	15	232.5
February	500	15	210
March	500	15	232.5
April	500	15	225
May	400	15	186
June	400	15	180
July	400	15	186
August	400	15	186
September	500	15	225
October	500	15	232.5
November	500	15	225
December	300	15	139.5
		ANNUAL TOTAL	2460

TOTAL DEMAND

Month	Total demand (m^3/month)
January	620.5
February	598.0
March	620.5
April	516.0
May	380.0
June	374.0
July	380.0
August	477.0
September	419.0
October	620.5
November	613.0
December	527.5
ANNUAL TOTAL	6146.0

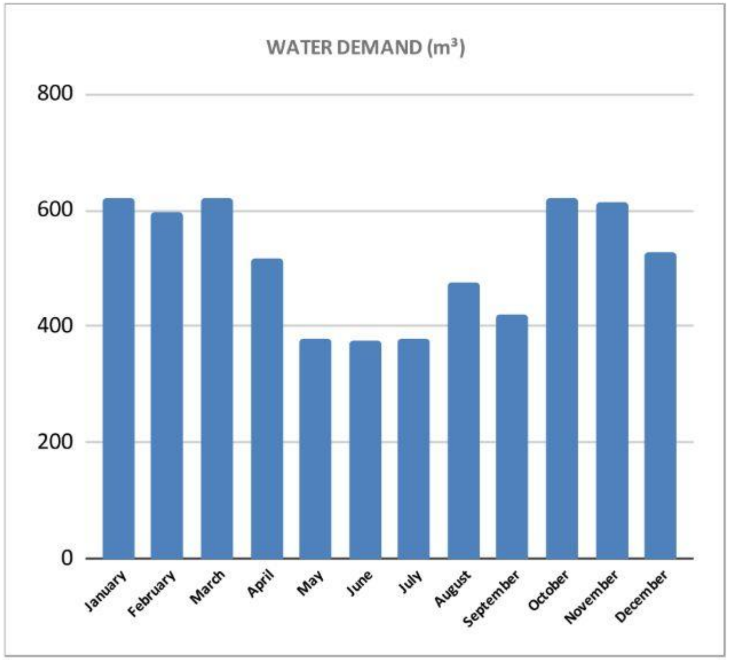


Figure 161: Water demand calculations (Author, 2021)

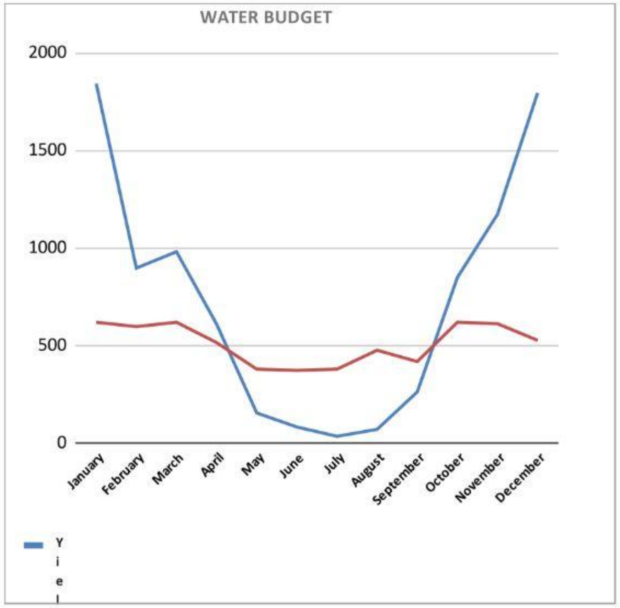
WATER BUDGET

Month	Yield (m³)	Demand (m³)	Monthly balance
January	1,843.7	620.5	**1,223.2**
February	897.9	598.0	**299.9**
March	981.7	620.5	**361.2**
April	610.6	516.0	**94.6**
May	155.6	380.0	**-224.4**
June	83.8	374.0	**-290.2**
July	35.9	380.0	**-344.1**
August	71.8	477.0	**-405.2**
September	263.4	419.0	**-155.6**
October	850.0	620.5	**229.5**
November	1,173.3	613.0	**560.3**
December	1,795.8	527.5	**1,268.3**
ANNUAL AVE.	8,763.5	6,146.0	2,617.5

WATER BUDGET (ACCUMALATIVE)

Month	Yield (m³)	Demand (m³)	Monthly balance	Vol. added water in reservoir (m³)
January	1,843.7	620.5	1,223.2	3,051.70
February	897.9	598.0	299.9	3,351.60
March	981.7	620.5	361.2	3,712.80
April	610.6	516.0	94.6	3,807.40
May	155.6	380.0	-224.4	3,583.10
June	83.8	374.0	-290.2	3,292.90
July	35.9	380.0	-344.1	2,948.80
August	71.8	477.0	-405.2	2,543.60
September	263.4	419.0	-155.6	2,388
October	850.0	620.5	229.5	2,617.50
November	1,173.3	613.0	560.3	560.3
December	1,795.8	527.5	1,268.3	1,828.60
ANNUAL AVE.	8,763.5	6,146.0	2,617.5	

	AREA (m2)	**REQUIRED AREA** FOR FILTRATION POND (m2)
25m SWIMMING POOL	500	1000
OPEN WATER TRAINING CHANNEL	2300	4600
	TOTAL	5600
REMAINING BALANCE OF HARVESTED RAINWATER		3800
TOTAL SURFACE AREA OF FILTRATION CHANNEL NEEDED		9400



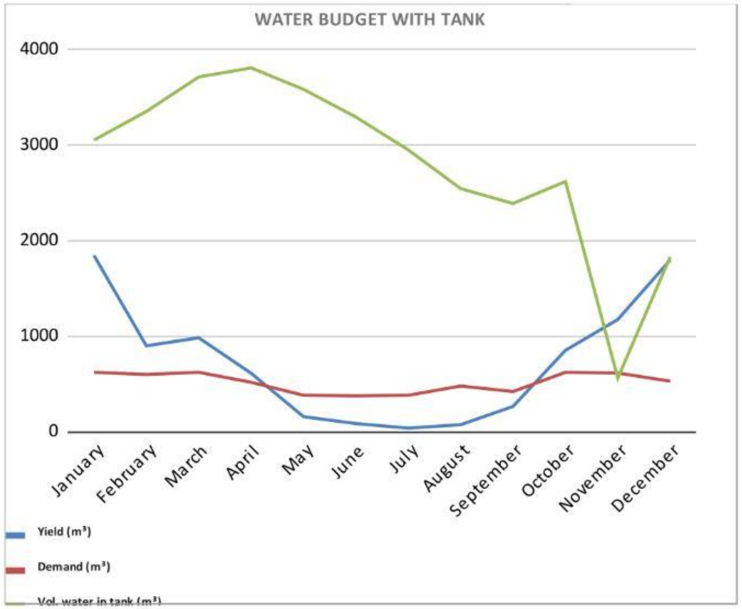


Figure 162: Water budget calculations (Author, 2021)

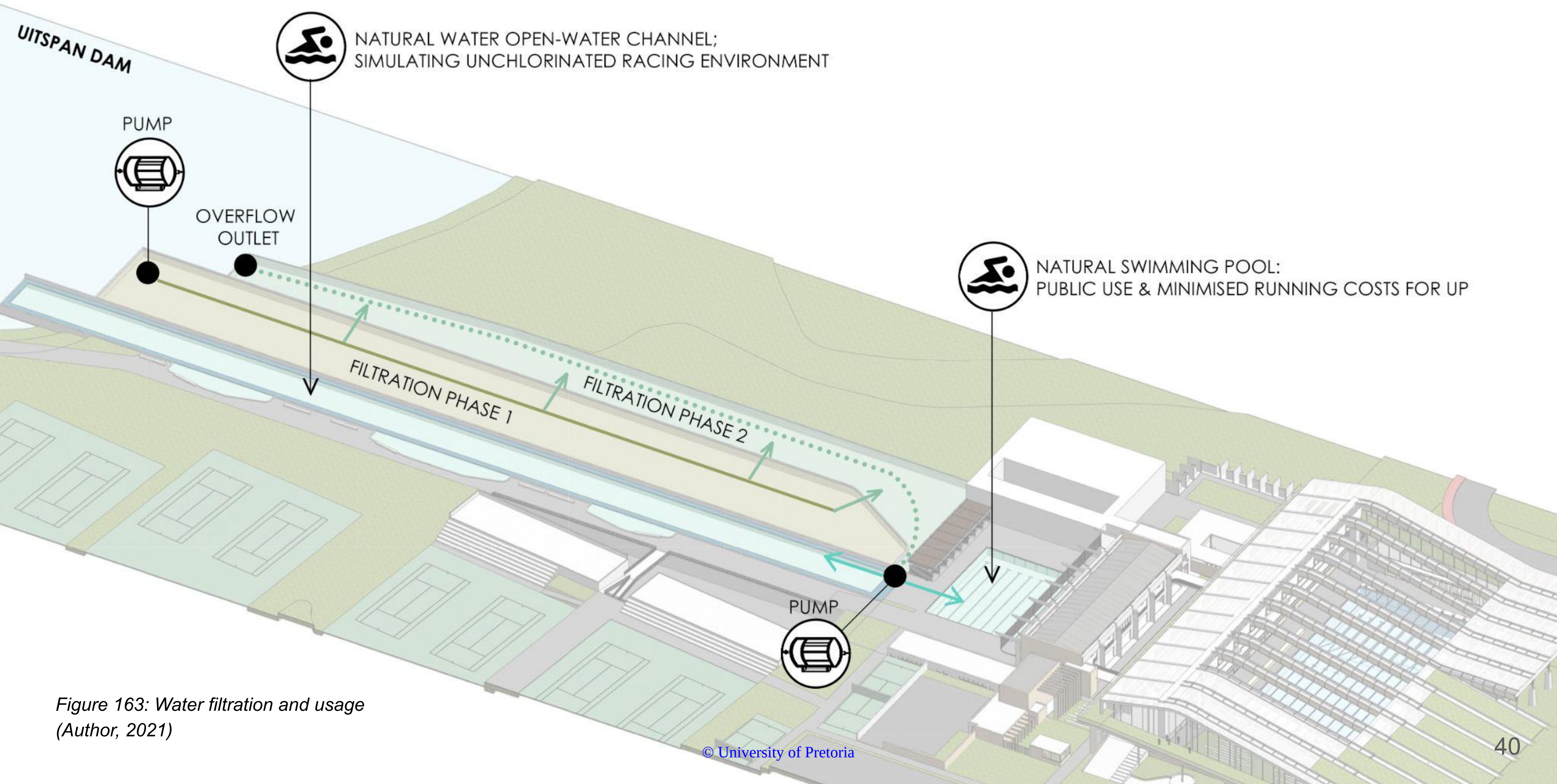


Figure 163: Water filtration and usage (Author, 2021)

Geothermal heating and cooling

Keeping indoor temperatures at a comfortable level is an important factor when considering athletic performance enhancement. Too cold or overly warm environments can detract from athletic performance (figure.164).

An asset of the campus is its large amount of natural open space (figure 165). This open space can be utilised for geothermal heating and cooling strategies. Due to the significant heat build-up by large groups of spectators during sporting events, paired with the humidity of indoor swimming pool facilities, low energy heating and cooling strategies becomes a key feature of the technological resolution of the design.

Figure 164: The effects of poorly heated or cooled spaces for athletes (Author, 2021)

Figure 165: The large amount of natural open space on the UP sports campus (Caldecott, 2019)

Geothermal heating and cooling (continued…)

In the summer, warm air is sucked in by the inlet turbine, where it travels through pipes that coil 2m beneath the natural ground level. The consistent cool temperature of the soil cools the air in the pipes. This cooled air is released into the building at ground level. As this cooled air becomes warmer it rises until, along with heat generated by large crowds in the spectator stands, it is able to escape through the outlet turbine at the highest point of the building (figure 166).

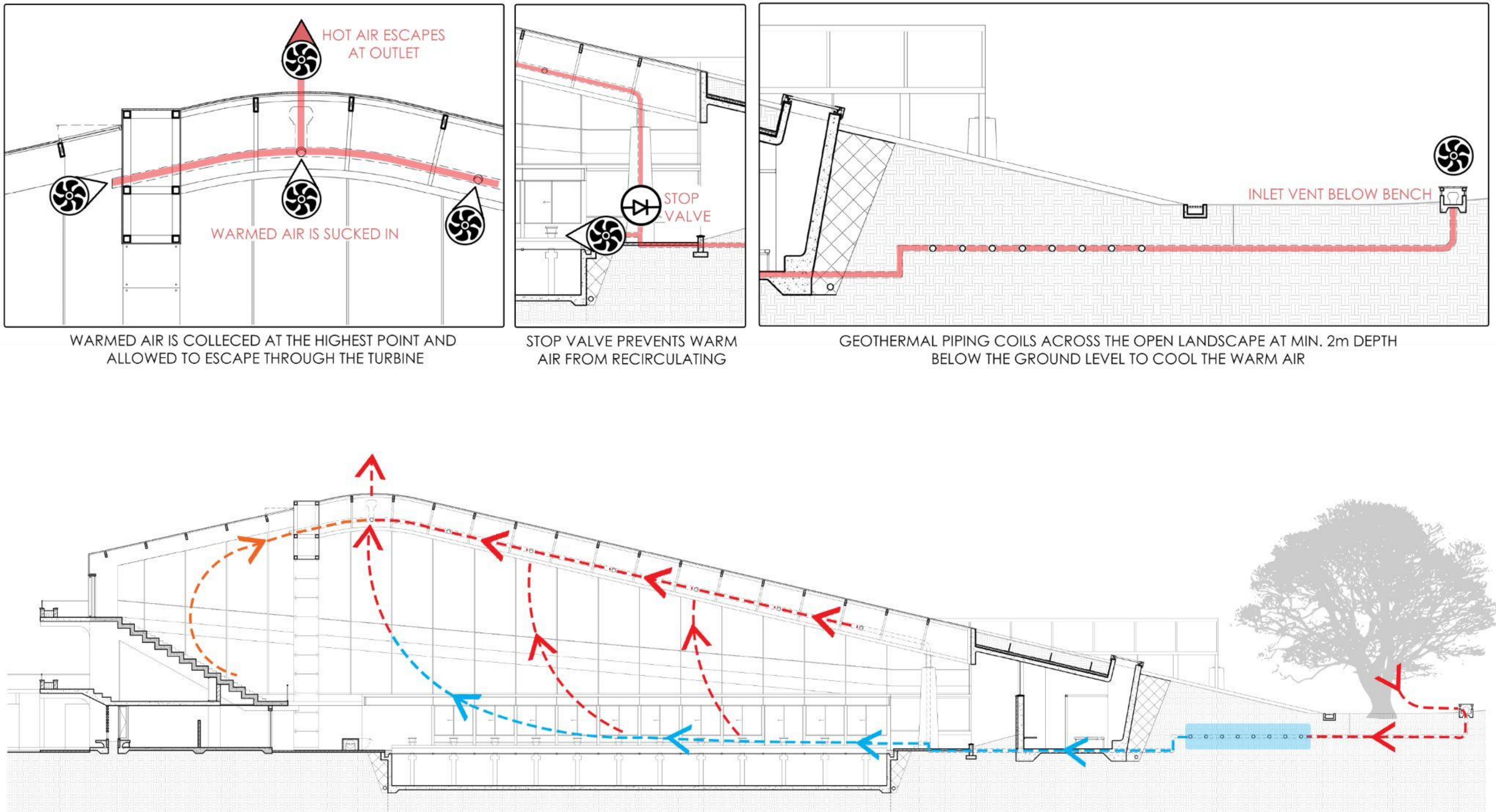


Figure 166: Cooling strategy during the summer months (Author, 2021)

In the winter time, cool outside air is sucked in through the inlet turbine, this time heated by the warmer temperatures of the soil. The warmed air is released into the arena where it rises and is sucked into the ventilation pipes that are stored within the roof trusses. A stop valve prevents the warm air from escaping the building, as desired, allowing it to be recirculated to keep the interior at a more comfortable temperature (figure 167). The turbines and stop valves are to be controlled electronically.

Due to the strict guidelines for water temperatures by aquatic sporting authorities, where water needs to remain at a constant temperature, solar heating strategies that fluctuate during overcast or rainy days would not prove effective. Instead, the existing electrical heating system is maintained. However, due to the swimming pool now being housed indoors, the heat loss that is experienced during colder months becomes significantly less, reducing the load required to keep the pool at the required temperature.

Conclusion

The technical resolution of the design remains highly important to the outcome of the final product and its performance enhancing impact on the athlete. If the technical resolution remains generic and standard, sports venue designers run the risk of compromising on the experiential quality of a space. Spaces that are too generic and standardised become purely functional. However, by detailing the construction in unique ways and over a scale of interventions as seen in four the structural languages that were discussed above, the design intervention is granted a richness of changing experiences that could contribute to an athlete's performance. These experiences, along with sustainable design features such as water harvesting and filtration systems and energy-saving geothermal heating and cooling strategies, allow the sports facility to better serve the athletes who use it at present and for years to come.

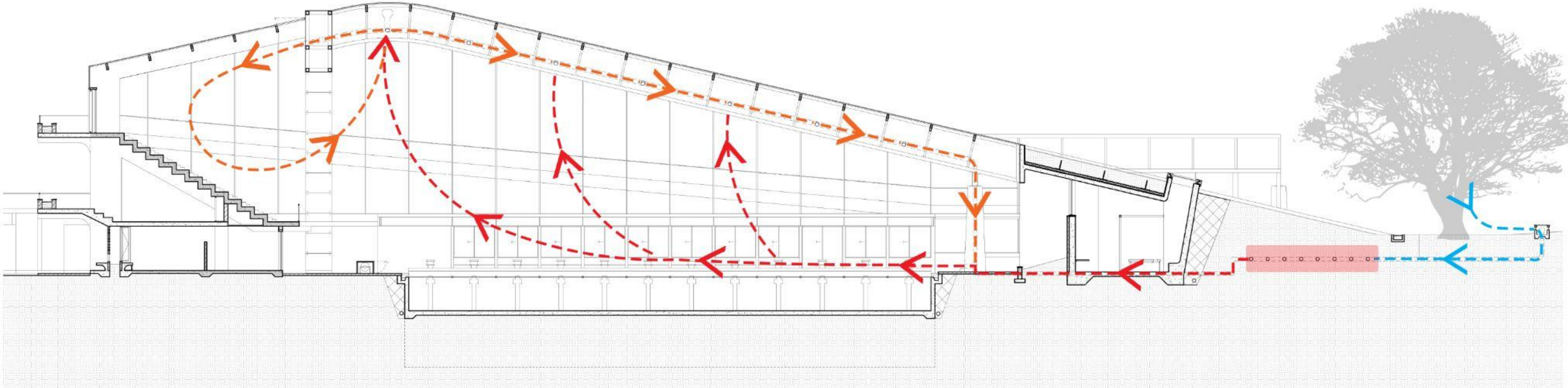


Figure 167: Heating strategy during the winter months (Author, 2021)

The final product

The following pages contain the final product of the design with its technological integration (figures 168-195). The following images take the format of the final exam poster layout.

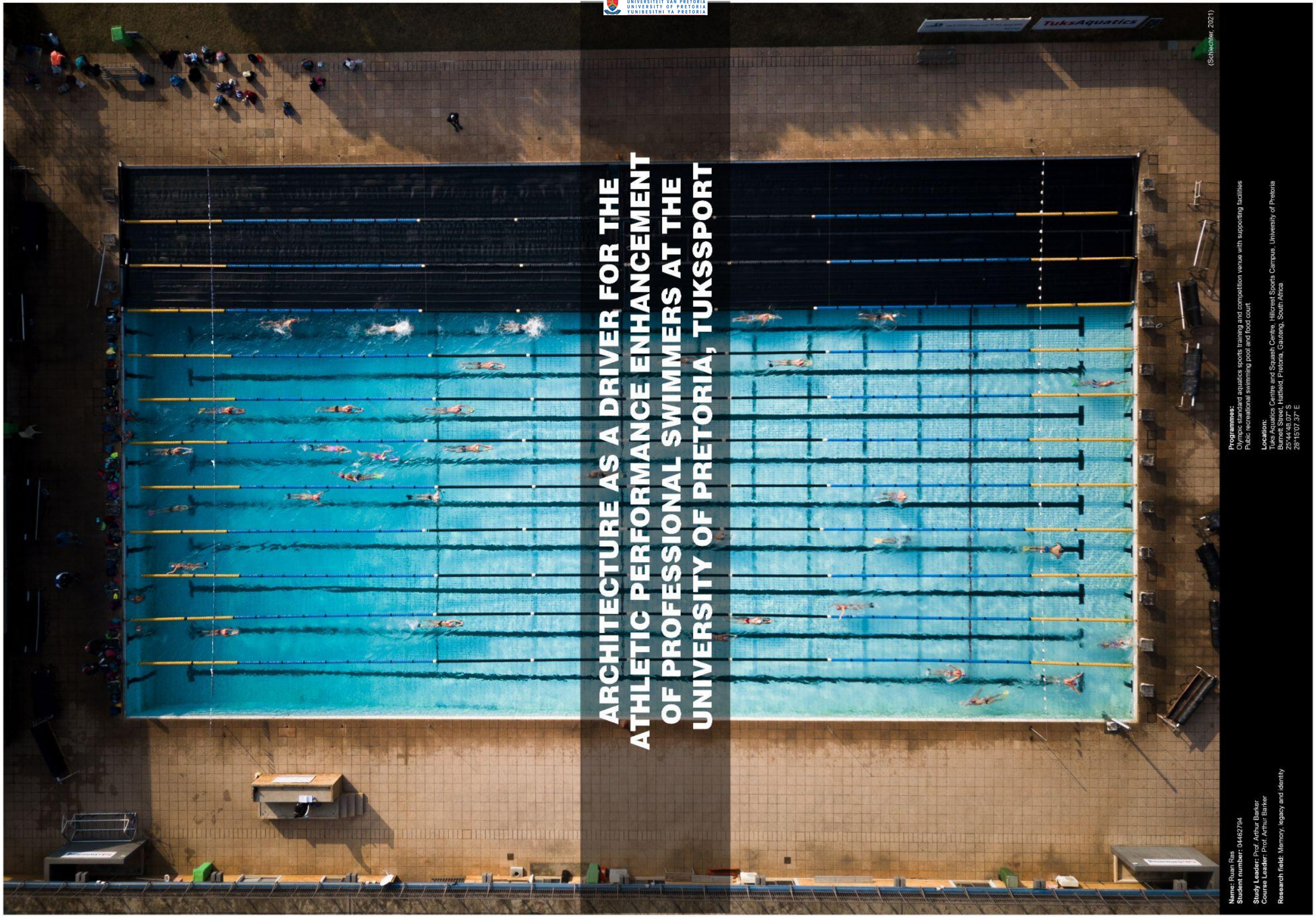
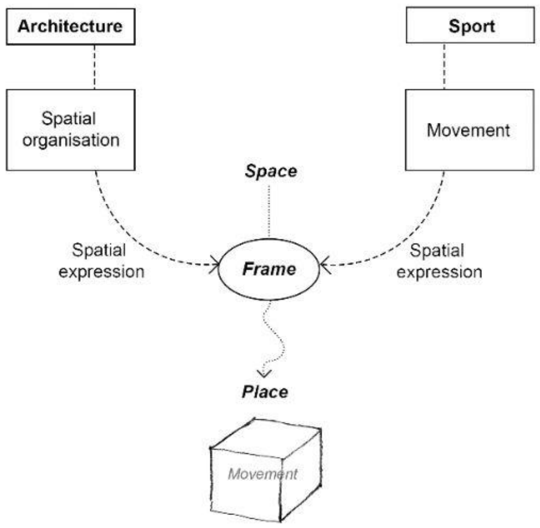


Figure 168: Title page (Author, 2021)

1 THEORY

PROJECT DEVELOPMENT

"Sport is a kind of architecture on the field. It is about movement but still it is about space, about organizing space." - David Winner.



Sports design therefore has an effect not only on the **physical structure** of a facility, but also on the **performance of the athletes** using it - the frame impacts the performance.

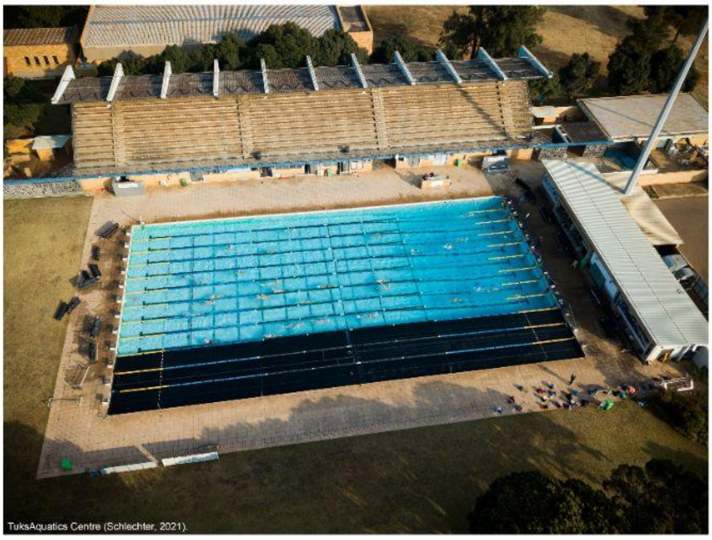
The **frame** describes the physical layout and structure of the playing field.

The **performance** speaks of the actual movements and actions of users in the space

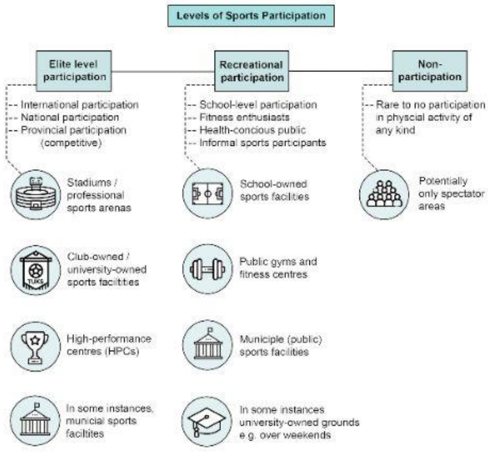
RESEARCH QUESTIONS AND OBJECTIVES

Through this research I aim to identify **spatial** and **functional** drivers that aid in physically and psychologically enhancing athletic performance by determining a prototype for professional-athlete-centred sports architecture in the **local** context, specifically related to competitive swimmers in TuksSport.

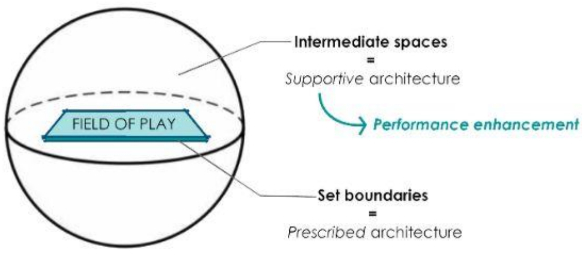
This poses the questions:
1. How is **current sports architecture**, for professional athletes specifically, failing the athletes who use it?
2. How can the design of sports architecture be improved to benefit and **enhance the performance** of the professional athletes it serves?



TuksAquatics Centre (Schlechter, 2021).



Sports architecture typologies are formed around well-defined 'boundaries'. These boundaries regulate how the sport is played (Cleary, 2017). Regulation authorities and sporting associations typically set standards and requirements for the design of facilities in each specific sporting code. This gives architects a relatively good reference when designing sports facilities. However, there are few building typologies or standards that regulate the optimum training or competition environments outside of the physical dimensions of the field of play; for example, the **intermediate spaces** that athletes interact with on the lead-up to their race or match, like the marshalling room where athletes report before their race.



Most sporting histories follow the general trend of the **transformation of informality and improvisation into standardisation** and specificity (Cleary, 2017). However, modern sport requires much more standardised settings (Figure 10). Most physical court or field dimensions became fully standardised in the 1920s (Cleary, 2017). Various sporting authorities emerged as a result of the need to govern this standardisation and fair practice in sport.

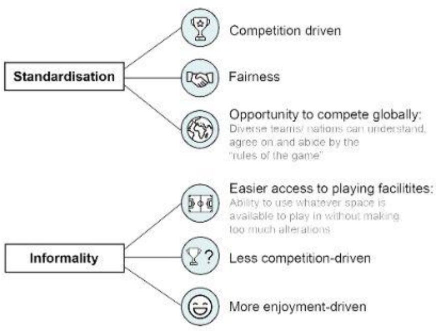
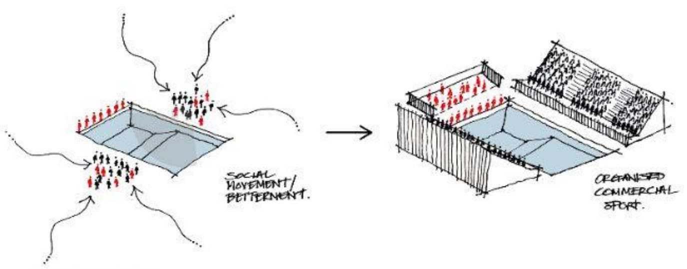
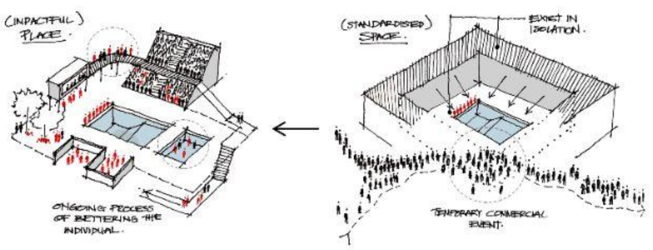


Figure :169: Theory (Author, 2021)

GENERAL ISSUE



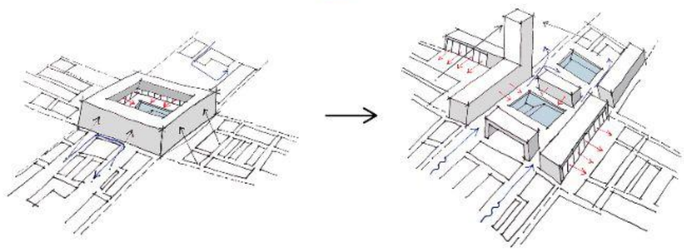
Sports architecture, through standardisation and the intense control held by sports authorities over the past century, **has experienced a change in identity**: from a tool for social movements to a shell for commercial institutions (Payandi: 2013, 5-6).



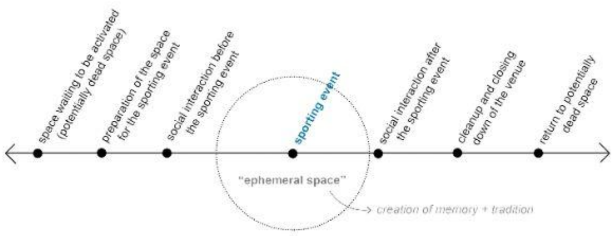
The commercialisation of sport has resulted in sport as an industry (and as a result, its architecture) having the main objective of economic gain - as opposed to the initial goal of **sport to "better the individual"** (Tao: 2017, 314).

URBAN ISSUE

Contemporary sports architecture, also through the process of standardisation, has evolved into a unified "international-style" of sports venue design (Payandi: 2013, 6-7). **This disconnect from context** and global approach to design, has resulted in sports architecture becoming **disintegrated from its urban environment** and from the people who live, work, **train** and play there.



Over the past century, notions of nationalism, militarism and totalitarianism have **skewed the role of sports architecture in the city: sports architecture as monument**. Fortunately, current sports architecture has started to move away from this idea of monumentalisation and started to look to sports architecture as **modern cathedrals** in the city: places for "mass-pilgrimage" (Payandi: 2013, 27-28).



(Author, 2021)

Locally, these issues of **monumental sports architecture that are disintegrated from their urban environments** can be seen in the stadiums constructed for the 2010 World Cup. The world-class stadiums remain heavily underused due to their design's lack of effective urban integration (Imray: 2012). The design, therefore, needs to respond to the **periodicity of sports events.**

More relative to the target sporting-code of this mini-dissertation, **rapidly decaying local swimming training and competitions facilities** has become widely evident in developing countries, including South Africa. With no users and activity, even the memory of place is eventually lost.

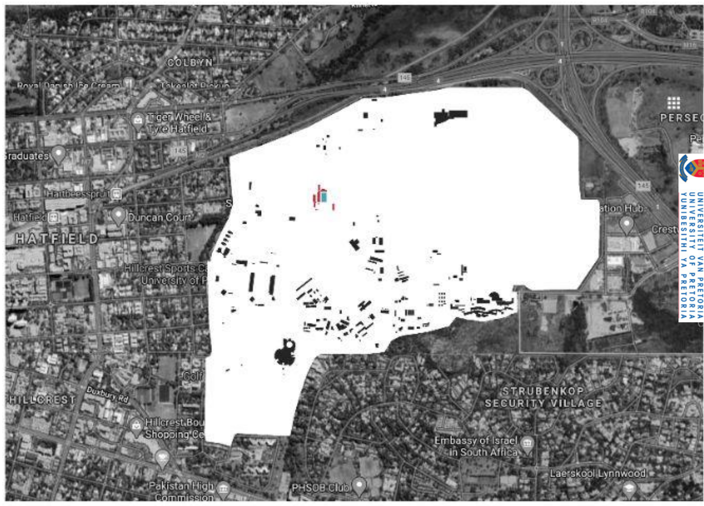
2 SITE

U.P. HILLCREST SPORTS CAMPUS

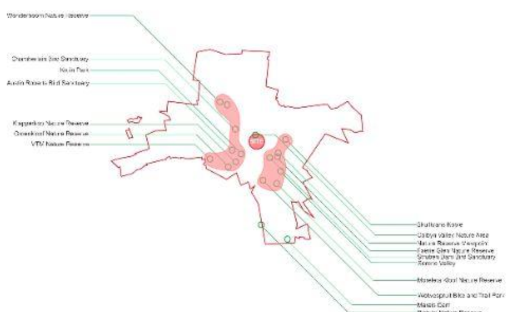
SITE:
TuksAquatics Centre on the University of Pretoria Hillcrest Sports Campus

CLIENT:
TuksSport - Director: Steven Ball
TuksAquatics - Head coach: Rocco Meiring

The buildings on campus employ varying methods of construction, materiality, architectural style and form. Current notions of sports architecture are expressed as urban [campus] icons - expressing an identity of place in the city (Payandi: 2013, 47). Similarly, the variety of architecture found here expresses various identities of place scattered across the campus.



The Hillcrest campus currently boasts highly natural, open-air and relief-inducing settings. Entering through the 2 main entrances, one can immediately notice a change in structural density. Few buildings seem to dominate the landscape - even large monumental buildings such as the sports centre's scale are mitigated by the vast water bodies and open fields surrounding the building. Thus, the campus is identified as a "pocket of relief" in the city.



NAME: RUAN RAS
STUDENT No.: 04462794

Figure 170: SIte information (Author, 2021)

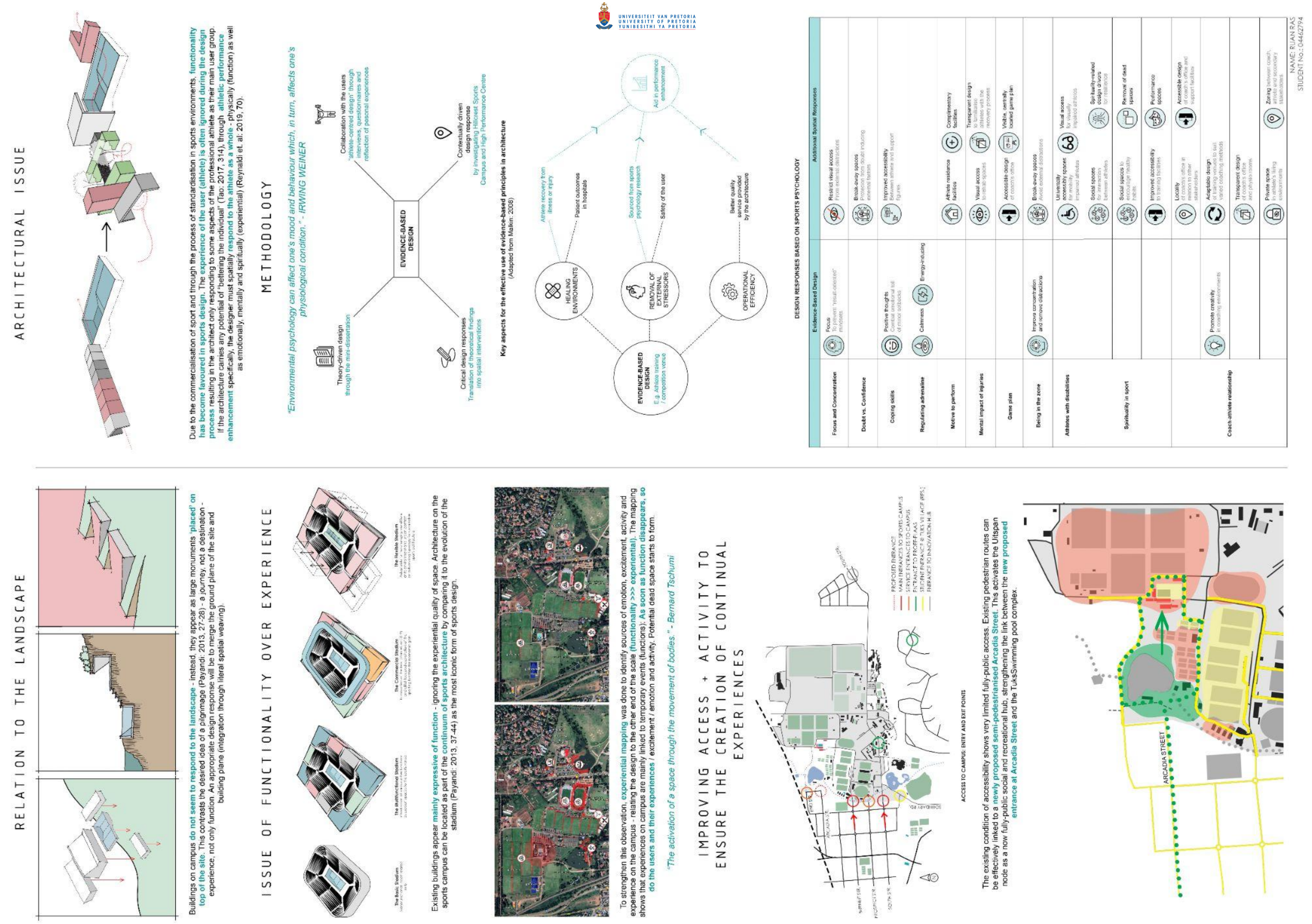
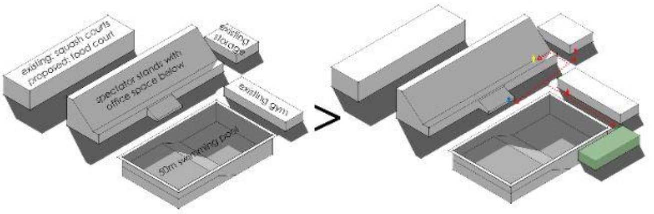


Figure 171: Site information and Architectural issue (Author, 2021)

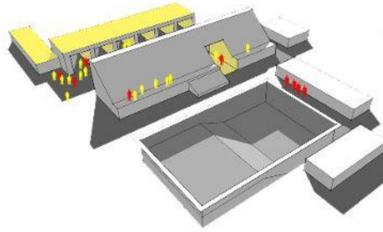
3 DEVELOPMENT

SPATIALLY TRANSLATING E.B.D. PRINCIPLES

ACCESSIBILITY

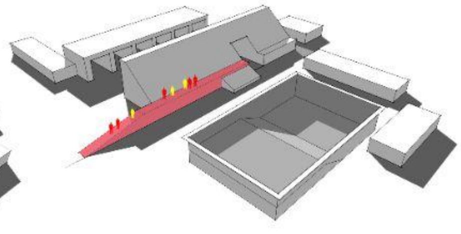


Free movement between athletes and supporting figures



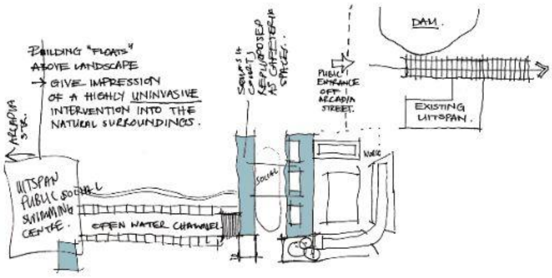
- Additions and alterations to the existing to incorporate public functions

Positive social interaction through public integration

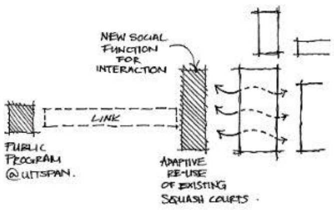


- Ramps for wheelchair accessibility incorporated into the main entrances of the facility.

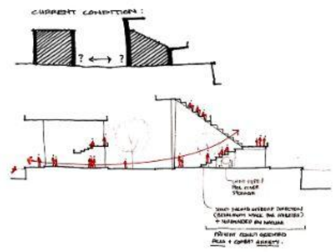
Inclusive design through the addition of ramps



Social core forms buffer between public and private space:
Interaction between athletes and the public (support systems)

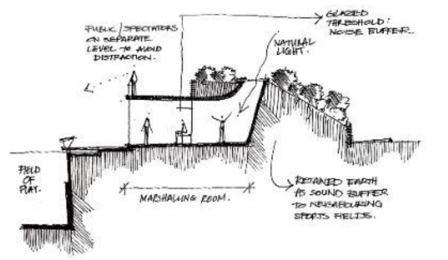


Linking the proposed public node to the site:
Enhancing *continual* social interaction

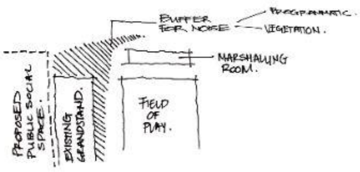


Opening up closed facades and impermeable edges
On a scale from physical to visual access

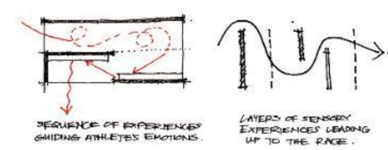
PRE-RACE SPATIAL IMPLICATIONS



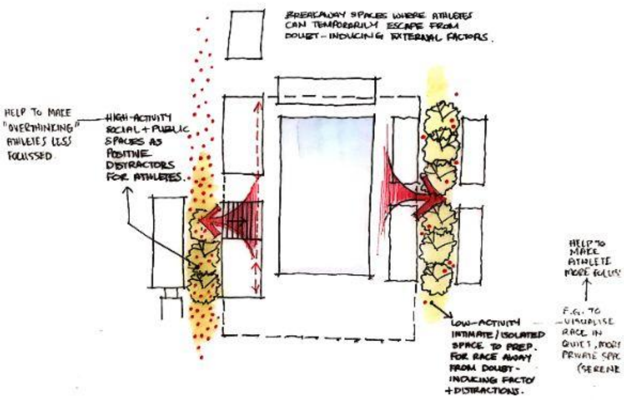
Design to enhance focus pre-race:
Noise reduction to prevent distractions + improved light conditions to reduce drowsiness



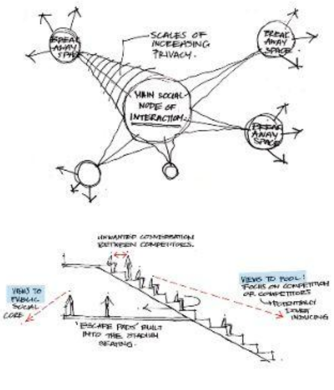
Buffer zones to prevent distractions from spectators:
Especially relevant to over-eager parents



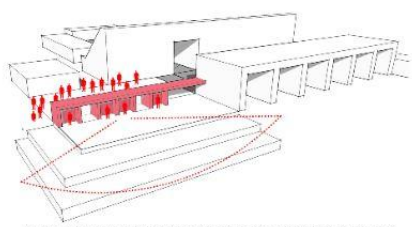
Controlling athletes' movement and views in marshalling rooms:
Prevents early release of adrenaline pre-race



Doubt prevention through breakaway spaces:
In addition, using nature to induce calm and reduce pre-race anxiety

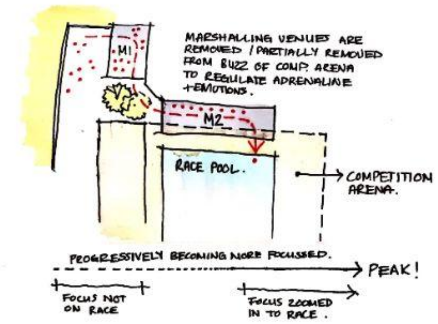


Buffer zones to prevent distractions from spectators:
Especially relevant to over-eager parents

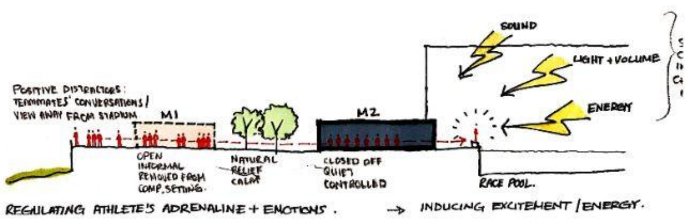


- Intimate private spaces where athletes can mentally prepare for their races away from distractions and interruptions.
- Views overlooking nature and the Uitspan dam to reduce anxiety.

Private nooks where athletes can mentally prepare for races:
Away from distractions and overlooking the Uitspan dam and nature



Progression of spaces to guide athletes' emotions:
From fully removed from the competition arena to directly within it.



Drastic spatial changes to induce adrenaline in athletes :
Shock changes in spatial, sound and light quality to induce emotion and adrenaline directly before a race.

NAME: RUAN RAS
STUDENT No.: 04462794

Figure 172: Design development (Author, 2021)

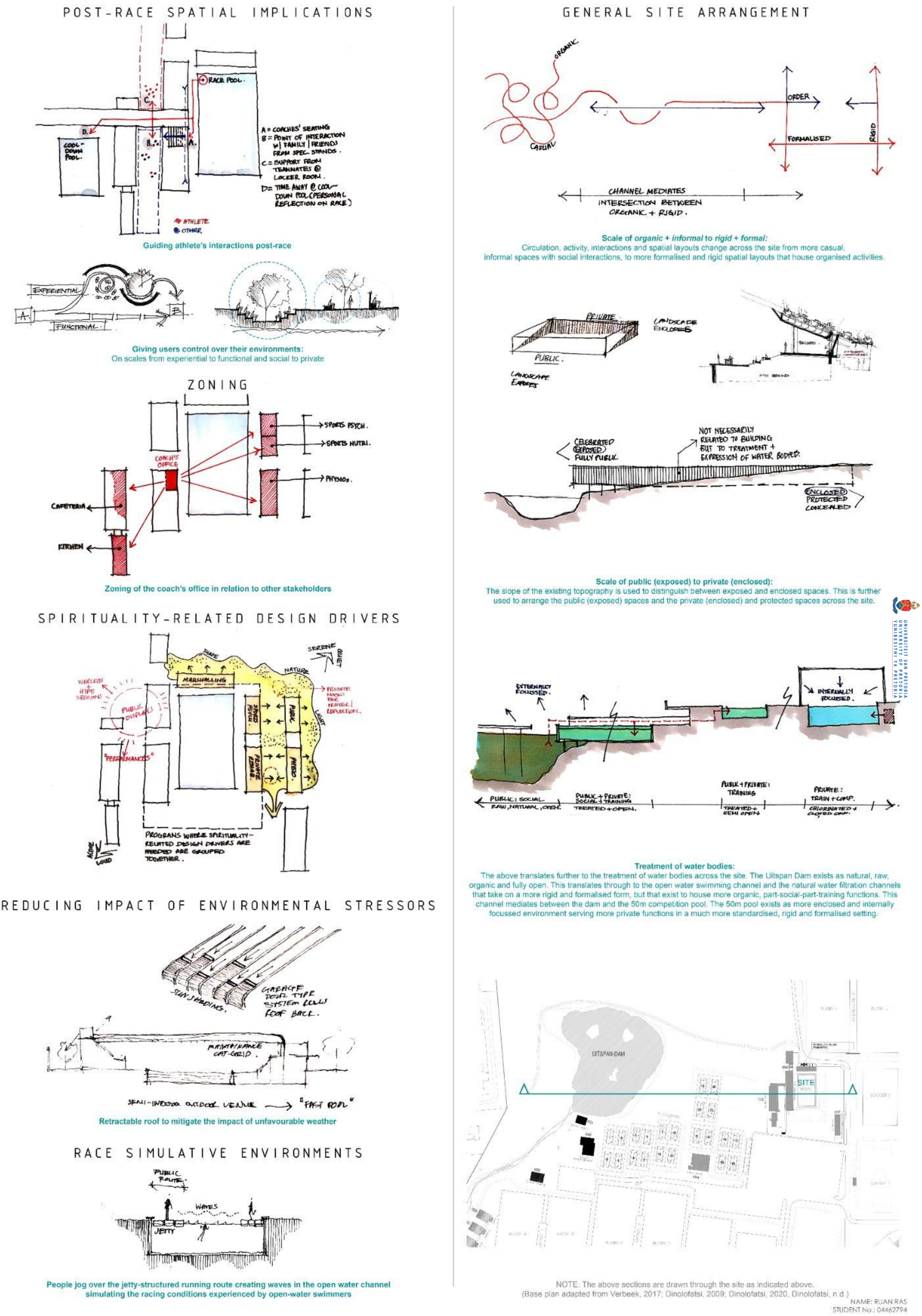


Figure 173: Design development (Author, 2021)

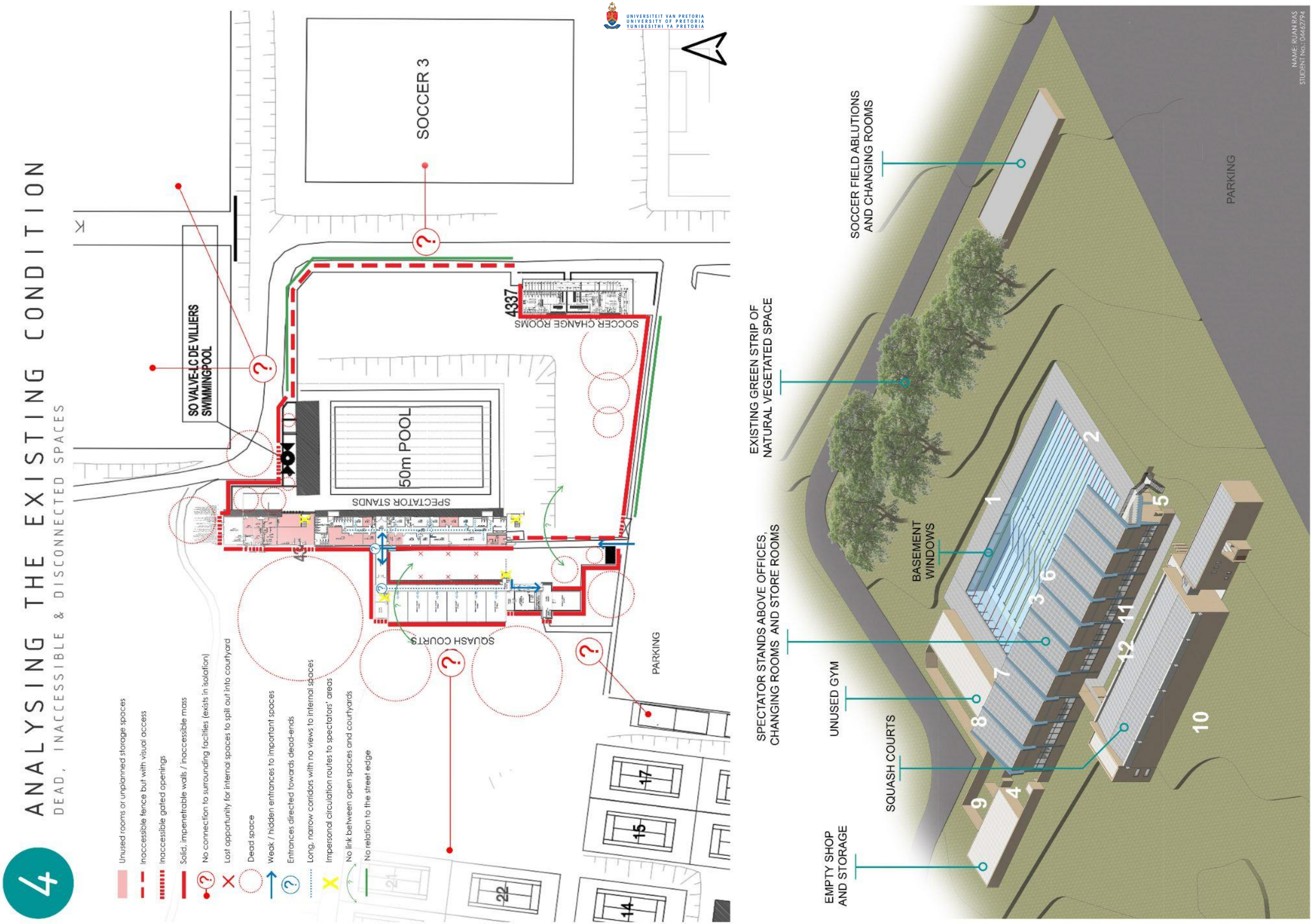


Figure 174: Analysis of the existing (Author, 2021)

5 ANALYSING THE EXISTING

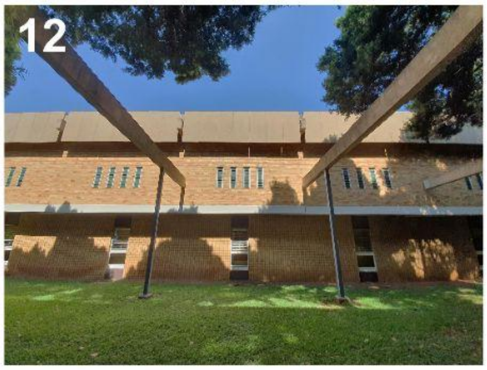
PHOTOS ON SITE SHOWING MATERIALITY & SPATIAL QUALITY

POOLDECK - MONUMENTAL SPECTATOR STANDS AND SURROUNDING GREEN SPACES:

FAILED TUKS-SHOP & MERCHANDISE STORE, UNUSED BRAAI AREA & INACCESSIBLE COACH'S OFFICE:

INFORMAL KIT-BAG STORAGE AND EQUIPMENT STORAGE & DEAD SPACES USED AS DUMPING SITES:

INACCESSIBLE WALLS, UNUSED OPEN LAND AND LACK OF VISIBILITY TO THE FIELDS OF PLAY:



NAME: RUAN RAS
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Figure 175: Analysing the existing (Author, 2021)

6 PRECEDENTS

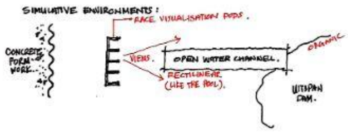
DESIGN PRECEDENTS:

Leça Swimming Pools by Álvaro Siza

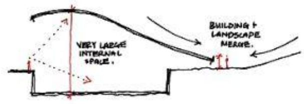

The man-made structure of the pools lie sensitively between and against the natural rock formations, merging the building with its context.


The view from the street edge is retained as passers by look over the new building.


The ramp immerses users into a space with no views, heightening their auditory experience of the ocean.



The building elements mimic those of nature (Author, 2021)

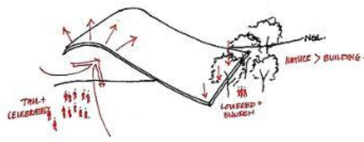


The change in level distinguishes the swimming pool complex from the surrounding urban infrastructure, acting as a more natural element in the landscape as opposed to built structure (Author, 2021)

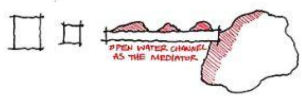

Function is not forgotten amidst all the sensory experiences: seen in the practically designed wet-to-dry transition of the changing rooms.


Sharp changes in direction create climax moments where views to the ocean are exposed.


The building, experienced in full height upon exiting the change rooms.



Calm private moments where nature dominates structure and climax public spaces where structure stands tall and celebrated (Author, 2021)



Linking the man-made and the natural water bodies vacross the site (Author, 2021)

Duna Arena by NAPUR Architects


The steel structure attempts to reflect the movement and undulating light quality of the adjacent river.


Layered facades step down towards the street edge, bringing the large mass to a more human scale.


The facade facing the river edge, how ever, stands tall and proud - acting as a landmark for boats passing by.


Continuity of internal spaces is created linking water elements to one another.


Social spaces for user interaction edges the perimeter of the field of play.

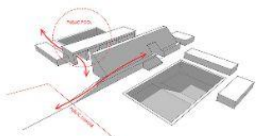

Transparency at ground level attempts to reduce the structural density of the arena and allows visual access to the internal activities.

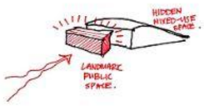
Category	Room name
Swimming training	50m swimming pool
	Open water channel
	Ablutions (wet and dry)
	Changing rooms
	Locker rooms
	Wetbag storage
	Pre session stretching
	Team talks
	Coach's office 1
	Shared coach's office 2 + 3
	Administrator's office
	Gym receptionist's office
	First-aid room
	Security house
	Parking lot
	Emergency pickup point
	Recovery quarters
	Physiotherapy consultation
	Nutritionist consultation
	Sports psych. consultation
	Support facility's reception
	Support facility's waiting area
	Gym
	Athletes' social space
	Athletes' living quarters
	Athletes' cafeteria + kitchen
	Maintenance + equip. storage
	Electrical control room
	On-deck showers
	Staff breakroom
	Auditorium
	Pool covers storage

Category	Room name
Swimming competition	Spectator seating
	Temporary food stands
	Permanent cafe' / snack shop
	Temporary product stands
	Tickets booth
	Additional / separate ablutions
	25m cool down pool
	Podium / performance platform
	Doping control room
	Dryland warmup space
	Media room
	Post-race interview space
	Race-suits changing rooms
	Marshalling venue 1
	Marshalling venue 2
	Officials meeting room
	Coaches' seating
	Starter's platform
	Timekeeper's seating
	Technical officials clear route
	Commentator's room
	Administrator's office
	Storage for comp. equipment
	Results wall

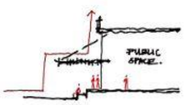
Category	Room name
Public spaces	Food court
	Kitchen
	Service and delivery
	Outdoor braai area
	Indoor braai area
	Events space
	Temporary market space
	Informal play space
	Recreational training pool
	Recreational social pool
	Changing + locker rooms
	Ablutions (wet and dry)
	Lifesaver's bench
	Public jogging / cycling route

Accommodation list for the new TuksAquatics Complex based on precedents of FINA-approved sports facilities as well as personal experiences.

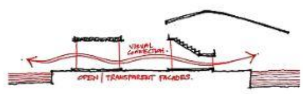

Continued use through public integration (Author, 2021)



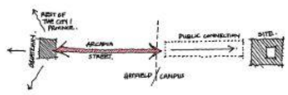
Stepped facades mitigate the building's scale (Author, 2021)



A landmark on the campus vs. a hidden facility (Author, 2021)



Water bodies are linked to one another (Author, 2021)

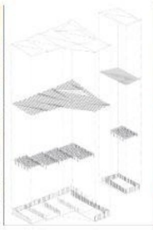


Linking the Gautrain, Arcadia Street and the site to enhance access to the facility and encourage continued use (Author, 2021)

TECHNOLOGICAL PRECEDENTS:

Work by Kengo Kuma


Exhibition Center of Strasbourg, Kuma and Associates, 2018 (arquitecturaviva, 2021)

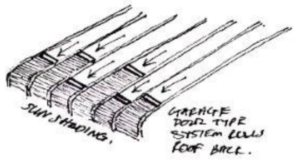



Japan National Olympic Stadium, Kuma, 2016-2019 (Lynch, 2016)

Due to the desired use of timber as a construction material for the roof ("the roof as an extension of the ground plane"), issues of span and material efficiency arose. Kengo Kuma does a lot of work using timber construction, however, for larger buildings, he resorts to hybrid structural systems where timer and steel are used in conjunction with one another. This creates an efficient solution where steel as the primary structure allows for the desired large spans, and timber as the secondary structure improves the general energy efficiency as well as the aesthetic of the roof.

Wimbledon Centre Court by Populous Architects

Retractable roofs have become common features in architecture. However, at larger spans like those needed to house sporting facilities, they become more challenging. The Wimbledon centre court employs a retractable roof that operates similar to a stacking door or concertina. The roofing material (translucent Tenara fabric), held by large steel trusses, stacks away to open up the space above the tennis court . However, in order to reduce the amount of structure that is needed to achieve this, the retractable roof in my scheme is broken into segments; each segment running on its own set of tracks, which is fixed to the steel trusses that run across the swimming pool. This breaks up the heavy weight of the retractable members, requiring less structure and creating a better aesthetic.

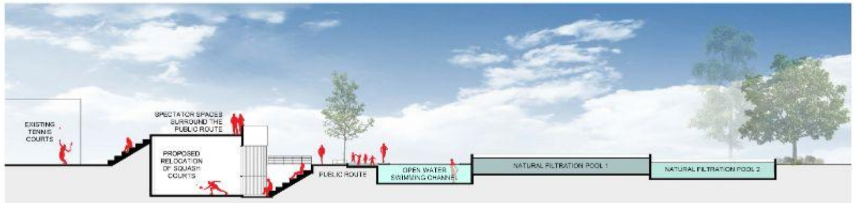


NAME: RUAN RAS
STUDENT No.: 04462794

Figure 176: Precedents (Author, 2021)

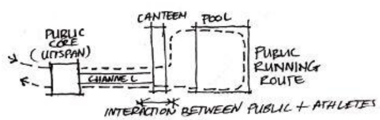
7 SITE PLAN

SCALE 1:500



SECTION D-D: Proposed relocation of the squash courts

Due to the low structural density and high natural quality of the Hillcrest Campus, it is identified as a 'pocket of relief' in the city. To become a public 'pocket of relief' in the city, the design's accessibility becomes vital. However, the existing condition of accessibility shows very limited fully-public access. Therefore, a new public pedestrian entrance is proposed to link the newly semi-pedestrianised Arcadia Street to the campus. This helps to activate the existing Uitspan node as a now fully-public social and recreational hub. Using Arcadia Street as a semi-pedestrian linkage also connects the Gautrain Station to the new TuksAquatics Centre: promoting use by out-of-city athletes living in Johannesburg, improving safety and passive surveillance in Arcadia Street, connecting the many Bed-and-Breakfasts to the wider out-of-city public and spectators as well as enhancing athlete-public interaction. Arcadia Street is connected to the site itself through a public jogging and cycling route. Parallel to the route, a 200m linear open water swimming channel further connects the water bodies on site, mediating between the now fully public social core of Uitspan and the semi-private training and competitions venues used by the athletes. Furthermore, the channel is supported by an adjacent natural filtration system that naturally filters the dam water making it safe to train in.



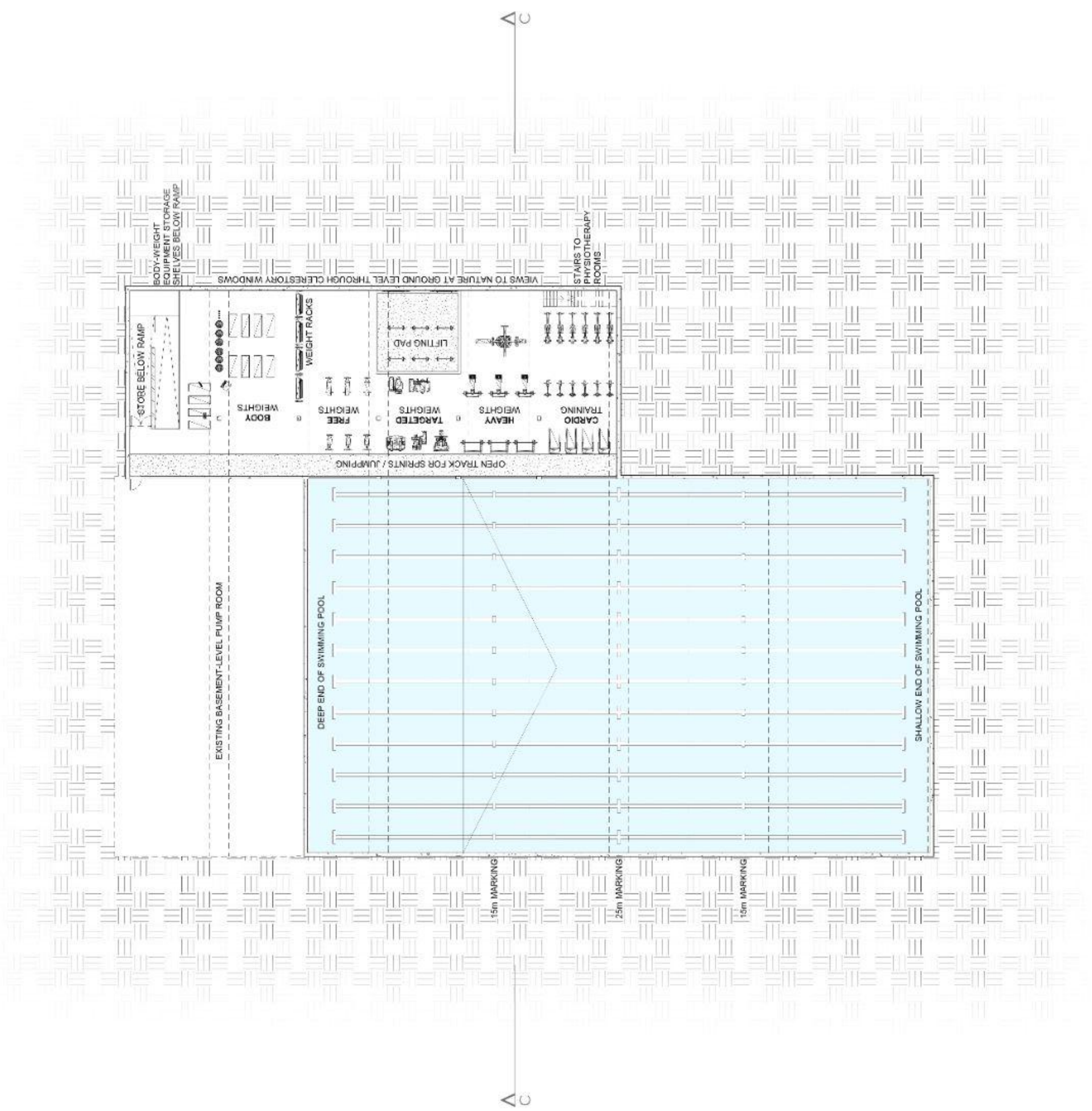
NAME: KUAN RAS
STUDENT No.: 04462/94

Figure 177: Site plan (Author, 2021)

BASEMENT FLOOR PLAN

SCALE 1:200

8



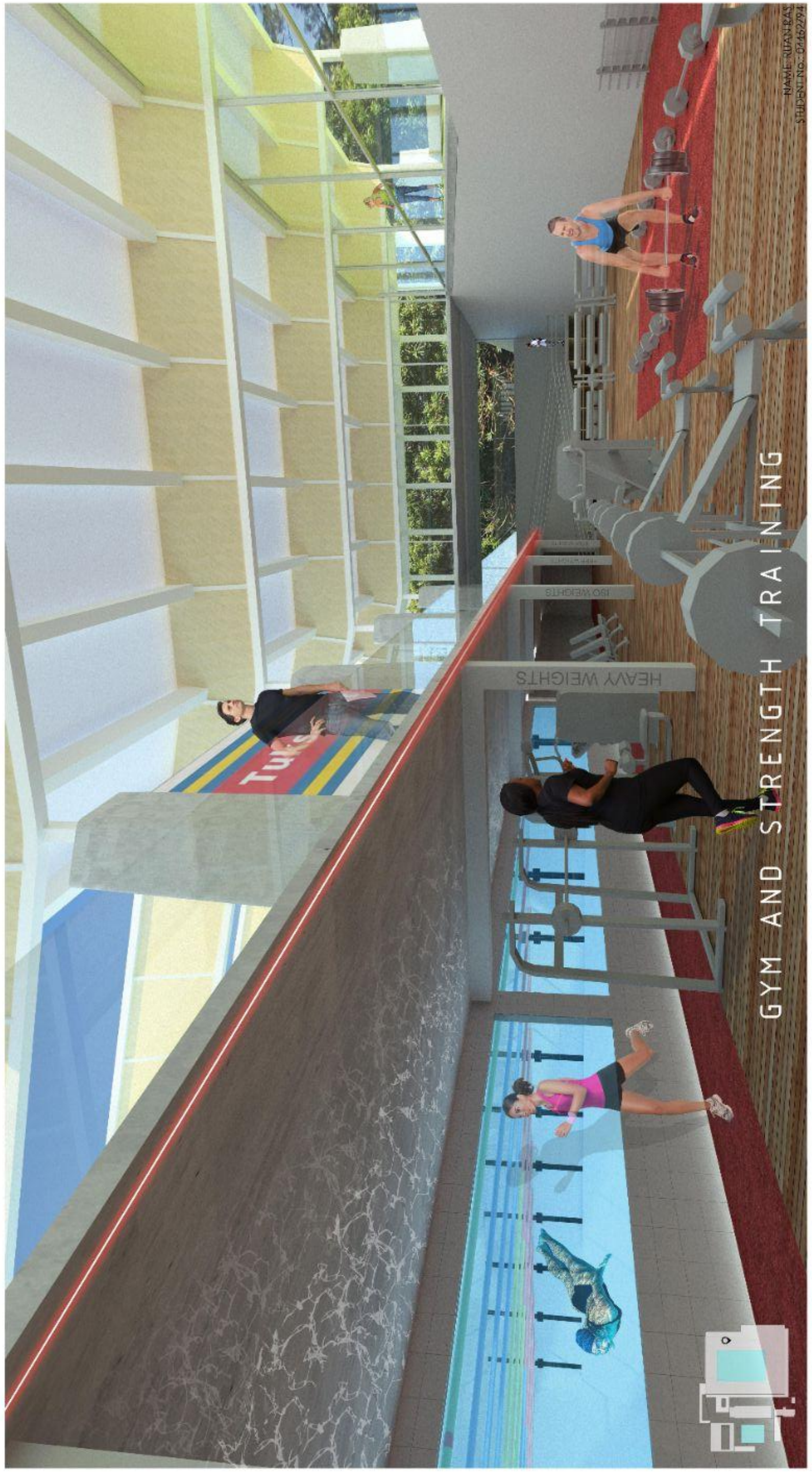


Figure 178: Basement floor plan (Author, 2021)

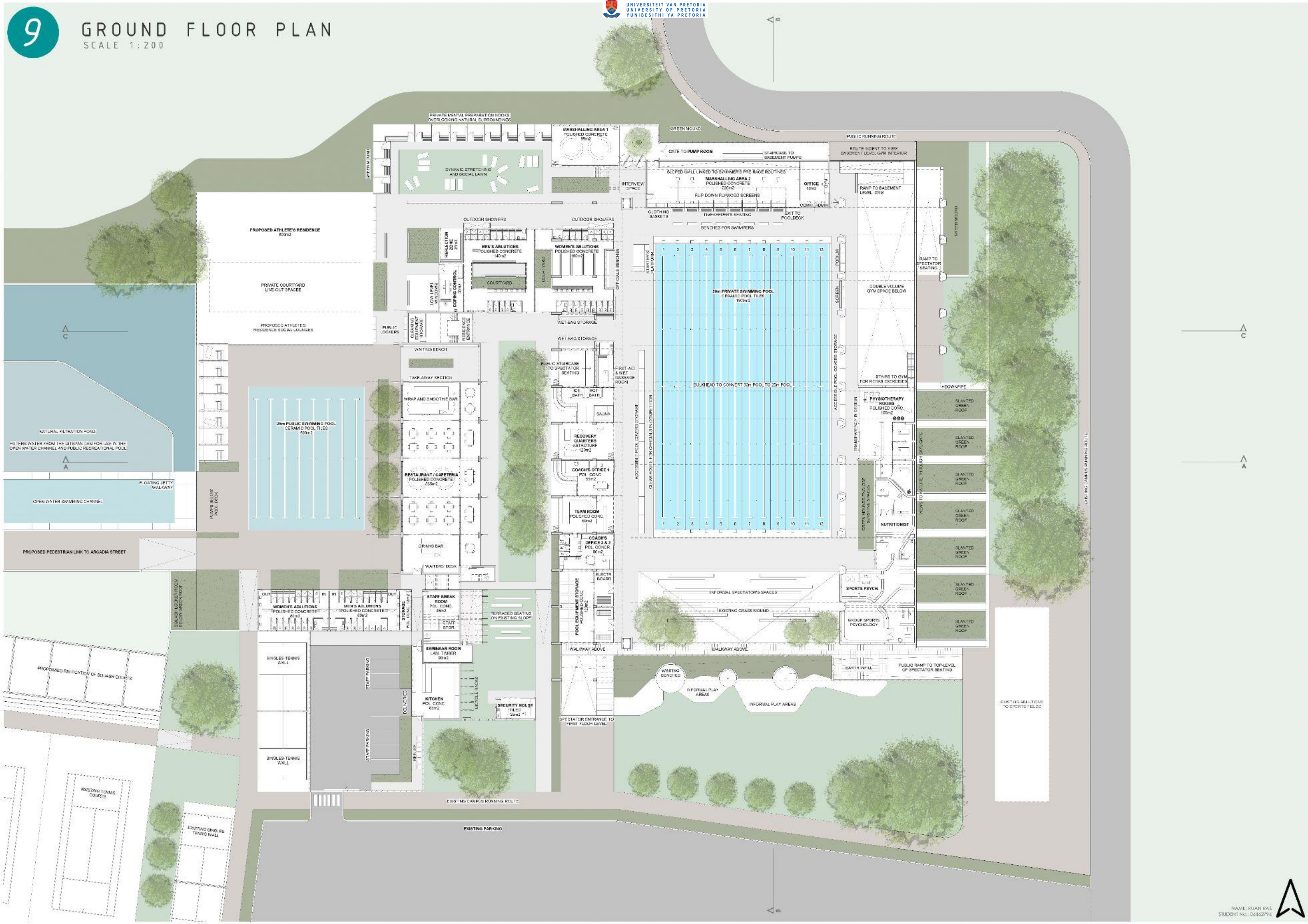


Figure 179: Ground floor plan (Author, 2021)

Figure 180: First floor plan (Author, 2021)

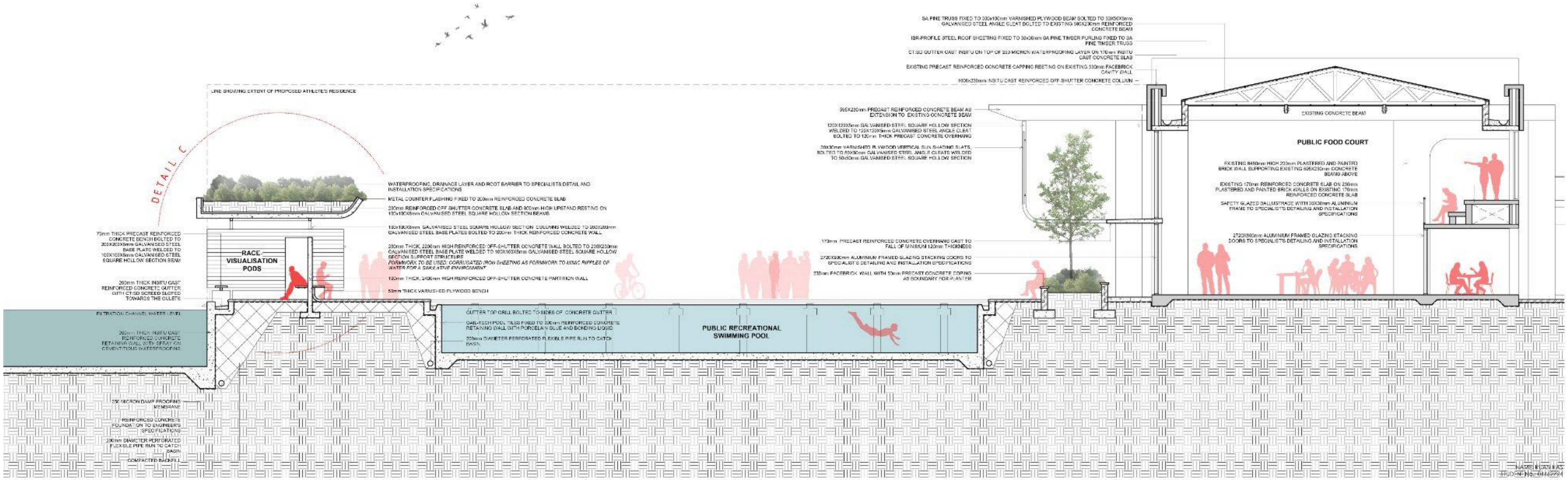


Figure 181: Section A-A (Author, 2021)

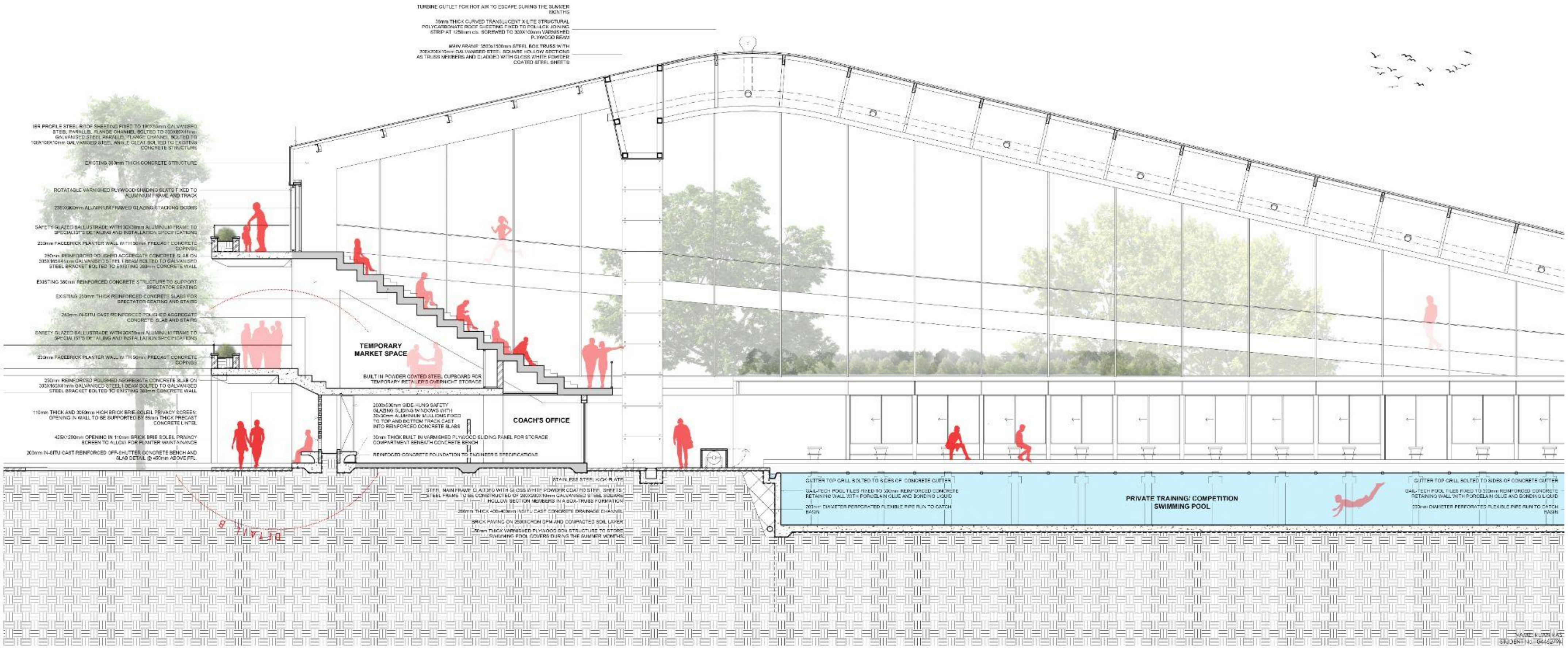


Figure 182: Section A-A continued (Author, 2021)

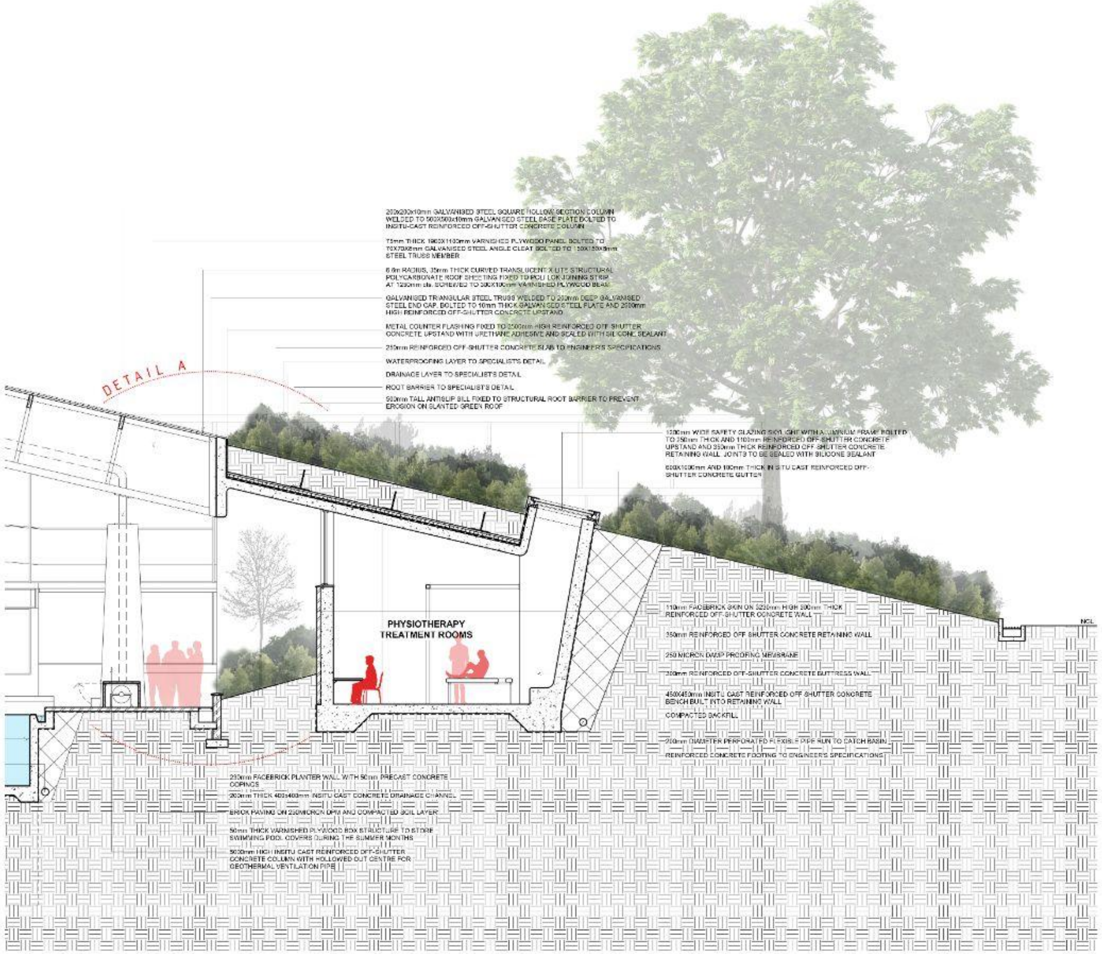


Figure 183: Section A-A continued (Author, 2021)

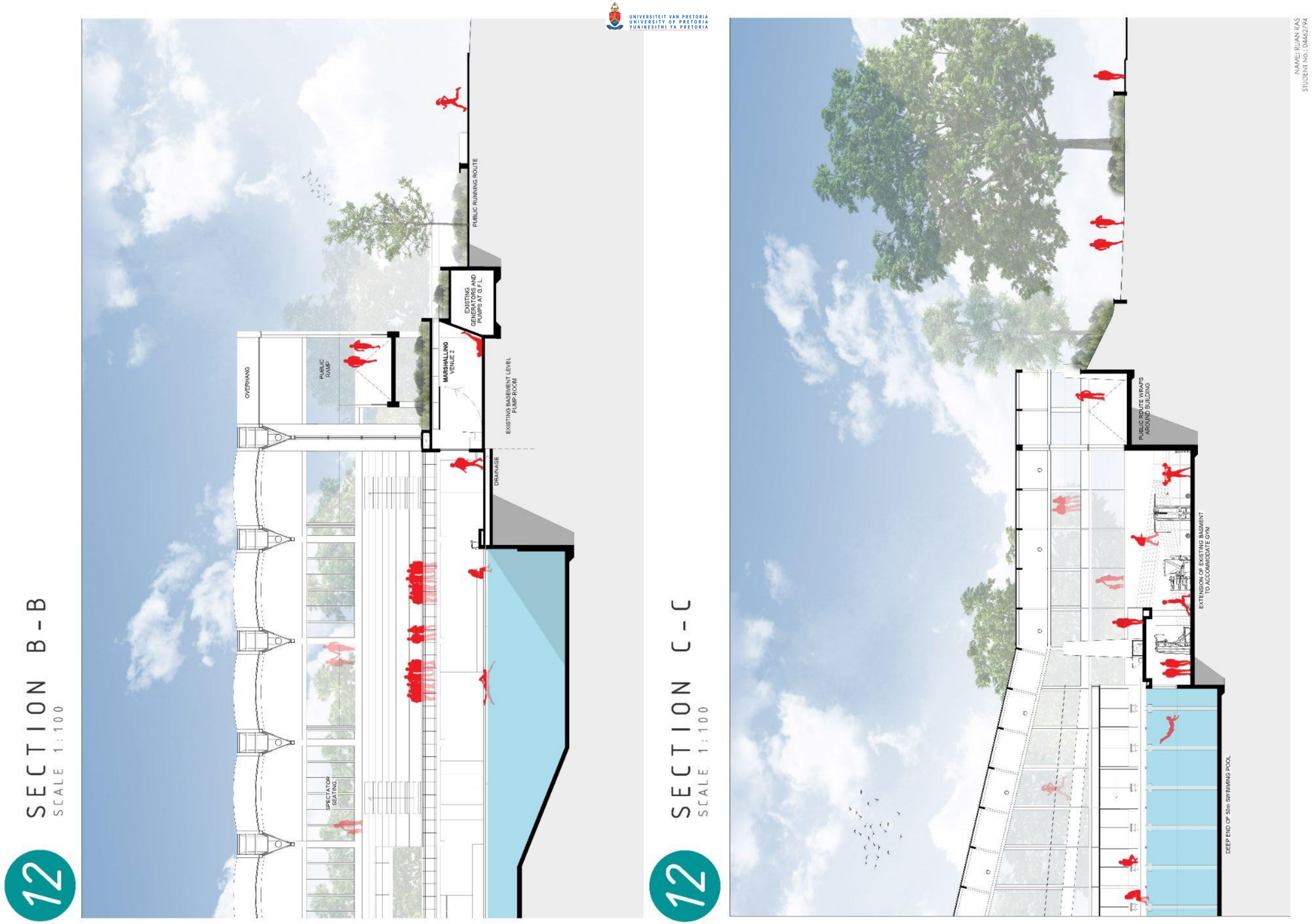


Figure 184: Section B-B and C-C (Author, 2021)

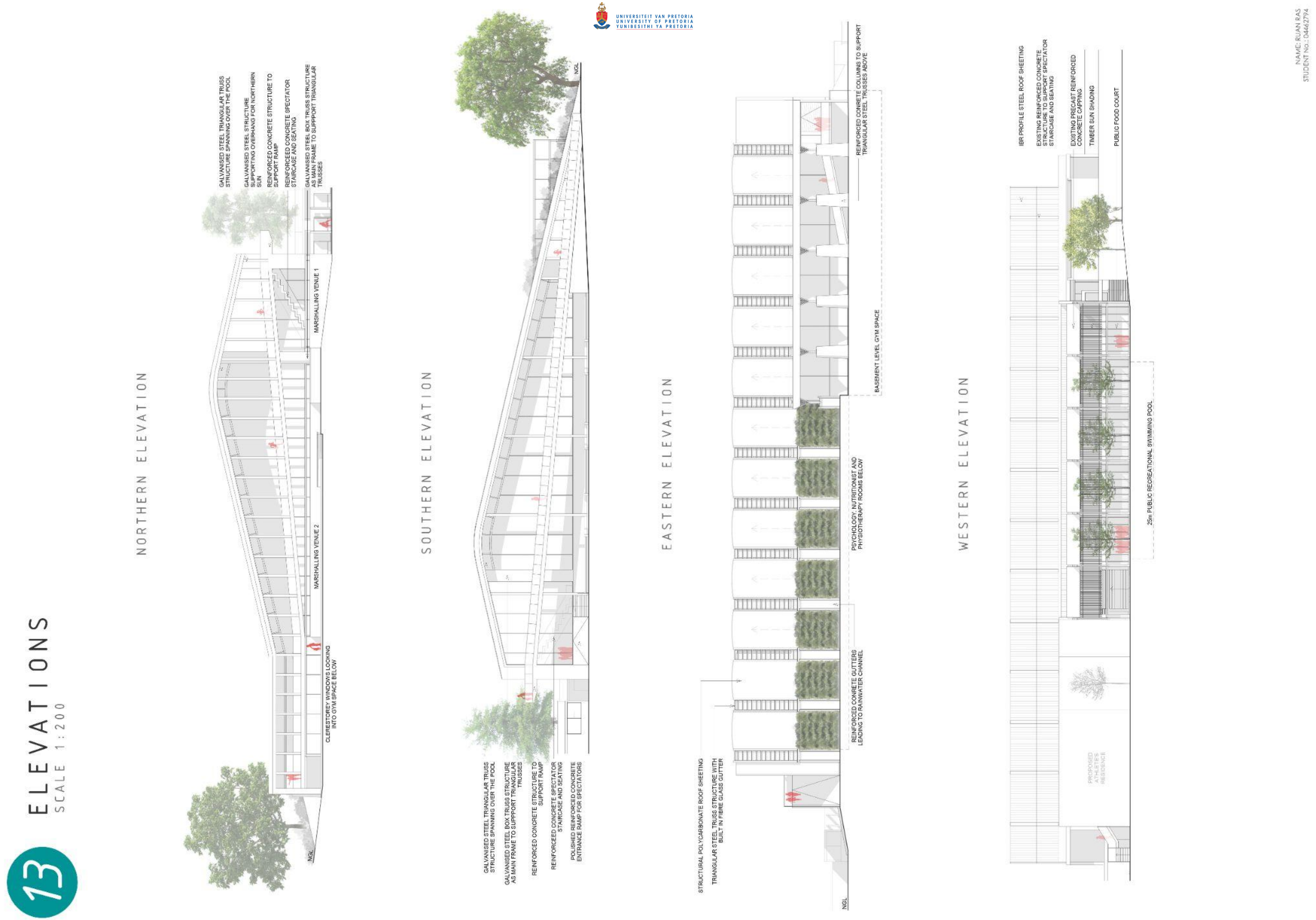
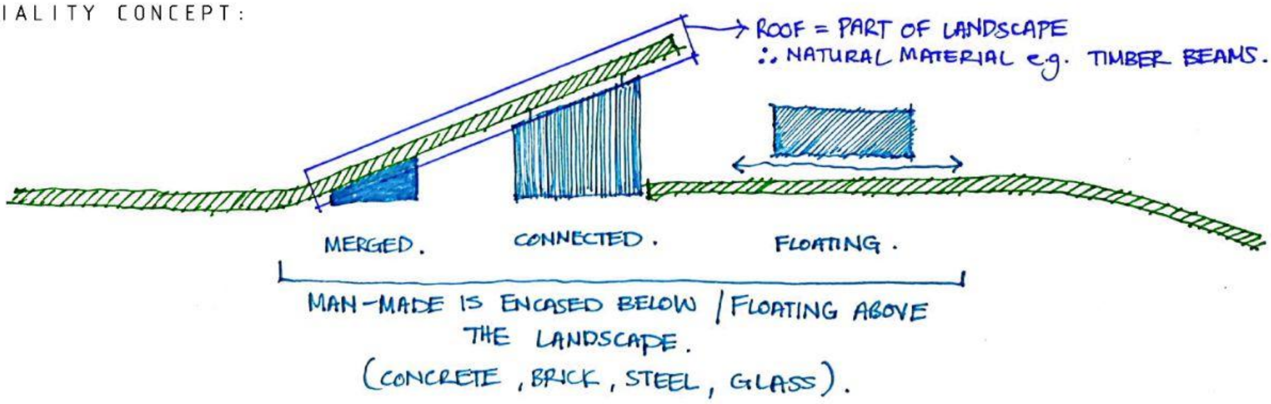


Figure 185: Elevations (Author, 2021)

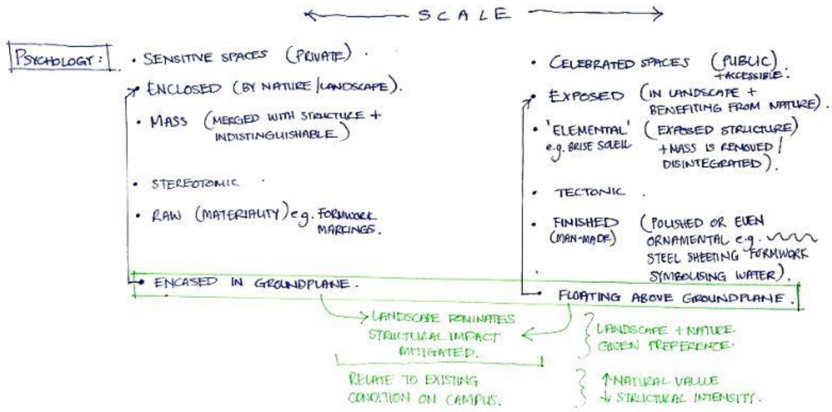
14 TECHNOLOGY IN DESIGN

CONCEPTUAL APPROACH TO MATERIALITY AND STRUCTURE

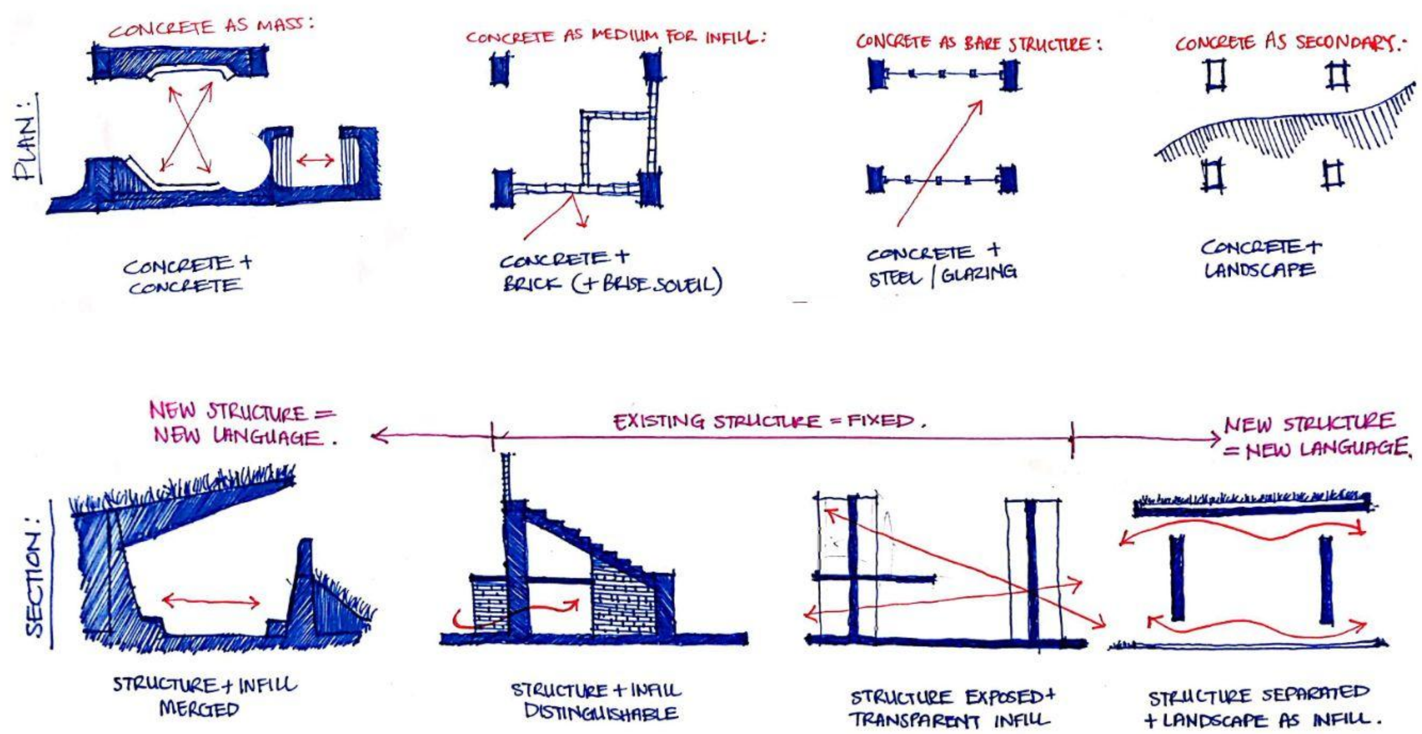
MATERIALITY CONCEPT:



STRUCTURAL LANGUAGES BASED ON A SCALE OF E.B.D. INTERVENTIONS:



FOUR STRUCTURAL LANGUAGES:



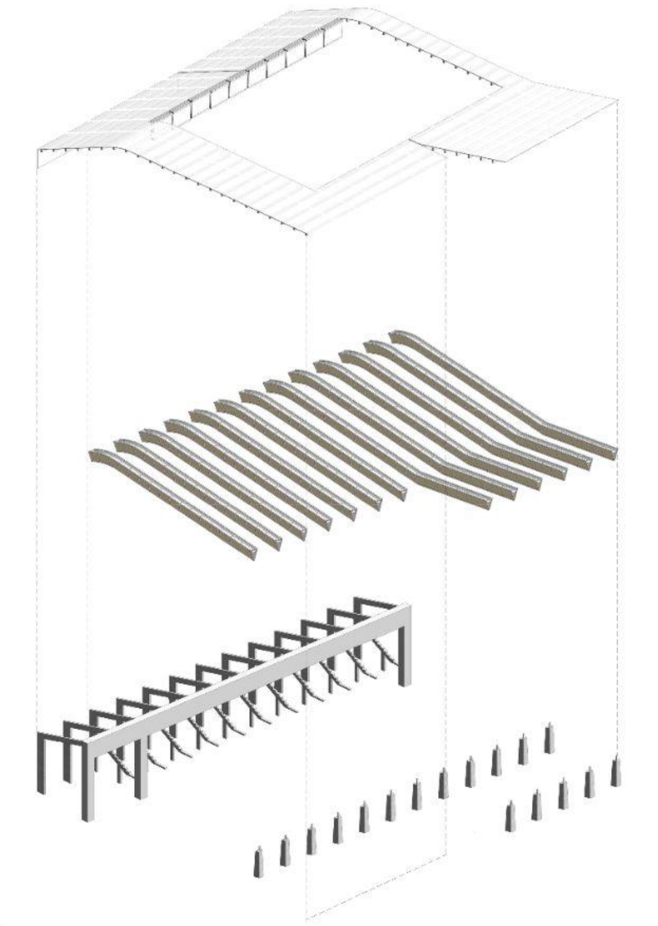
NAME: RUAN RAS
STUDENT No.: 04462794

Figure 186: Technology in design (Author, 2021)

15 TECHNOLOGY IN DESIGN

STRUCTURE AND GREENSTAR RATING

BREAKDOWN OF STRUCTURE:

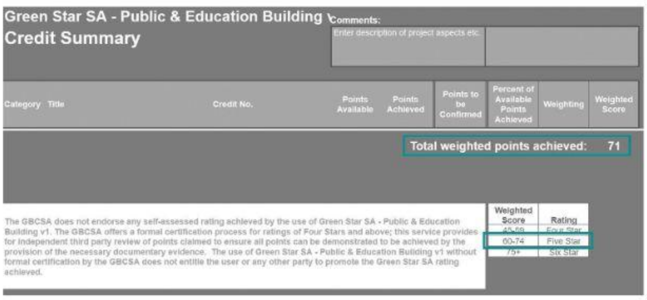


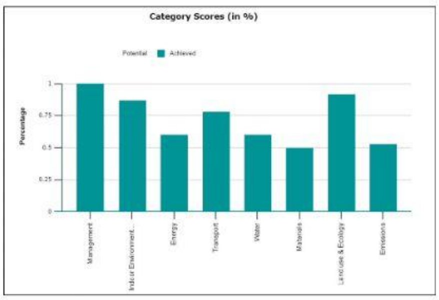
TERTIARY STRUCTURE:
POLYCARBONATE ROOF SHEETING
ON 50x50mm PLYWOOD PURLINS
ON 300x100mm PLYWOOD BEAMS

SECONDARY STRUCTURE:
2000mm DEEP WHITE POWDER COATED GALVANISED STEEL TRIANGULAR TRUSS WITH 50mm PLYWOOD INFILL PANELS AS LATERAL BRACING

PRIMARY STRUCTURE:
- EXISTING CONCRETE STRUCTURE
- NEW STEEL MAIN FRAME: 3500x1500mm RECTANGULAR TRUSS ON SIMILAR STEEL FRAMED SUPPORTS CLADDED WITH GLOSS WHITE POWDER COATED ALUMINIUM SHEETS
- NEW CONCRETE COLUMNS

GREENSTAR RATING:





GreenStar rating achieved: 71 points (5 stars)

Sustainable design measures have been taken in the form of improved natural daylighting in internal environments. This has been achieved without resulting in too much heat gain on the interiors through the use of various shading devices and large roof overhangs that also help to reduce glare. Openings in smaller spaces like the food hall allow natural ventilation, while larger spaces such as the competition venue employ mechanical ventilation strategies that work to minimise energy consumption. This is done through a geothermal heating and cooling strategy that works to keep internal environments thermally comfortable. This ventilation also prevents unwanted humidification of the indoor spaces that house the swimming pool, further helping to prevent mould and other health hazards from occurring.

In terms of water usage, stormwater is retained in large natural water filtration channels that filter rainwater, stormwater and water from the Hartbeesspruit. This water is reused for the public ablutions, showers in the changing rooms as well as to fill the 25m public recreational swimming pool. These channels, along with the vast natural open space surrounding the site has also allowed many visual connections to be created between internal spaces and natural external spaces.

Building materials are also chosen with sustainability in mind where materials are chosen based on their low embodied energies, local availability as well as, where relevant, their insulative properties. Furthermore, materials that are left over after the demolishing of parts of the existing building; for example: the facebrick left over after opening up the facades of the old squash courts, is reused to fill gabion structures that can be used to terrace the landscape.

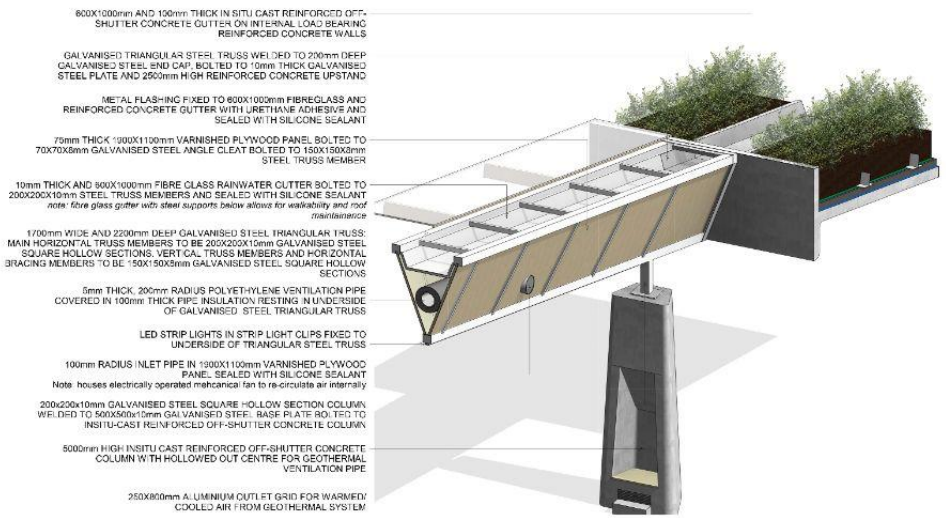
Lastly, public and community are brought into the scheme through the site's connection with the Gautrain station, the proposed semi-pedestrianised Arcadia Street, the braai areas at the Uitspan dam and the public running and cycling route that stretches across the campus. This encourages continued use of the site, healthy habits of running and cycling for the users of the site as well as minimising fossil-fuel emissions by encouraging the use of public transport. Furthermore, community members are able to use the public 25m recreational swimming pool, which adds value to the site's context.

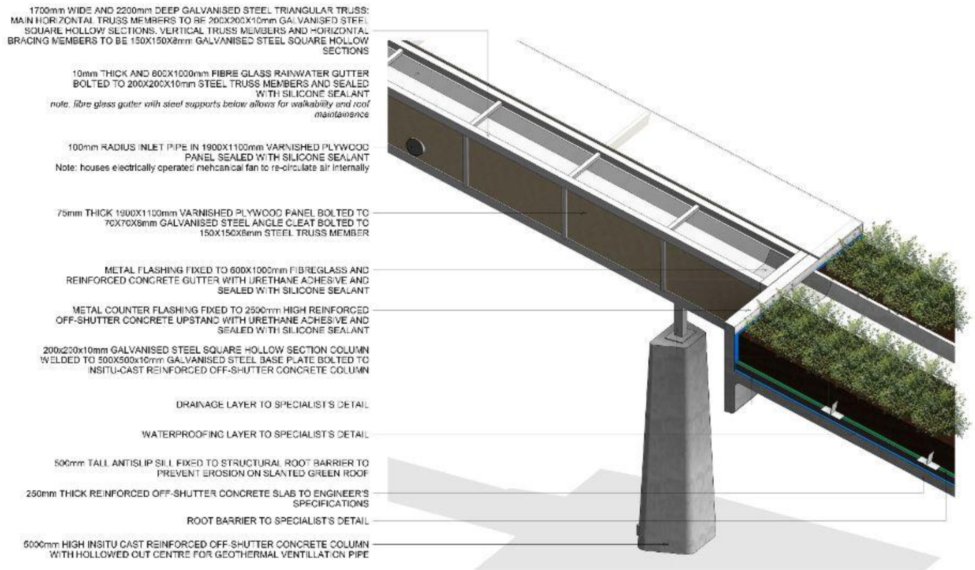
NAME: RUAN RAS
STUDENT No.: 04462794

Figure 187: Structure and Greenstar rating (Author, 2021)

16 DETAIL A

SCALE 1:40





PROCESS WORK:

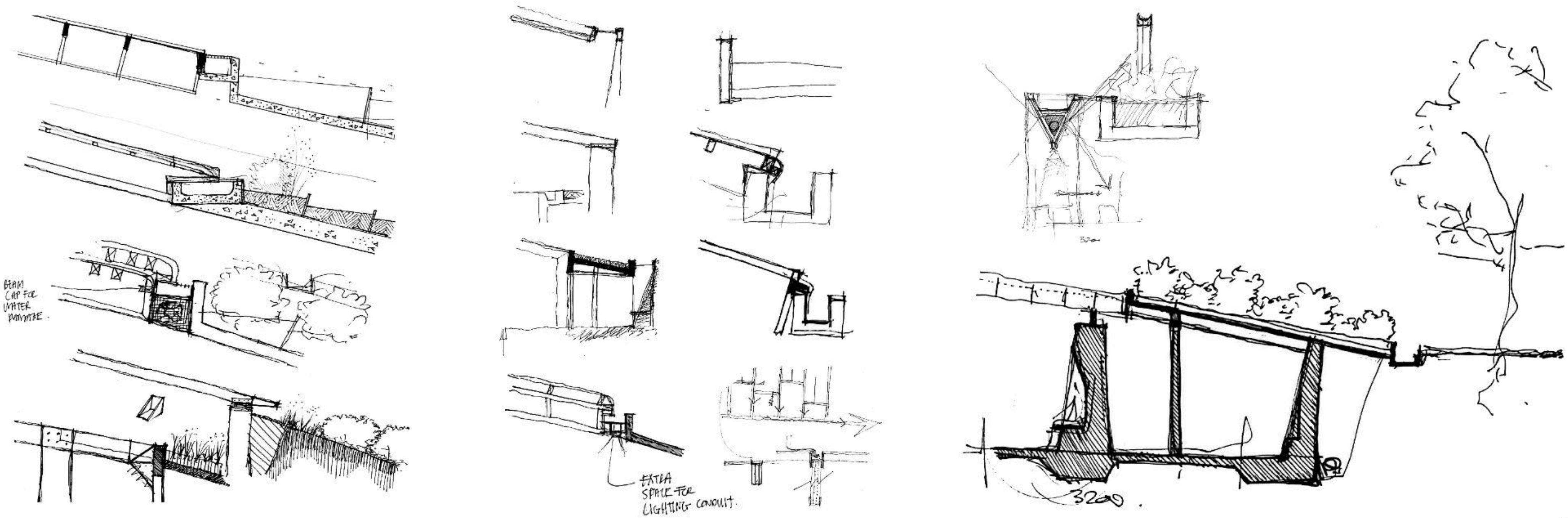


Figure 188: Detail A (Author, 2021)

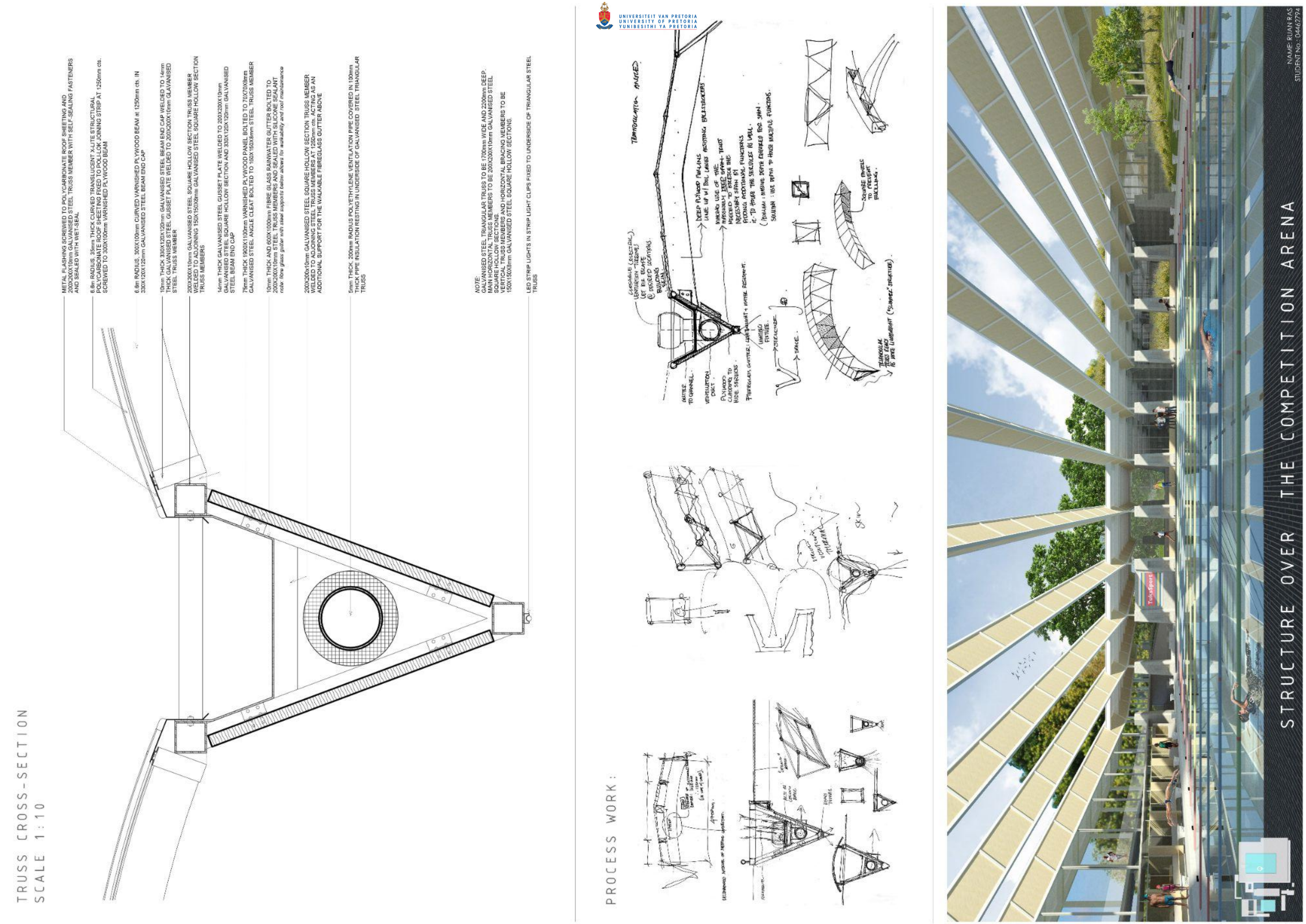


Figure 189: Detail A continued (Author, 2021)

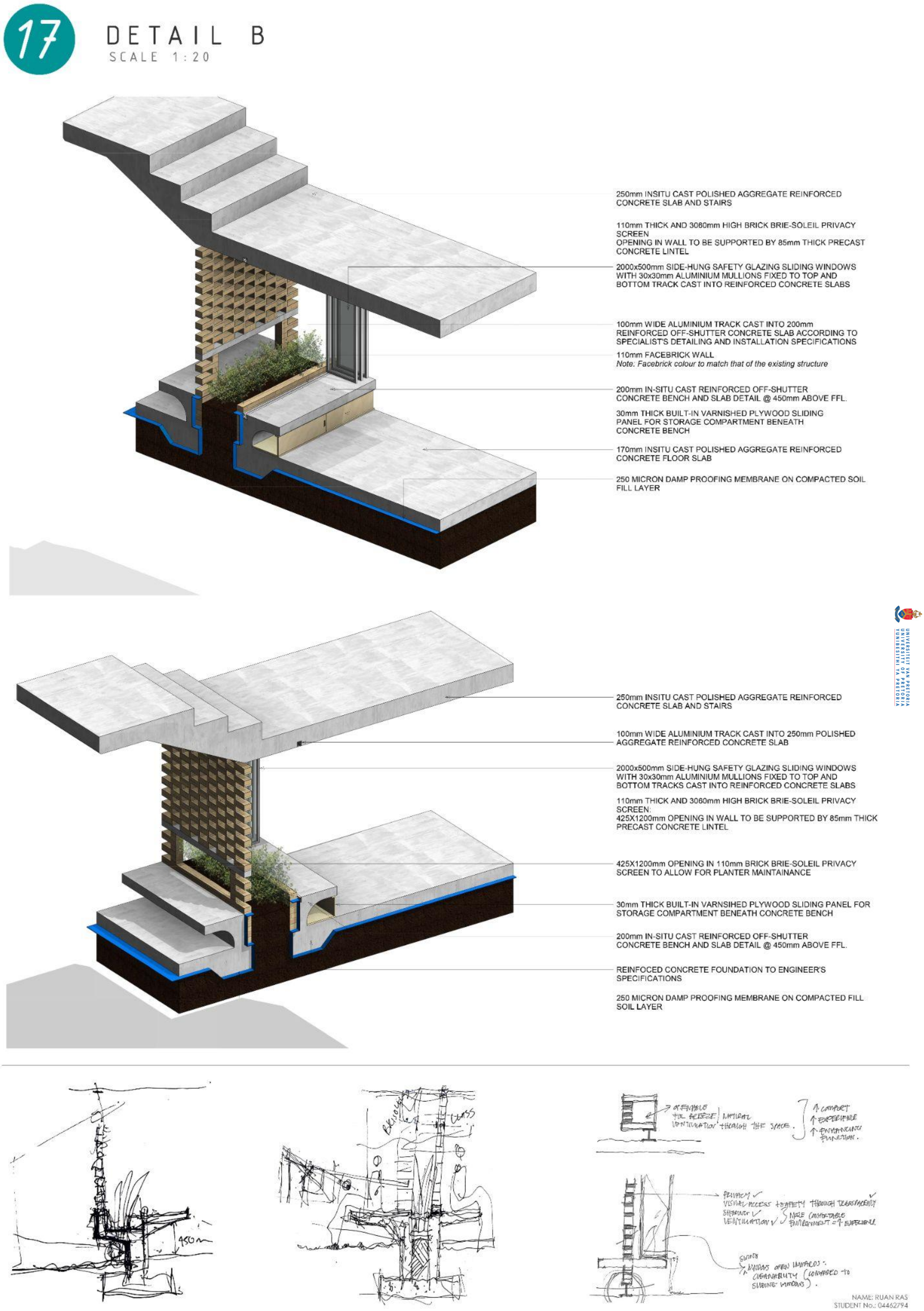


Figure 190: Detail B (Author, 2021)

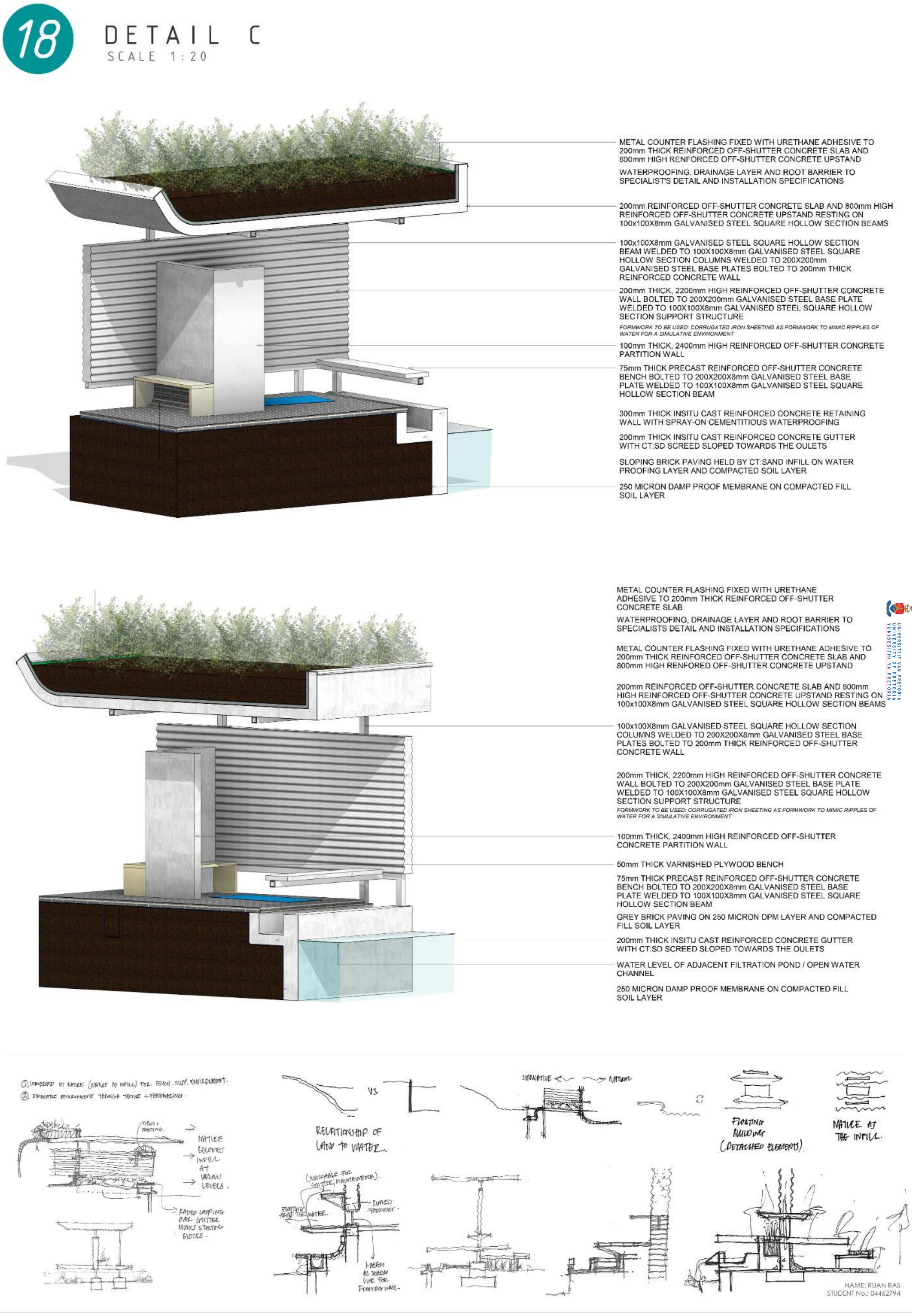


Figure 191: Detail C (Author, 2021)

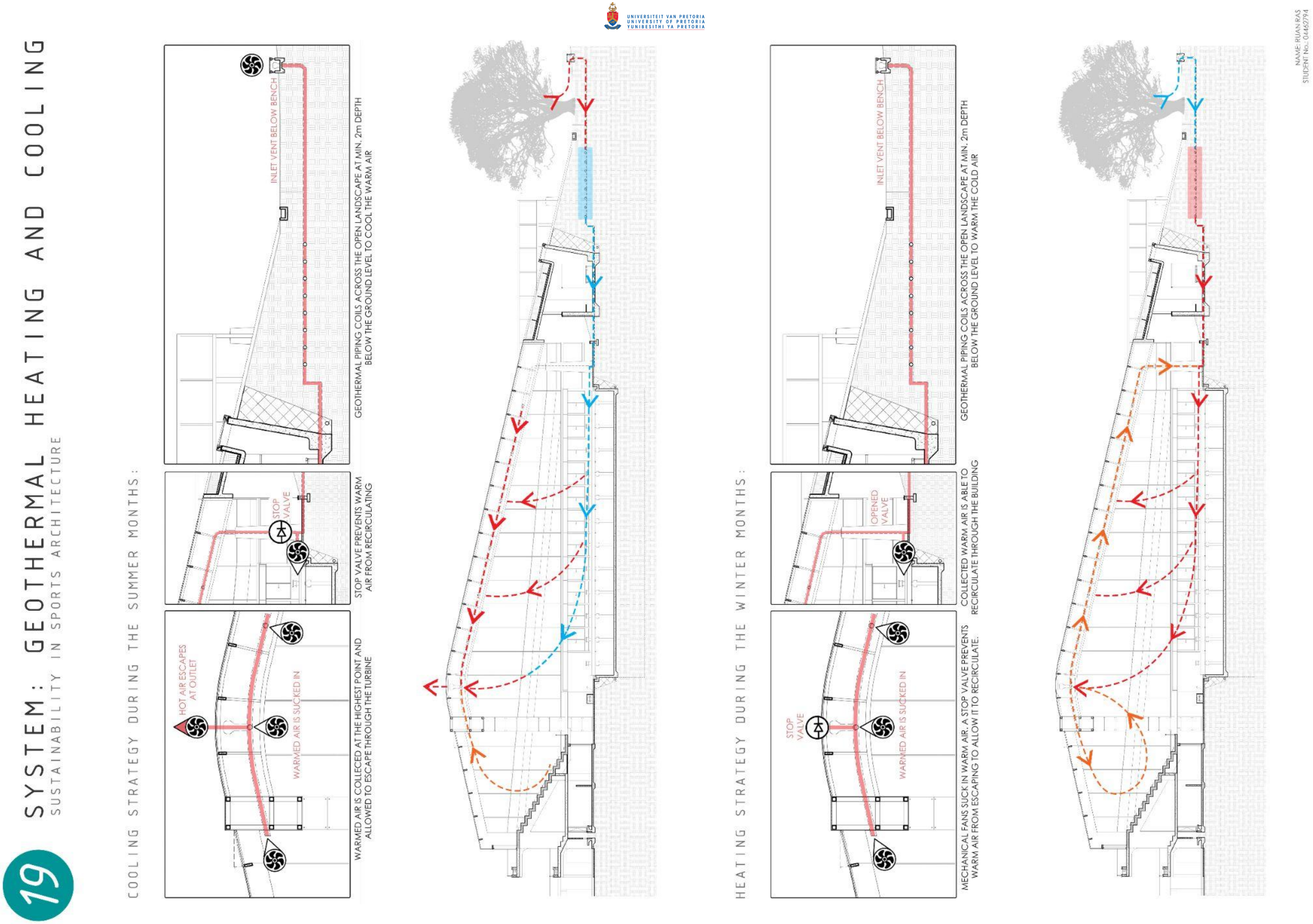
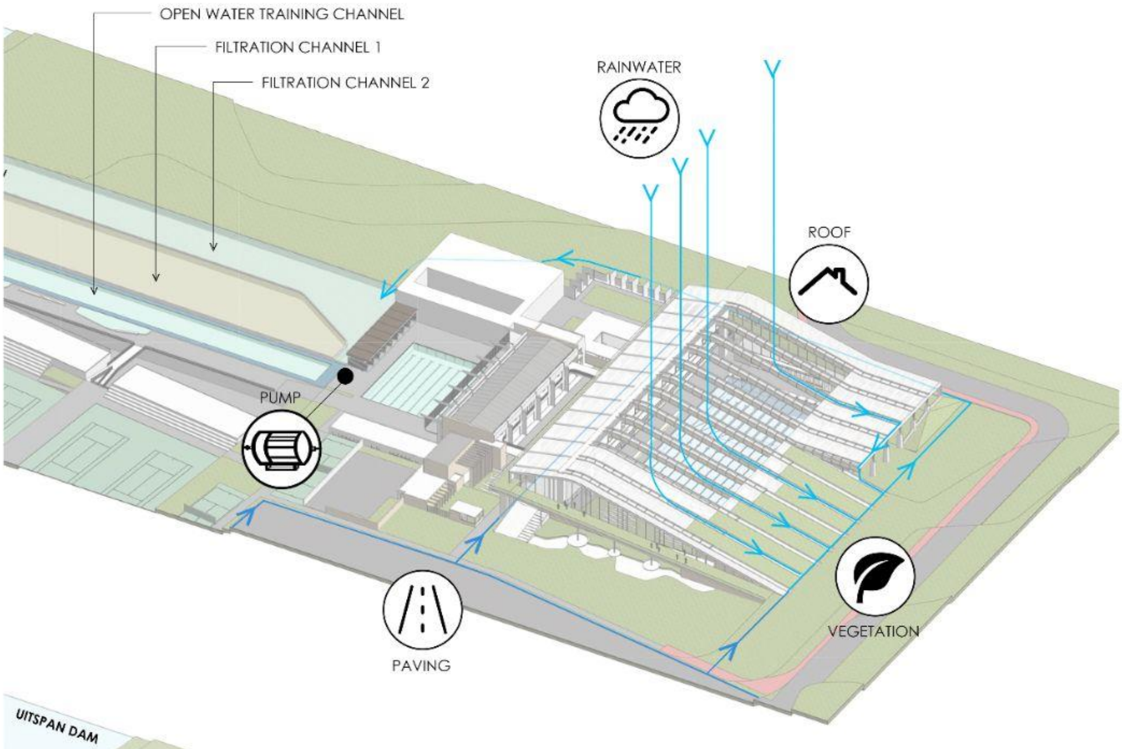


Figure 192: Geothermal heating and cooling systems (Author, 2021)

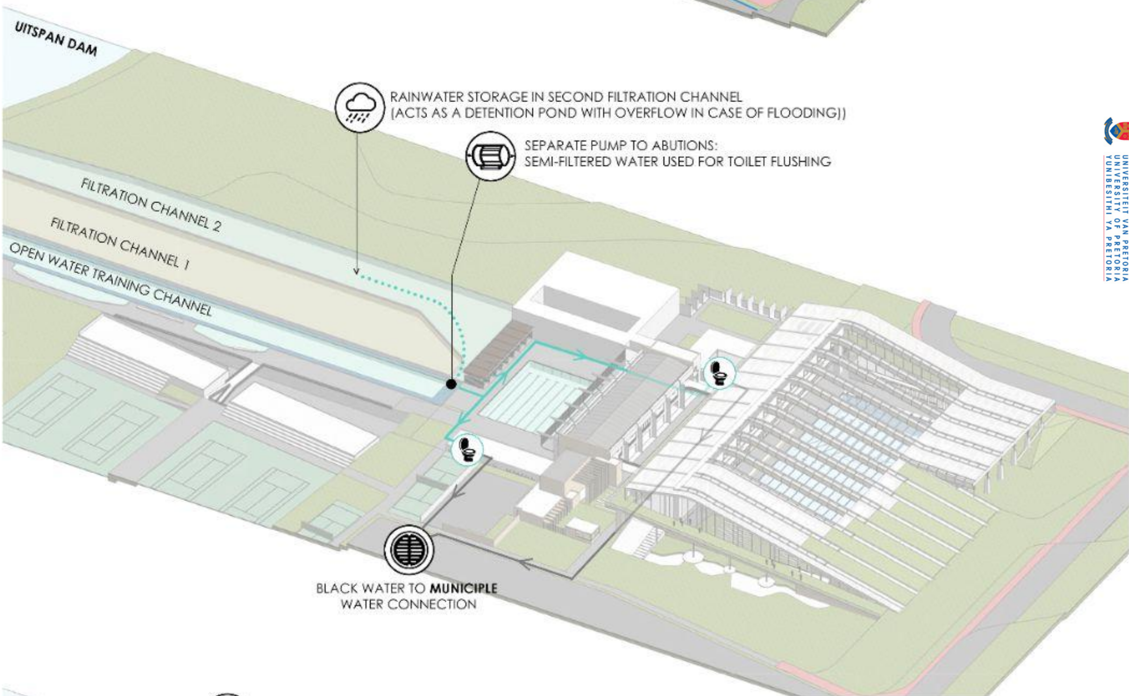
20 SYSTEM: WATER HARVESTING & USE

SUSTAINABILITY IN SPORTS ARCHITECTURE

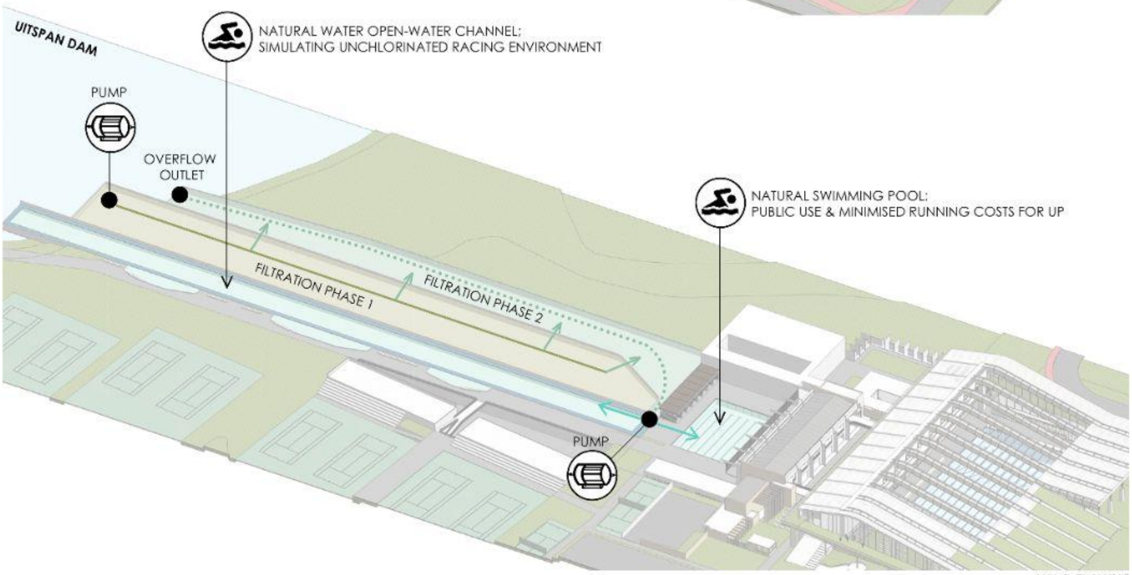
WATER HARVESTING STRATEGY AND USE ON SITE



RAINWATER STORAGE AND USAGE



WATER FILTRATION AND USAGE



NAME: RUAN RAS
STUDENT No.: 04462794

Figure 193: Water harvesting systems (Author, 2021)

CALCULATING RAINWATER YIELD

AREA CALCULATIONS

Catchment	Area, A (m²)	Runoff Coefficient,	
Lawn, sandy	3400	0.08	0.01
Roof	6100	0.9	0.30
Paving	7000	0.8	0.30
Veld Grass	0	0.3	0.00
Gravel	0	0.5	0.00
Slope lawn, 25%	1200	0.2	0.01
Cultivated vegetition	740	0.5	0.02
TOTAL	18440	3.28	0.65

RAINWATER YIELD CALCULATION

Month	Ave. rainfall, P (m)	Yield (m³) (Yield = PxAxC)
January	0.154	1843.688
February	0.075	897.9
March	0.082	981.704
April	0.051	610.572
May	0.013	155.636
June	0.007	83.804
July	0.003	35.916
August	0.006	71.832
September	0.022	263.384
October	0.071	850.012
November	0.098	1173.256
December	0.15	1795.8
ANNUAL AVE.	0.674	8763.504

TOTAL YIELD

Month	Total Yield (m³/month)
January	1843.688
February	897.9
March	981.704
April	610.572
May	155.636
June	83.804
July	35.916
August	71.832
September	263.384
October	850.012
November	1173.256
December	1795.8
ANNUAL TOTAL	8763.504

CALCULATING WATER DEMAND

IRRIGATION DEMAND

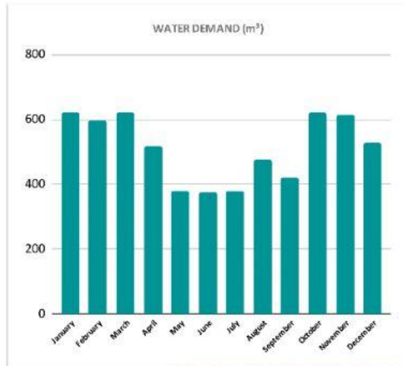
Month	Planting area (m²)	Irr. depth / week (m)	Irr. depth / month (m)	Irrigation demand (m³/month)
January	1940	0.05	0.2	388
February	1940	0.05	0.2	388
March	1940	0.05	0.2	388
April	1940	0.04	0.15	291
May	1940	0.03	0.1	194
June	1940	0.03	0.1	194
July	1940	0.03	0.1	194
August	1940	0.03	0.15	291
September	1940	0.03	0.1	194
October	1940	0.05	0.2	388
November	1940	0.05	0.2	388
December	1940	0.05	0.2	388
			ANNUAL TOTAL	3686

ALT DEMAND

Month	Entity (Persons ?)	Entity demand / day (l)	Alt demand (m³/month)
January	500	15	232.5
February	500	15	210
March	500	15	232.5
April	500	15	225
May	400	15	186
June	400	15	180
July	400	15	186
August	400	15	186
September	500	15	225
October	500	15	232.5
November	500	15	225
December	300	15	139.5
		ANNUAL TOTAL	2460

TOTAL DEMAND

Month	Total demand (m³/month)
January	620.5
February	598.0
March	620.5
April	516.0
May	380.0
June	374.0
July	380.0
August	477.0
September	419.0
October	620.5
November	613.0
December	527.5
ANNUAL TOTAL	6146.0



CALCULATING THE WATER BUDGET

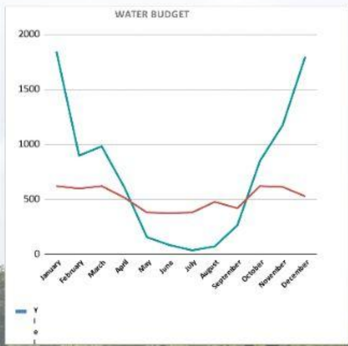
WATER BUDGET

Month	Yield (m³)	Demand (m³)	Monthly balance
January	1,843.7	620.5	1,223.2
February	897.9	598.0	299.9
March	981.7	620.5	361.2
April	610.6	516.0	94.6
May	155.6	380.0	-224.4
June	83.8	374.0	-290.2
July	35.9	380.0	-344.1
August	71.8	477.0	-405.2
September	263.4	419.0	-155.6
October	850.0	620.5	229.5
November	1,173.3	613.0	560.3
December	1,795.8	527.5	1,268.3
ANNUAL AVE.	8,763.5	6,146.0	2,617.5

WATER BUDGET (ACCUMALATIVE)

Month	Yield (m³)	Demand (m³)	Monthly balance	Vol. added water in reservoir (m³)
January	1,843.7	620.5	1,223.2	3,051.70
February	897.9	598.0	299.9	3,351.60
March	981.7	620.5	361.2	3,712.80
April	610.6	516.0	94.6	3,807.40
May	155.6	380.0	-224.4	3,583.10
June	83.8	374.0	-290.2	3,292.90
July	35.9	380.0	-344.1	2,948.80
August	71.8	477.0	-405.2	2,543.60
September	263.4	419.0	-155.6	2,388
October	850.0	620.5	229.5	2,617.50
November	1,173.3	613.0	560.3	560.3
December	1,795.8	527.5	1,268.3	1,828.60
ANNUAL AVE.	8,763.5	6,146.0	2,617.5	

	AREA (m2)	REQUIRED AREA FOR FILTRATION POND (m2)
25m SWIMMING POOL	500	1000
OPEN WATER TRAINING CHANNEL	2300	4600
	TOTAL	5600
REMAINING BALANCE OF HARVESTED RAINWATER		3800
TOTAL SURFACE AREA OF FILTRATION CHANNEL NEEDED		9400



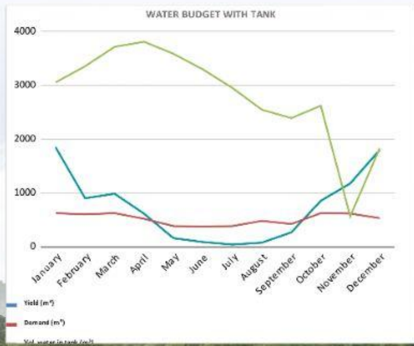


Figure 194: Water calculations (Author, 2021)

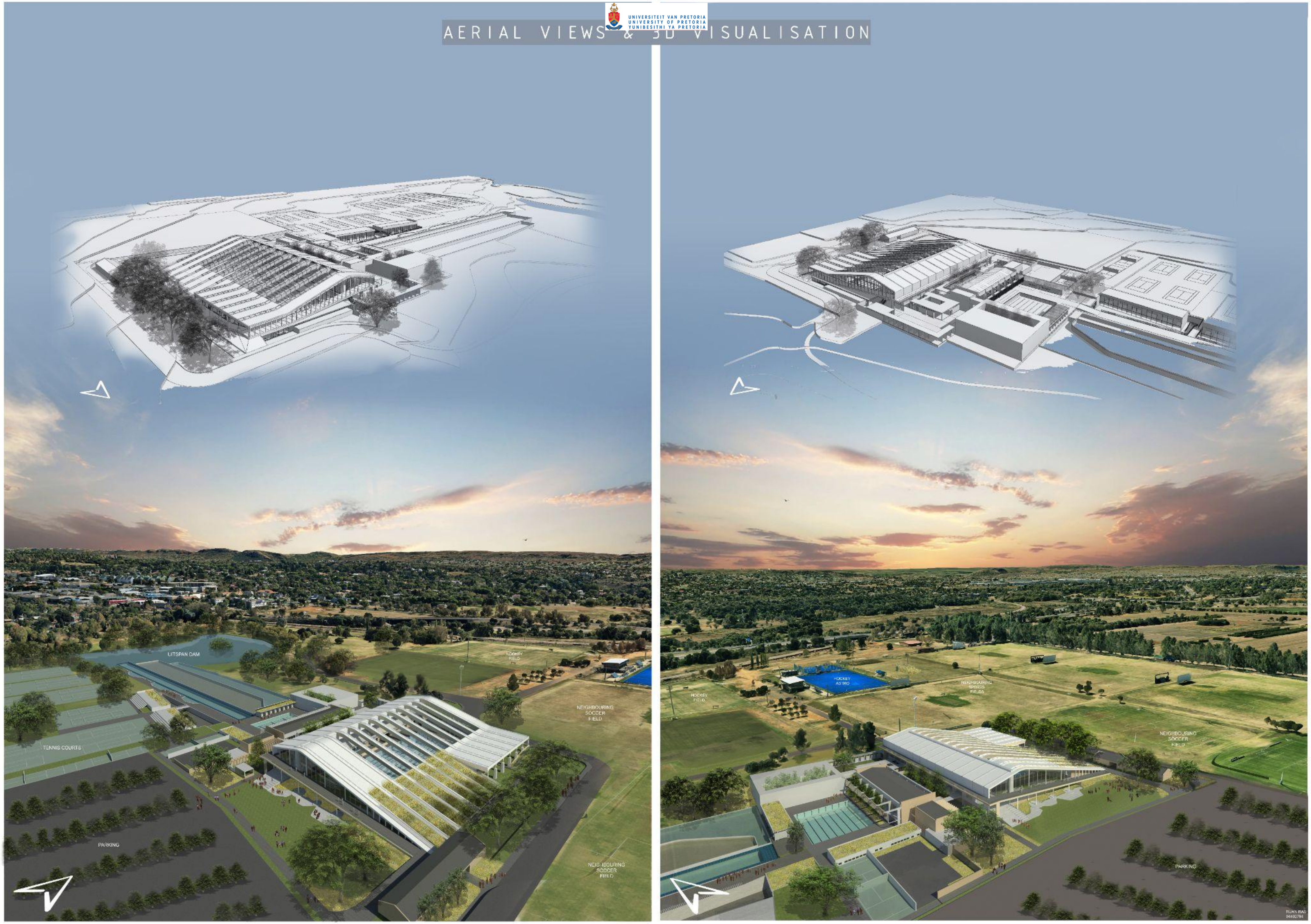


Figure 195: Aerial views and 3D visualisation (Author, 2021)