





technical investigation

Roof and façades

7.1 Addressing the problem:

In order for a facility of this kind to be successful, it is preferable to have growing-out greenhouses with large clear spans to allow optimum use and flexibility of space. Specific climatic zones and degrees of sun exposure are required for various plant types to allow for the proper germination of species and their propagation. After consideration of all these requirements, a tensile cable structure (Figures 7.1 & 7.2) proved to be the optimum choice that allows for the following:

- Considerable free span areas beneath the structure.
- A construction process with a more sensitized impact on the existing site and garden.
- Transparent roof panes that can easily be replaced by opaque ones, or be left open depending on the program of the spaces below.
- Cable net structures that allow extraordinary structural transparency that can be very dramatic with regards to the architectural experience, apart from being a lucid solution resulting in a lightweight structure to ultimately keep the elements out.

7.2 Design considerations:

Technologies for building cable net structures are not regularly used in South Africa, although a variety of different tensile structures using textile membranes have been constructed locally.

Loads:

One of the key characteristics that distinguish cable net structures from standard membrane tensile construction is the coordination of the cladding material with the architectural interface such as the fixtures and cables. Loads are much more excessive and must be provided for. Subsequently the choice of cladding material has a great influence on the bearing capacity of the cables. Today, a great variety of transparent polymer cladding materials other than glass exist, but these will be discussed later in the chapter.

Deflection:

Cable structures are more susceptible to deflection under wind loads, and to fluctuations in temperature, than standard concrete or steel structures. Therefore provision should be made for movement between roof cladding components and areas where the tensile structure meets rigid construction components like curtain walls or other façade components.

Water runoff:

Most of the materials used to cover cable net structures are impermeable to water and can therefore result in vast volumes of water run-off during the short, intense rainstorms which are frequently experienced in Pretoria. It is therefore important to deliberately incorporate designated run-off points on the roof and to direct the pitch of the roof in such a manner so as to ensure that run-off is directed away across the entire roof area in a uniform manner. The water can be accounted for where it leaves the roof by means of appropriate gutter systems, groundwater recharge trenches, bio-retention ponds etc, on ground level.

For the 1972 Olympic Stadium in Munich, Frei Otto designed a bespoke system of 140mm wide neoprene gutters that are tightly fitted between glass panels to direct water run-off (black lines visible in Fig. 6.1). Today, commercial products by large polymer corporations such as BASF still use the logic behind Mr. Otto's design, but these will be discussed later in the chapter.



FIG 7.1 Frei Otto institute museum building (<http://kubuildingtech.org/cooltour/gallery/ILEK/source/30.html>)



FIG 7.2 Frei Otto institute museum building (<http://kubuildingtech.org/cooltour/gallery/ILEK/source/22.html>)



FIG 7.3 Munich olympic stadium roof (Nerdinger 2005:266)



FIG 7.24 Evaporative cooling units and heat exchangers



FIG 7.25 Evaporative cooling units cold air release ducts



FIG 7.26 Solar curtains

Green roof, laboratories and quarantine rooms

PLEASE REFER TO DETAILED SECTION BB

Climate control

PLEASE REFER TO DRAWINGS ON THE ADJACENT PAGE

South African greenhouses are different to their European counterparts. European incident solar radiation is considerably less than in South Africa, which means that solar greenhouses in South Africa tend to overheat. Greenhouses in South Africa need ample ventilation and cooling apparatus.

Artificial lighting is controlled by time switches. Greenhouse climates are continuously monitored and air conditioning systems are automatically started when the greenhouse starts to overheat.

There are three main growing environments within the greenhouse complex with specific light and ventilation requirements.

1 Plant growth rooms (solar)

- Lighting intensity of 250-700 micromoles m^2 /second
- For the propagation of example tobacco, tomato etc. plants.
- With reference to the glasshouses at Murdoch University in Perth, Western Australia, we can fairly accurately make assumptions on how a facility of this kind will react in the South African solar climate since it is fairly similar to those experienced in Australia whereby solar control is achieved by means of solar curtains (Fig 7.27) that is automatically controlled by a central computer system.
- A method that has proved sufficient at Murdoch University is the use of evaporative cooling heat exchangers. These draw in air from the outside, blow it over dry ice reservoirs and expels the cold air onto the plants from a plastic tube in the roof space (Fig 7.26).

2 Interior plant growth rooms (artificial lighting)

- Lighting intensity of 150 micromoles m^2 /second
- Biolux fluorescent bulbs E.g. Osram L58W/72 technical lamps with aluminum reflectors
- Suitable for Arabidopsis (small flowering plants for the study of plant genome biology)

3 Plant Tissue culture growth rooms (artificial lighting)

- Standard fluorescent tubes with aluminum reflectors
- High requirement for air quality to remain pure, therefore the air in such a facility needs filtering. This is achieved by making use of PAD (Fig. 7.28) screens or HEPA filters (Fig. 7.29). This prevents the unwanted ingress of pathogens and the spread of pollen and other biological material to the rest of the facility.

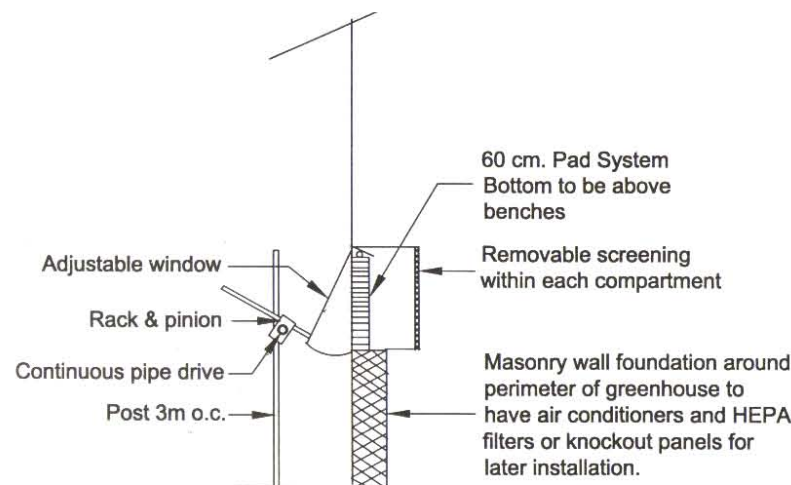


FIG 7.27 PAD screens and filters (Kahn 1999:82)

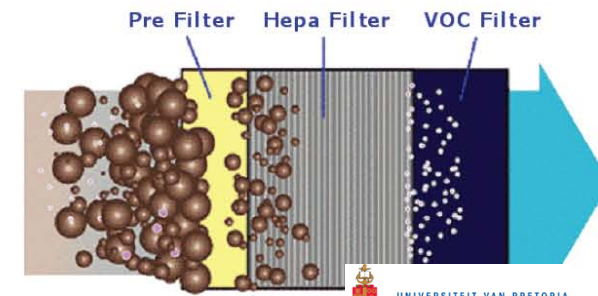


FIG 7.28 HEPA filter (<http://www.americansafeair.com>)

7.3.1 Roof Structure:

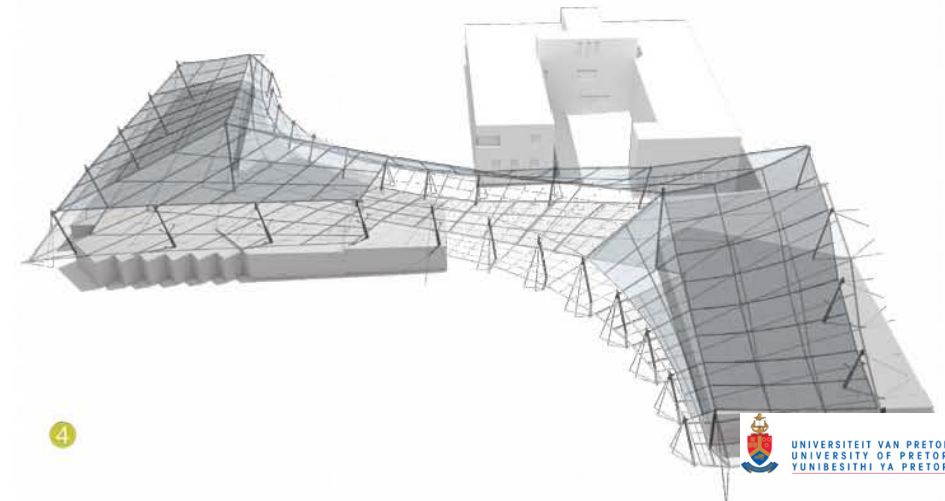
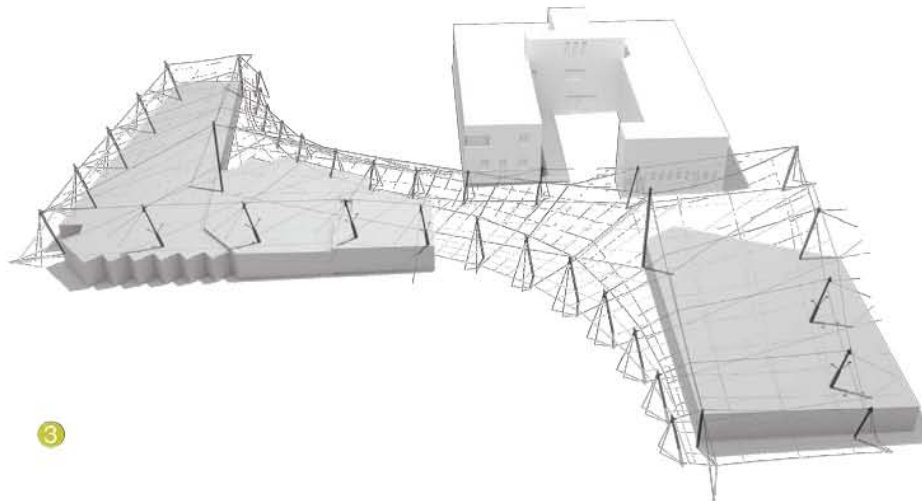
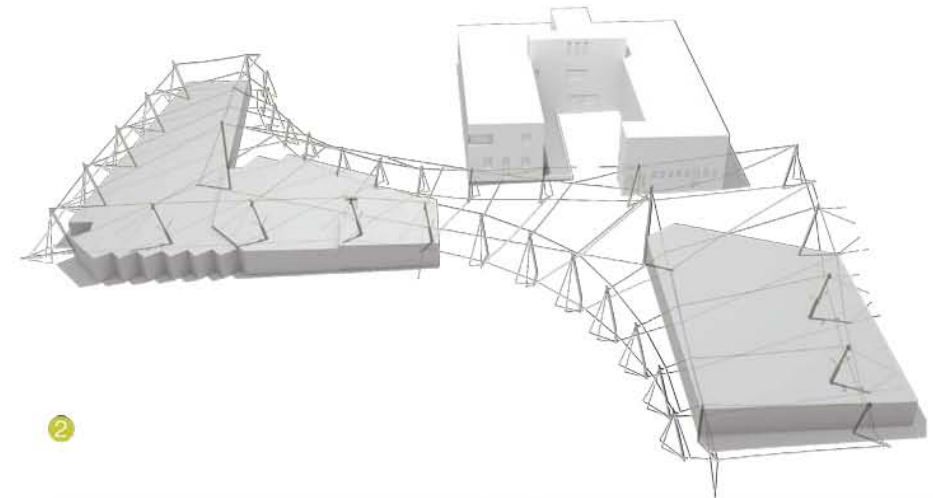
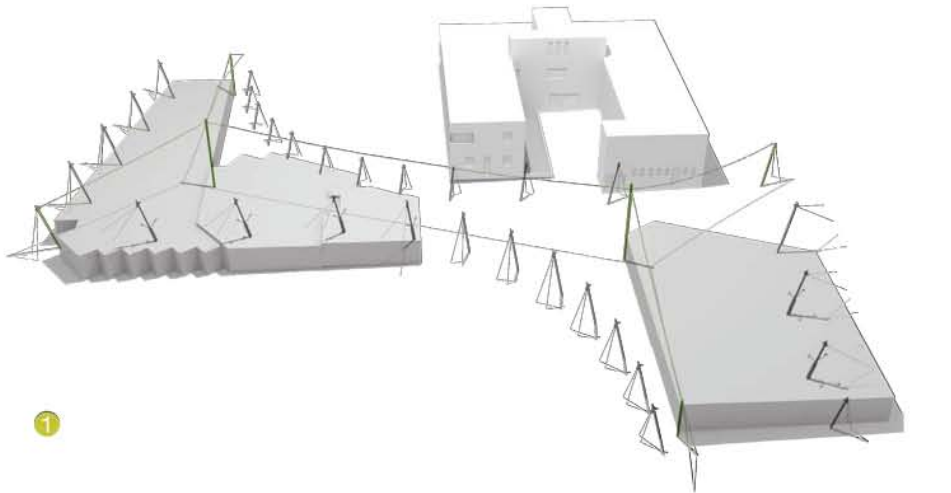
Regarding the aforementioned design considerations, it is necessary first of all to ensure structural stability by reducing deflection to a minimum. Therefore it is essential to ensure axial stiffness in the main supporting cables.

1 Primary Cables: Six main support columns (273x6mm Ø) form the backbone of the structure, keeping 50.8mm Ø, 126 ton nominal strength wire steel rope in place. Four of the columns function in line with each other, whilst two other columns work in at oblique angles to counter bending moments that are induced at the two tallest points.

2 Secondary cables: A network of 31.75mm Ø, 58.1 ton nominal strength wire steel ropes are fixed to 29 support columns (152.44mm Ø or 252mm Ø depending on cable span) at oblique angles to the primary cable. This infill structure transfers dead and live loads evenly from the roof cladding to the foundations.

3 Cable net: An intersecting network of 11.1mmØ, 8.1 ton nominal strength wire steel rope forms a platform for single-point glass fixings to be attached to the cables. These allow roof cladding panels that differ in size to be attached to the structure.

4 Roof cladding and gutters: Irregularly shaped 10mm deep translucent acrylic panels with a 140mm neoprene strip seal gutter at joining edges are fixed to the cable net structure. Material selection for the cladding panels and type of gutter seals will be discussed in Details 1 and 2.



7.3.2 Roof Structure assembly possibilities:

In order to make tensile structures economically more feasible, a wide variety of standard components are available on the market. Most of these fixtures are used for heavy lifting equipment in the shipping industry. Fixtures are available in a wide range of finishes. Depending on the manufacturing process, they are either chrome plated, galvanized or made of stainless steel.

The two sketches in Figures 7.4 and 7.5 illustrate in very basic terms the two paradigms of assemblies that can be achieved in tensile construction. Being spoiled for choice over the vast array of available fixtures, the challenge of designing a tensile structure is more like putting together a three dimensional rope puzzle. Fig. 7.2 shows a fixed construction method, where resin impregnated spelter sockets (discussed below) are used to anchor cables. The benefit of this type of assembly is that spelter sockets are available in large sizes and subsequently they can resist substantial loads from cables with large diameters. The liability in using such a construction methodology is that cables have to be cut to size very accurately before installation, because post-tensioning is not possible when resin anchors are used.

Alternatively, as in Fig. 7.3, a clevis-threaded rod assembly can be used. This allows for a more dynamic type of system where post tensioning is possible if turnbuckles are included. Threaded rods are less flexible than wire steel ropes (cables) and therefore a combination of anchoring assemblies are preferable as they allow for more flexibility of use. An example of such a combined installation is the Urban-Loritz Platz Straßenbahn by Tillner Architects in Vienna, Austria (Fig. 7.6). The roof canopy consists of a combination of PVC membrane sheets and glass panels. More interesting though is the way in which the architect combined the use of spelter socket anchors at the column supports, creating fixed points to provide a stronger reaction to tensile forces. Adjustable clevises are used inside the structure closer to the roof covering materials, where loads are more evenly distributed.

A method called swaging can also be used, but this is meant for net structures with lower tensile forces, such as cable net walling systems. With swaging a fitting is mechanically pressed into the cable end.

Where cables intersect they are held together with cable clamps. In most cases a single-point fixing will be used in combination with a cable clamp to attach the cladding material. This process will be discussed in greater depth in Detail 2.

7.3.3 Structure anchors and fixers:

1 Clevis: Mechanical connection for fixing threaded rods to the structure, mainly available in stainless or galvanized steel. The connection is secured to the structure with a pin-head and cotter pin.

2 Pin-head and cotter pin: Manufactured from stainless steel, the pin head diameter should be selected to be 125% of the size of the clevis thread-to-rod connection. This is to ensure that the pin-head does not fail due to high tensile forces

3 Spelter socket: Manufactured from either chrome plated or galvanized high-carbon steel, the socket has a cone shaped termination where the splayed wires of the cable termination is inserted and bound by melted zinc alloy or a resin wedge.

4 Turnbuckle: Available in a variety of finishes, turnbuckles are mechanical connections used to connect two threaded rods. These are used to allow post tensioning of the structure.

5 Swivel socket: Painted high-grade steel with cable end swaged into socket.

6 Threaded rod & 7 Rod-end: These rods form part of the lateral structure and can be custom ordered in various lengths. The diameter of the threaded rods should match those of the clevis and turnbuckle anchors. Rod-ends are used to allow connections to spelter socket or clevis pin heads.

8 Hook assembly: Probably the most basic component of any cable structure, but this type of assembly is versatile, adjustable, and can withstand high tensile forces.



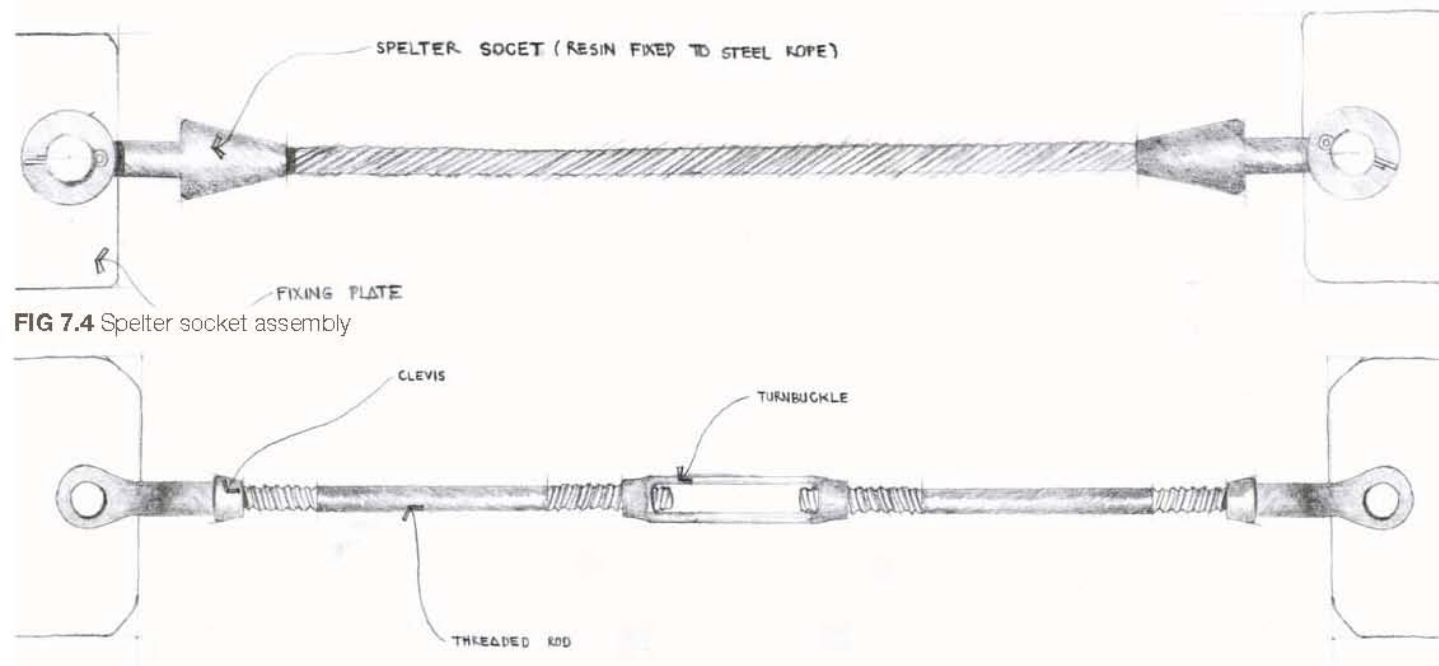


FIG 7.4 Spelter socket assembly

FIG 7.5 Clevis-rod assembly with turnbuckles



FIG 7.6 Urban-Loritz Platz Straßenbahn by Tillner architects in Vienna, Austria clevis-rod assembly

7.3.4 Structure façade assembly:
PLEASE REFER TO DETAILED SECTION AA

1 Run-off water trench:

To adhere to the prescribed guidelines in SABS 0400 Part RR2, a water run-off trench, placed along the periphery of the roofline on ground level, directs stormwater run-off towards the rainwater retention pond for future re-use (Fig. 7.7). Its construction is similar to that of a recharge trench with a coarse aggregate surface layer and a finer aggregate sub-base. In the case of recharge trenches where a porous fabric-separating layer is used to separate aggregate and surrounding groundfill, an impermeable concrete gutter, in adherence to SABS 0400 Part JJ.2 (b), is poured with a minimum fall of 1:70 and slopes towards the retention pond.

The aggregate fill for the trench enables a primary filtering process for rainwater collected from the roof. Water is then directed towards the recharge pond, where it is pumped and filtered for use in the appropriate growing-out greenhouses. In the case of the hydroponic greenhouses, the water is pumped into storage tanks in the greenhouse control room after it has been filtered. The water is then treated with a pre-calculated nutrient solution and used in the greenhouse. Wastewater from the greenhouses and retention pond are directed to the stormwater sewer as prescribed in SABS 0400 Part RR5. For more information regarding the different hydroponic systems used in the greenhouse, please refer to discussion point number 4: Growing-out greenhouse – Hydroponic systems.

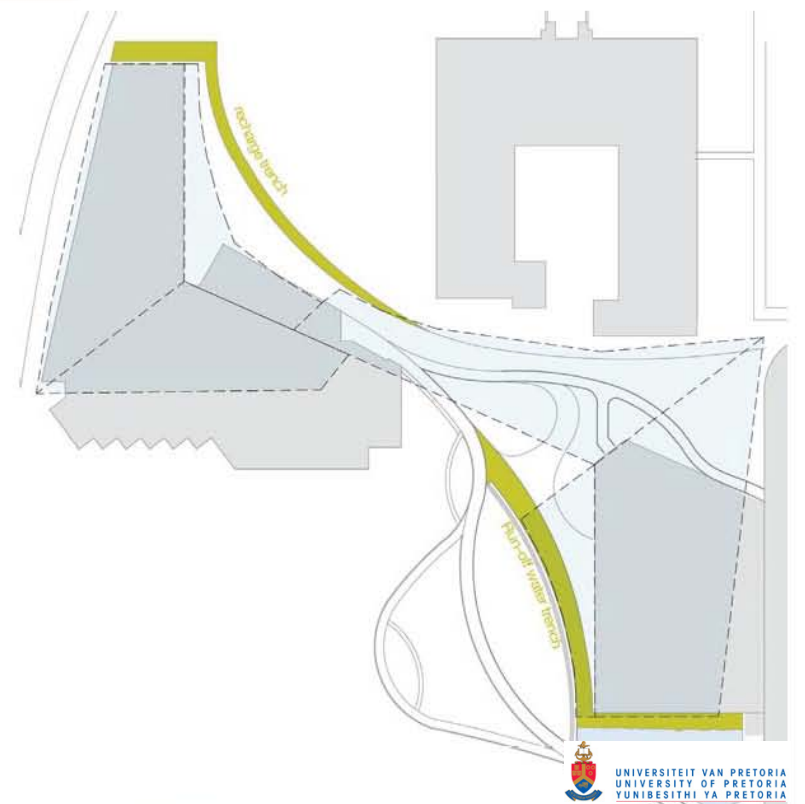


FIG 7.7 Rainwater falloff trenches and retention pond

2 Façade – Assembly and material selection:

Growing-out greenhouses represent the lowest order of the containment hierarchy at a research facility (Kahn & Mathur, 1999:82) and therefore allow more design freedom. Plants reach this stage after seeds have been incubated under strictly controlled environmental conditions and have been cleared of bacteria and viruses that may pose threats to local plant species. Plants propagated in the growing-out greenhouses primarily need to be protected from pests, insects and harsh fluctuations in ambient air temperature. Due to the moderate and sub-tropical climatic conditions of Pretoria, where short spells of frost are only experienced irregularly during very cold winter nights, the possibility of having natural ventilation for the greenhouses during the daytime is unarguable.

The façade of the proposed building consists of a basic rigid timber skeleton built up of PAR 144X50 wrought and varnished timber studs intersected by PAR 44x94 wrought and varnished timber joists in accordance with SABS 1783. The skeleton timber studs are fixed to the concrete floor upstand (eliminating ingress of water onto timber) with stainless steel L-shaped brackets, and suspended with 11.1mmØ, 8.1 ton nominal strength wire steel rope from the primary cable of the roof structure, utilizing clevis, turnbuckle and swivel socket assemblies.

The timber skeleton is clad with 20mm wide, 1.45 W/m²K polycarbonate panels similar to the system used in Fig. 6.8. Polycarbonate panels are milled during manufacturing to give the façade an irregular profile, as illustrated in Figures 7.9 and 7.10. Every third panel of polycarbonate is operable for natural ventilation (see drawing of detailed section) and follows the same design integrity shown in Fig. 7.10, which depicts a similar mechanical window opening system used for a restaurant in Vienna.

The material selection for the timber skeleton and polycarbonate sheeting was primarily made on the basis of structural dead weight and inherent embodied energy. The aim was to create a lightweight façade that can be suspended from the tensile roof structure. The alternative to timber was aluminium, but it was decided in this case that the two main liabilities of aluminium (high cost and high embodied energy) would not prove feasible for this project. Timber was considered a wise choice due to the fact that it would be protected from moisture by the polycarbonate cladding and the roof overhang. Relatively high humidity levels in the greenhouse would also prevent the timber from drying out.

3 Flexible membrane infill:

A tensile roof structure system that deflects easily under wind pressures, and that is at the same time connected to a fairly rigid façade system, calls for an intermediate connection that allows both interfaces to behave independently. Due to the façade skeleton's fixed height and the roof structure's changing levels, a flexible material is needed that could easily cover any shape of opening and could be fixed to both assemblies without too much difficulty.

ETFE (ethylene tetrafluoroethylene) has been used since the seventies as a means of covering organic-shaped structures. In recent years, ETFE has developed into a versatile transparent material with exceptional chemical properties. Texton, its current trade name, is composed of three layers of custom-shaped ETFE sheets fused together to form part of a pneumatic system restrained by aluminium extrusions. The cushions formed in this way are inflated with low-pressure air. See Figures 7.12-7.14.

This flexible, transparent material is visually and physically light. It is able to follow the contours of the roof and can serve as a seal between the roof and the façade.

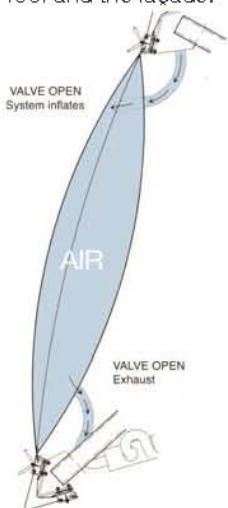


FIG 7.12 ▲

▲ FIG 7.13

FIG 7.14 ▶

FIG 7.9



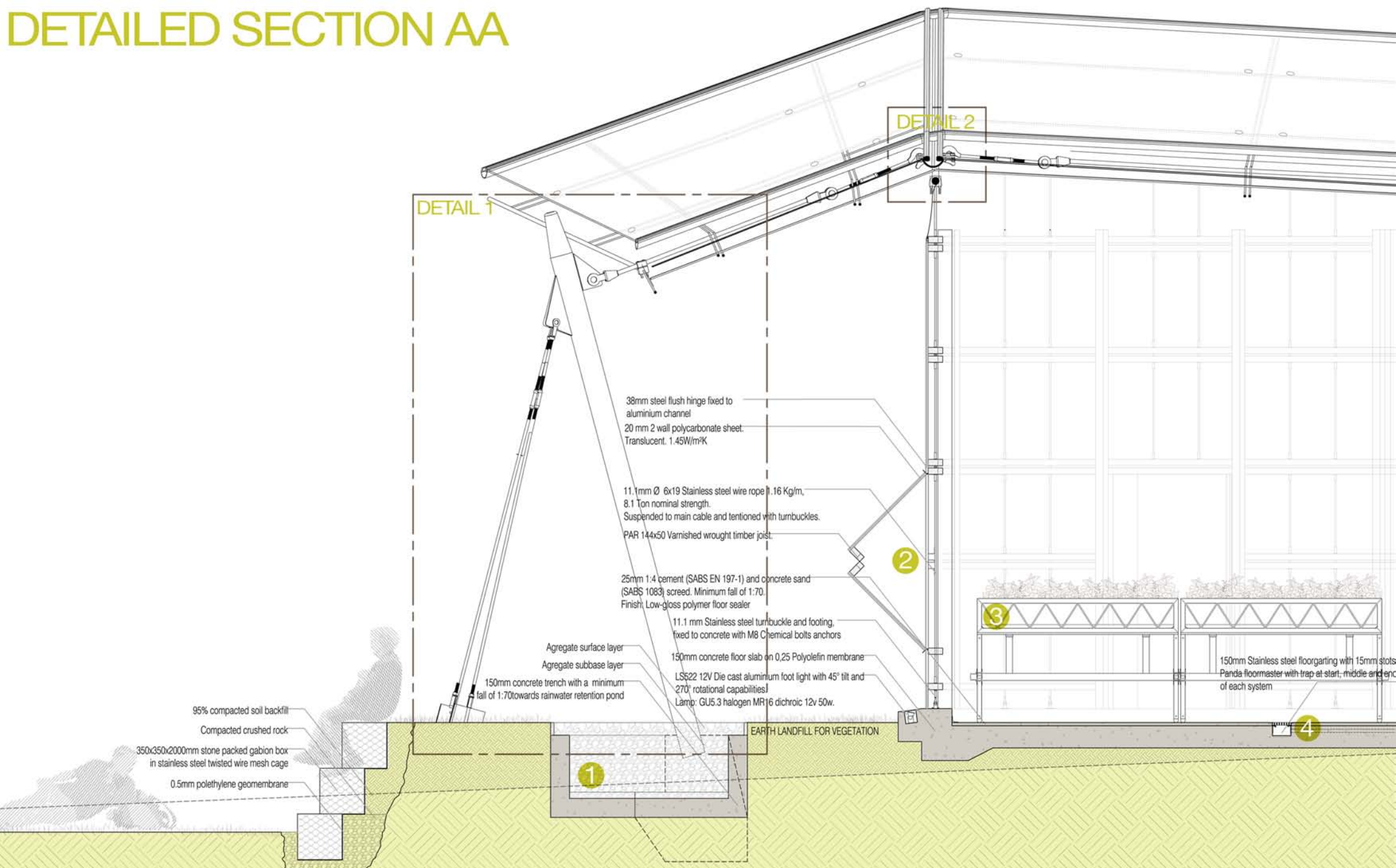
FIG 7.8 ▲

FIG 7.11 ▶

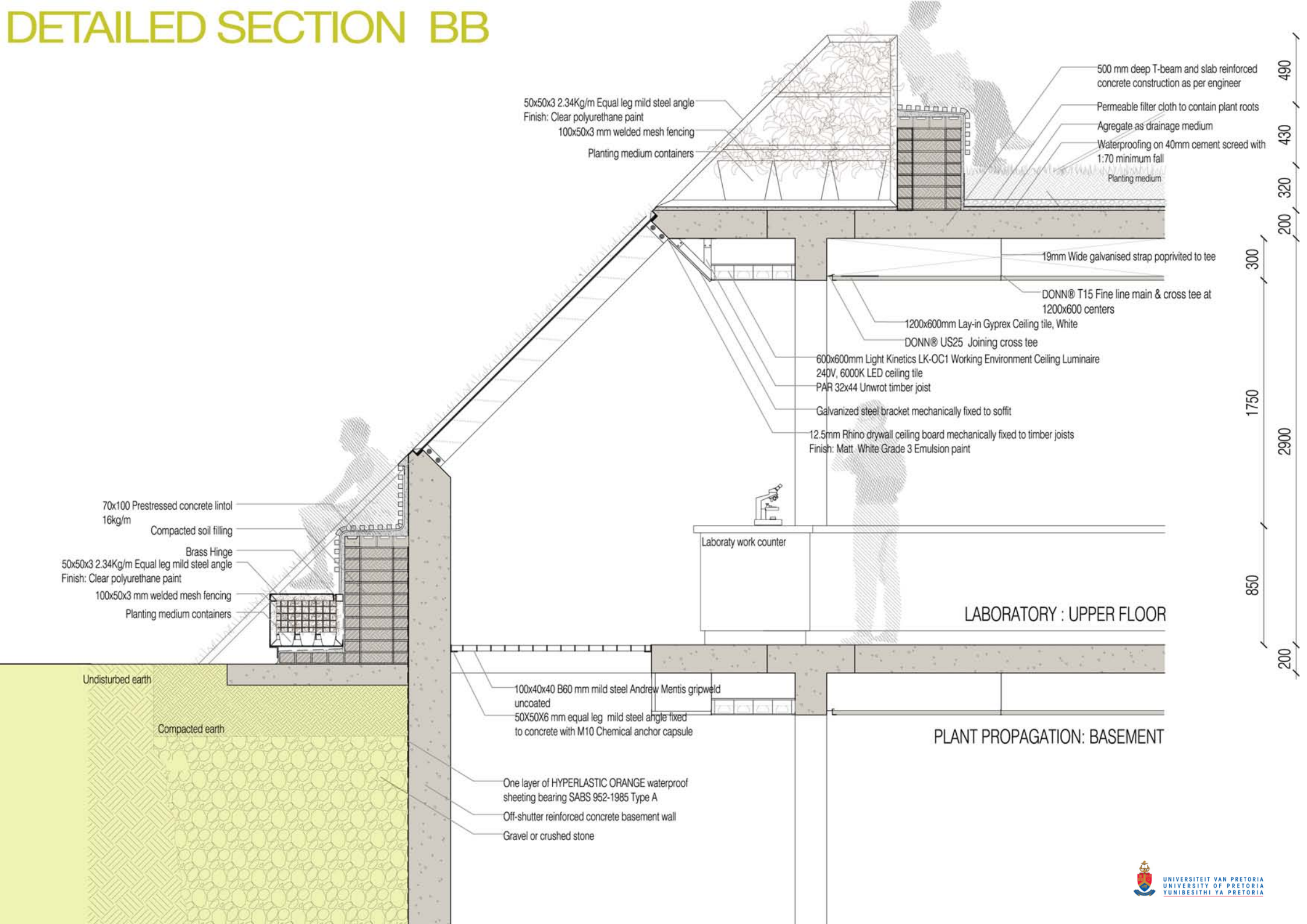
FIG 7.10 ▼



DETAILED SECTION AA



DETAILED SECTION BB



4 Growing out greenhouse – Hydroponic systems:

Hydroponics is the commercial practice of growing plants without soil and by only immersing their roots in aerated nutrient solutions. It usually uses some type of substrate (gravel, rockwool, foam etc.) to support the plant, but the roots are always saturated by a recirculating nutrient solution (Resh, 1993:9). Hydroponics are successfully used commercially these days to propagate fruits, vegetables, herbs and flowers.

Different hydroponic systems are more suitable for cultivating certain plant species than others. For the research purposes of the proposed facility, the following three methods of hydroponic plant propagation were selected to ensure that a vast array of plant species can be cultivated.

PLEASE REFER TO THE **GROUND FLOOR LAYOUT PLAN: HYDROPONIC GROWING OUT GREENHOUSE**

System 1: Water raft

A water raft system is a typical water-culture bed system where plant roots are entirely immersed in a re-circulating nutrient water solution. The system is fairly static with a circulation of approximately 2-3 liters per minute. The solution runs through a nutrient tank where it is aerated by an air pump, chilled in a refrigeration unit and pumped back (Fig. 7.15). On the nutrient solution's return to the beds, it is passed through an ultraviolet sterilizer. Plants are kept in position with Styrofoam sheets (Fig. 7.16).

FIG 7.16 Hydroponic raft system (Resh 2002:138)

FIG 7.15 Hydroponic nutrient tanks (Resh 2002:133)

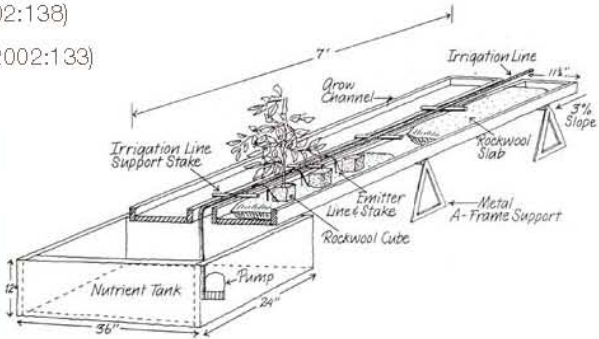
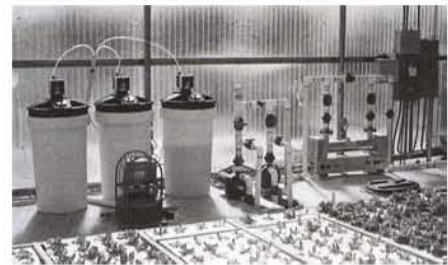


FIG 7.18 **FIG 7.17**

System 2: Rockwool culture

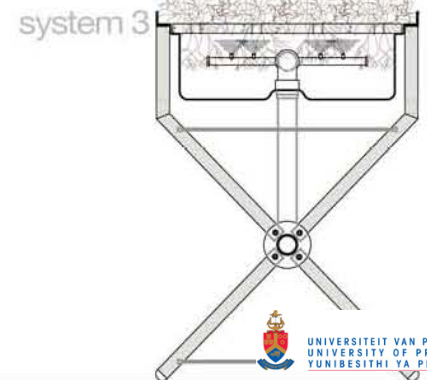
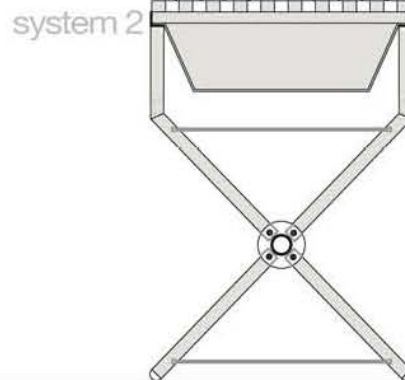
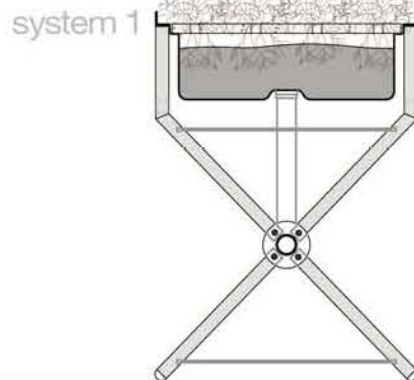
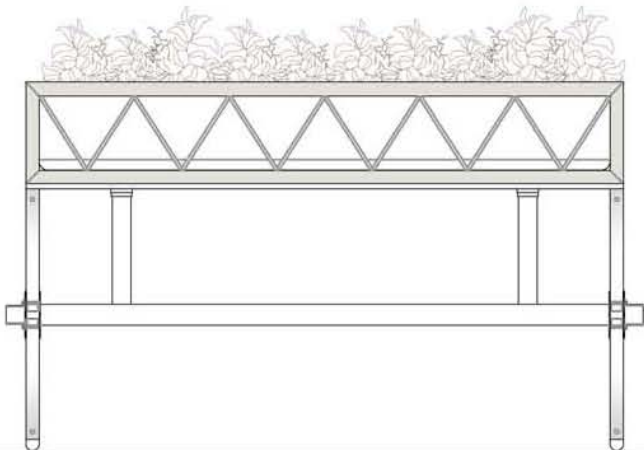
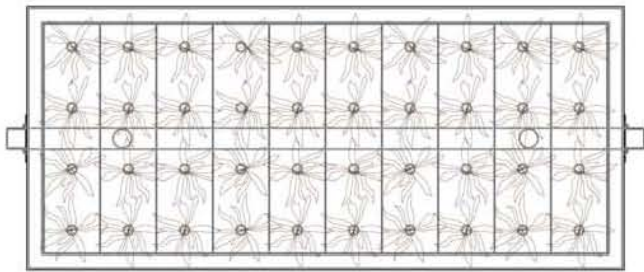
Rockwool culture is arguably the most common method of hydroponic plant propagation. Rockwool is an inert, fibrous material manufactured by heating a mixture of limestone, volcanic rock and coke (See Fig. 7.17 depicting rockwool cubes). It is 95% porous, but has a high water retention capability and drains well. This allows for effective air exchange with plant roots (Resh 1993:73). Figure 7.18 illustrates a basic rockwool culture system that is used in many greenhouses.

Rockwool culture generally entails an open, non-recycling hydroponic system in which nutrients are fed to the root of the plant via an emitter and drip line.

System 3: Aeroponics

Aeroponics is argued by experts to be the truest hydroponic system. Plant roots are suspended in mid air inside a planting tray and kept at 100% humidity. The nutrient solution is sprayed directly onto the plant roots with a fine spray. The two biggest benefits of the system is the fact that when the plant roots are suspended in mid-air they absorb much needed oxygen. This speeds up the metabolism of the plants so that they can grow up to 10 times faster than in regular soil. The second benefit of using such a system is that the water temperature can be controlled very accurately and therefore a much wider array of plant species can be propagated in this way.

5 Interior floor drains wit trap at both ends



7.4 Critical connections:

7.4.1 Detail1

STRUCTURAL SUPPORTS 1:20

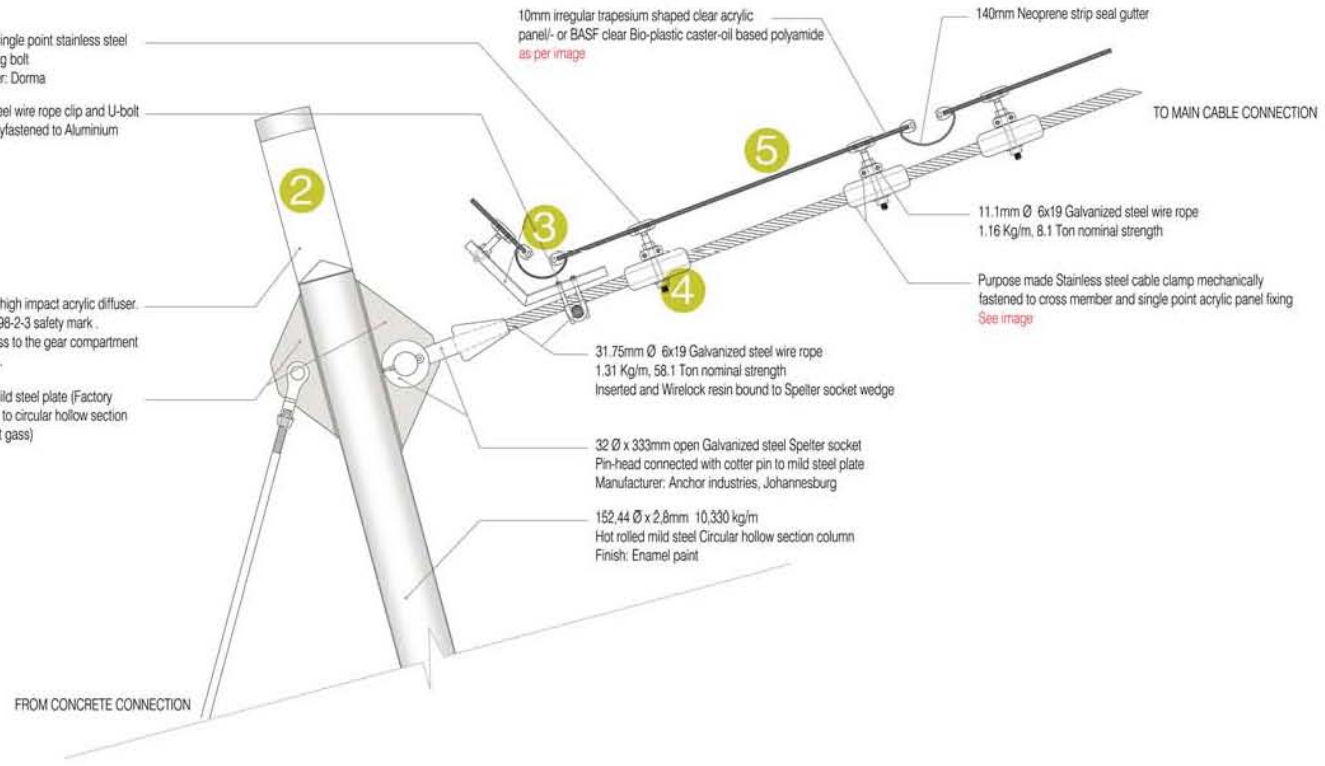


BEKA CH Column Lamp compartment with a clear high impact acrylic diffuser. 150W metal halide lamp adhering to the SANS 60598-2-3 safety mark. Control gear housed within the Steel column. Access to the gear compartment gained through an access door in the steel column.

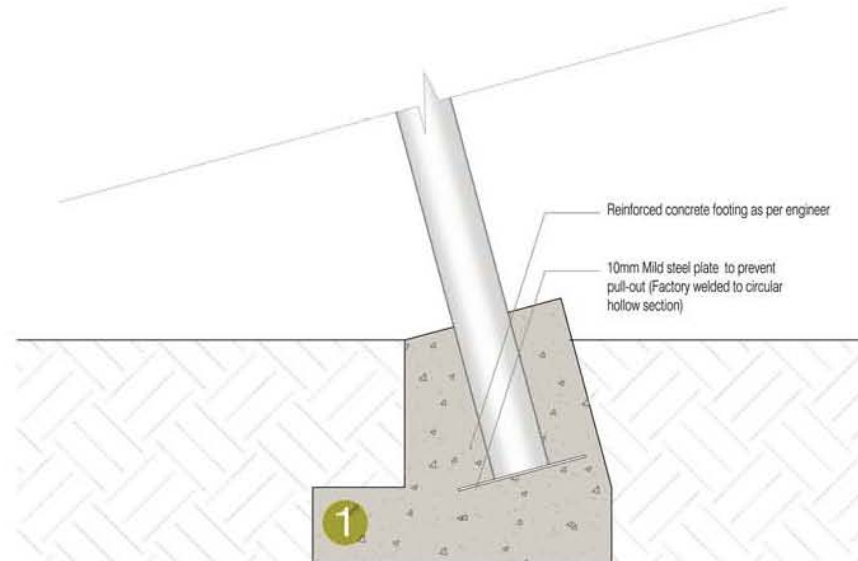
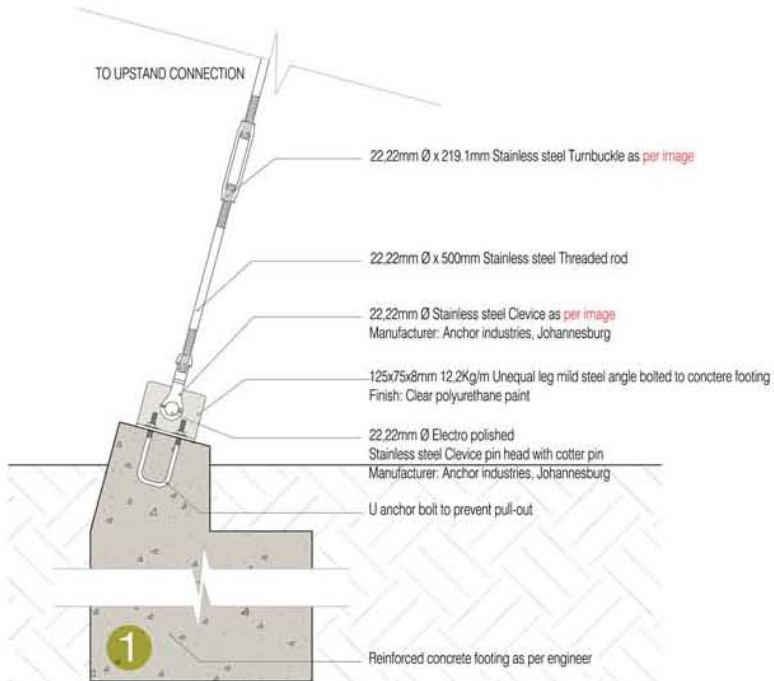
8mm Mild steel plate (Factory welded to circular hollow section with hot gass)

36.5mm Ø single point stainless steel Canopy fixing bolt
Manufacturer: Dorma

Stainless steel wire rope clip and U-bolt mechanically fastened to Aluminium channel



TO UPSTAND CONNECTION



1 Column foundations:

The column foundations of the tensile structure must be designed in accordance with SABS 0161. The foundation depth may vary depending on the tensile forces that the support must resist. The foundation shape as illustrated by the sections allows for the weight of the soil to exert a pressure that will help anchor the support more effectively.

2 Ambient column lighting fixtures:

The luminaire fitting at the top of each structural support of the roof is a modified system from the BEKA CH lighting column range. The off-the-shelf system makes use of a GRP (glass reinforced plastic) column that is bolted to a foundation. The standard system has control gear housed within the GRP. The same system is applied in the case of the proposed facility, apart from the fact that the GRP column is replaced with the structural mild steel columns of the building structure. For reference purposes please see Fig. 7.19. The following specifications apply to the luminaire fitting as provided by BEKA:

- The lighting sculpture consists of a separate lamp compartment with a clear diffuser for use with a 150W metal halide lamp.
- The control gear is mounted on a removable gear tray and is suitable for operation with the specified rating of the lamp on a 230V +3%/-10% 50 Hz single-phase system.
- All internal wiring is coated with Teflon® protective sleeves to prevent damage due to possible abrasion.
- HQI 150W lamp, 12000 lumen
- The luminaire bears the SANS 60598-2-3 safety mark.



FIG 7.19 BEKA CH Lighting column (Product catalogue)

3 Roof gutters:

a) Run-off water calculations:

ROOF PORTION	AREA (m ²)	RELATIVE PITCH (%)	FURTHEST RUNOFF LENGTH (m)
1	400	8	21.74
2	145	9	12.22
3	265	14	21.74
4	410	23	24.7
5	125	10	11.21
6	585	6	34.13

RUNOFF COEFFICIENT C

Impermeable hard surfaces:

Concrete	0.8-0.95
Asphalt	0.7-0.95

Permeable surfaces:

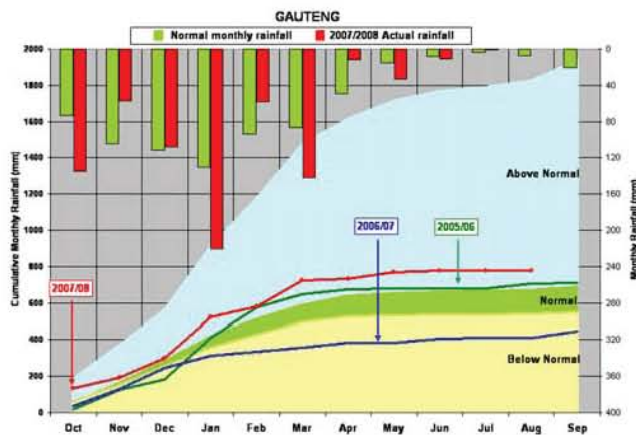
Lawns, well drained (sandy soil)	0.10-0.15
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A relative coefficient of **0.90** was taken for the Acrylic roof sheets

RETARDANCE COEFFICIENT (C_r)

Smooth asphalt	0.007
concrete pavement	0.012

A relative retardance coefficient of **0.055** was taken for the Acrylic roof sheet panels



	Rainfall depth (mm)	Rainfall duration (min)	Rainfall max rate (mm/h)	Runoff volume (m ³)	Run-off peak (m ³ /s)
Minimum	0.40	20	2.40	264.00	0.10
Maximum	21.03	120	64.80	12 601.00	5.15
Median	3.81	64.17	12.00	2 409.00	1.63
Mean	7.12	71.03	23.60	4 543.15	1.77
St. dev.	6.84	27.37	23.87	4 013.65	1.48

Maximum rainfall intensity for Gauteng = **64.80 mm/h**

RUNOFF DISCHARGE (Q=V.a, Velocity x Area of flow)

ROOF PORTION	FLOW TIME (s)	DISCHARGE (m ³ /s)
1	7.9	0.006
2	5.7	0.002
3	6.6	0.004
4	6	0.006
5	5.3	0.002
6	11	0.009

REQUIRED SIZE OF GUTTER CHANNELS:

Using the n-value of Brass and Glass for the acrylic panels as = **0.013**

ROOF PORTION	MINIMUM FULL GUTTER SIZE (mmØ)	MINIMUM HALF GUTTER SIZE (mmØ)
1	30.7	40.1
2	19.3	25.4
3	23.1	30.2
4	24.6	32
5	19.1	24.6
6	36.8	48

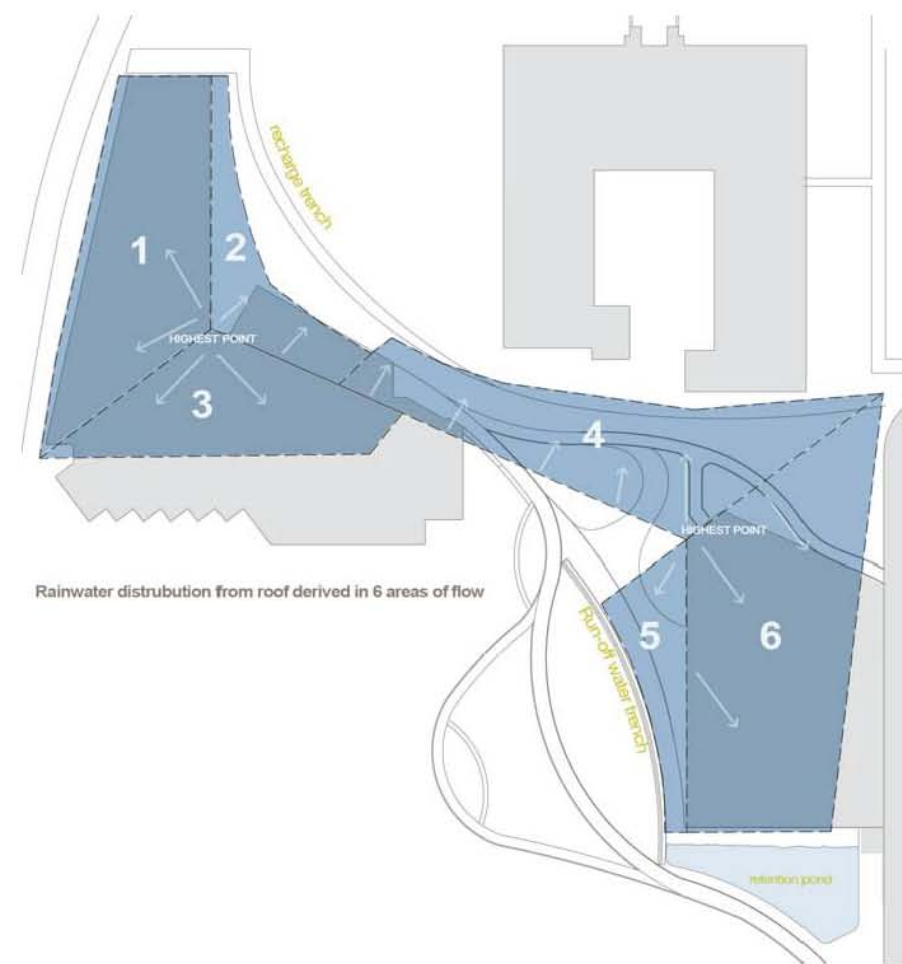


FIG 7.20 Neoprene roof gutter system Munich Olympic stadium, Germany (Nerdinger 2005:268)



FIG 7.21 BASF Wabo® gutter flex channels (Product catalogue)



b) Gutters:

- Acrylic bracket upstands:

As shown in Fig. 7.20 and Detail 1, acrylic panels are fixed at oblique angles on the periphery of the roof. This is to direct water to dedicated discharge points when no rainwater collection trench is provided below.

- Neoprene channels: Where the acrylic roof cladding panels meet, neoprene BASF Wab® gutter flex channels form a flexible joint between the panels and also serve to drain away excess rainwater (Fig. 7.21). The gutters have almost 100% flexibility and are fixed with an adhesive tape to the underside of the acrylic panels. Optional small drainpipes can be installed at 7,5m centre to centre intervals to handle excess water over short periods of time.

4 Cable clamps and point fixings:

Cable nets are made up of cables connected at their intersections and held together by cable clamps. As cable net curtain walls are used more frequently these days, there are already numerous manufacturers that supply these combined joints. See Figures 7.22 and 7.23.

5 Roof cladding – material selection:

	Acrylic (Polymethylmethacrylate)	Polycarbonate	Bio-plastic castor-oil polyamide
Corrosion resistant	✘	✓	✘
Impact resistant	✘	✓	✘
Stiff	✓	✓	✓
Strong	✓	✓	✓
Tough	✘	✓	✘
UV resistant	✓	✓	✓
Wear resistant	✘	✓	✓
Flame retardant	✘	✓	✓
Opacity	High	High	60%
Recycle potential	High	High	High
Price	Low	High	High

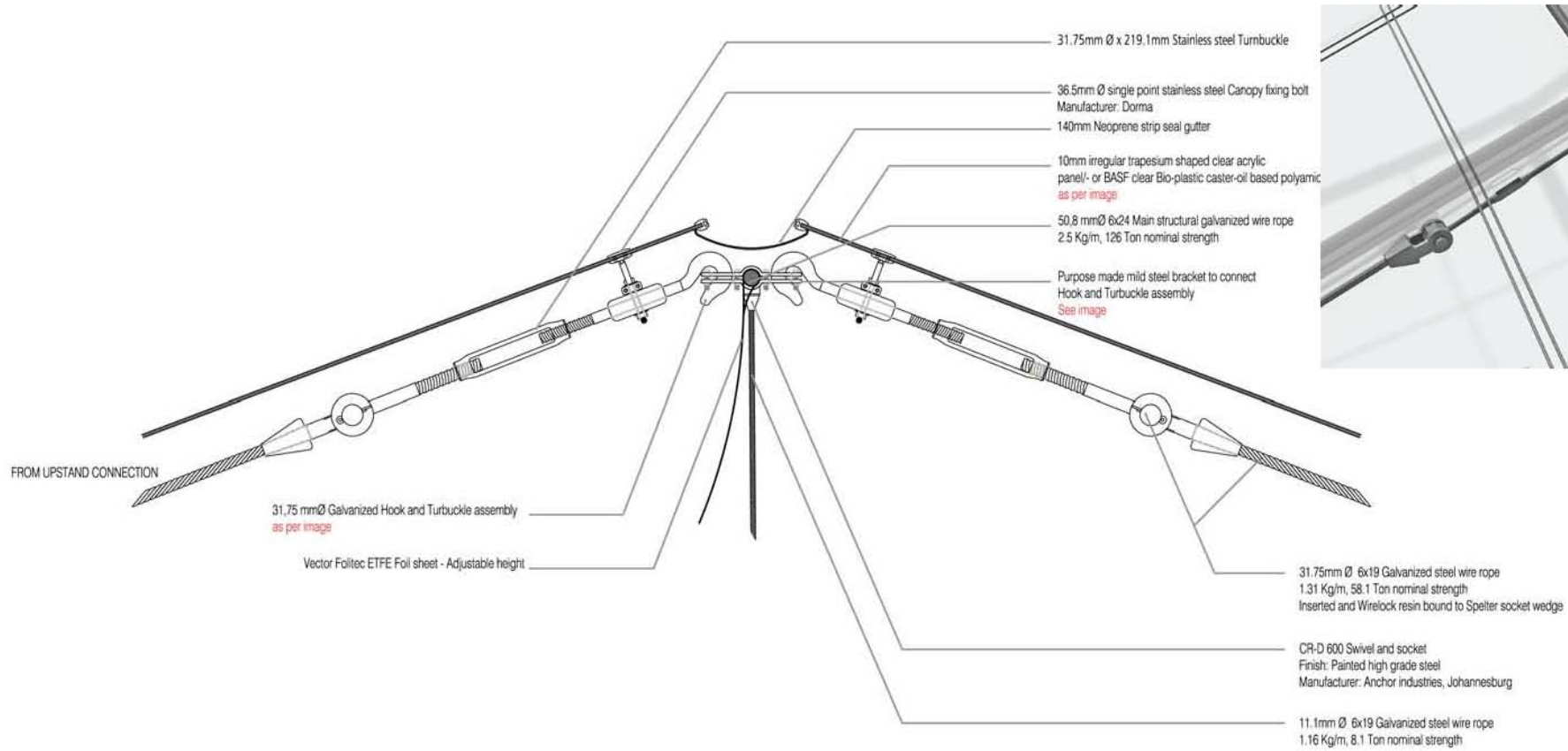


FIG 7.22 ▲

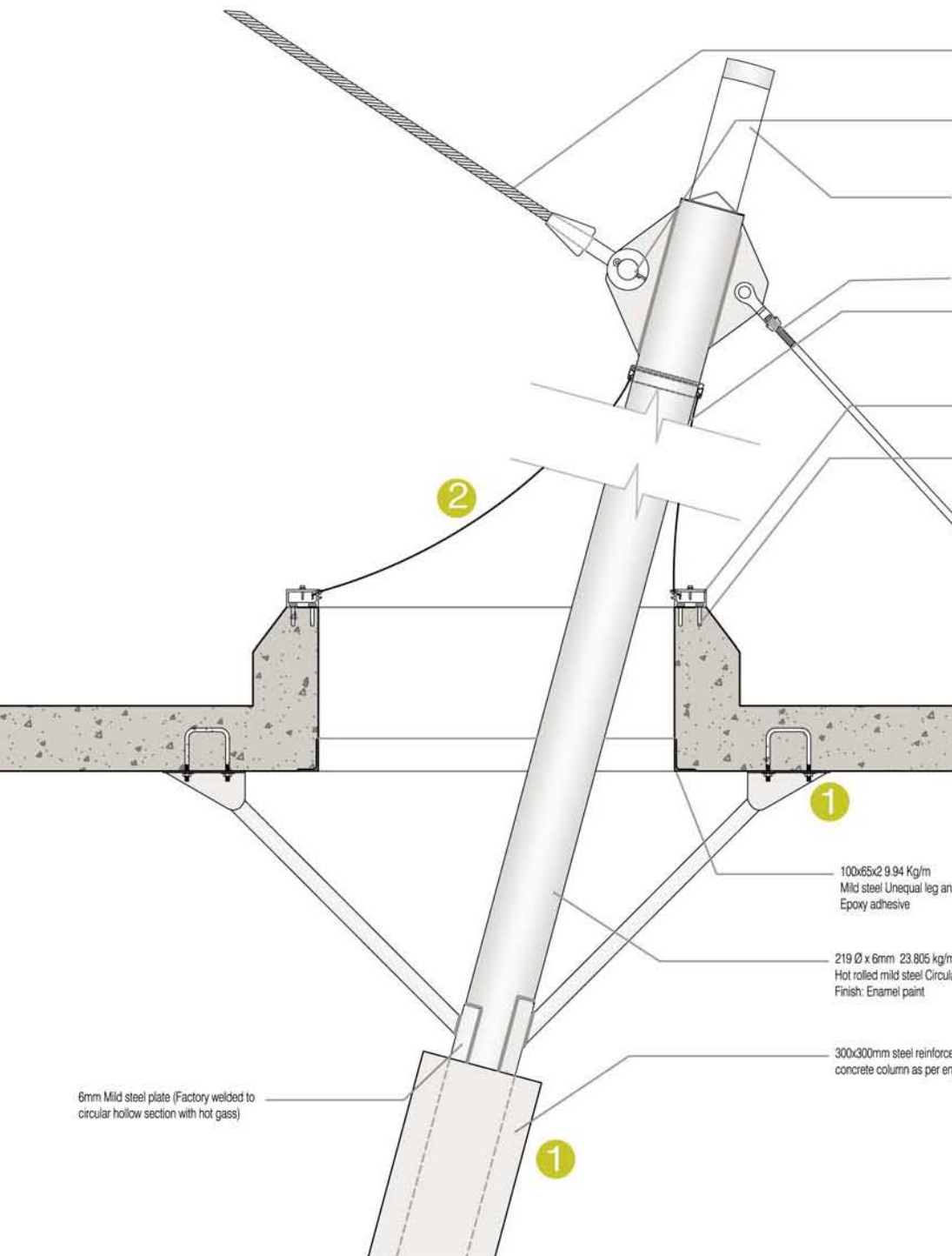
FIG 7.23 ▼



MAIN CABLE TO SECONDARY CABLE CONNECTION 1:20



7.4.3 Detail 3
 CABLE STRUCTURE TO FIXED STRUCTURE CONNECTION 1:20



- 31.75mm Ø 6x19 Galvanized steel wire rope
 1.31 Kg/m, 58.1 Ton nominal strength
 Inserted and resin bound to Spelter socket wedge
- 32 Ø x 333mm open Galvanized steel Spelter socket
 Pin-head connected with cotter pin to threaded rod end
- BEKA CH Column Lamp compartment with a clear high impact acrylic diffuser.
 150W metal halide lamp adhering to the SANS 60598-2-3 safety mark.
 Control gear housed within the Steel column. Access to the gear compartment gained through an access door in the steel column.
- 22.22mm Ø x 500mm Stainless steel Threaded rod
- Vector Folitec ETFE Foil sheet - Adjustable height
- Folitec F15 Aluminum extrusion with shim as required between F15 extrusion and concrete upstand
- M10 Chemical anchor capsule
- TO CONCRETE CONNECTION

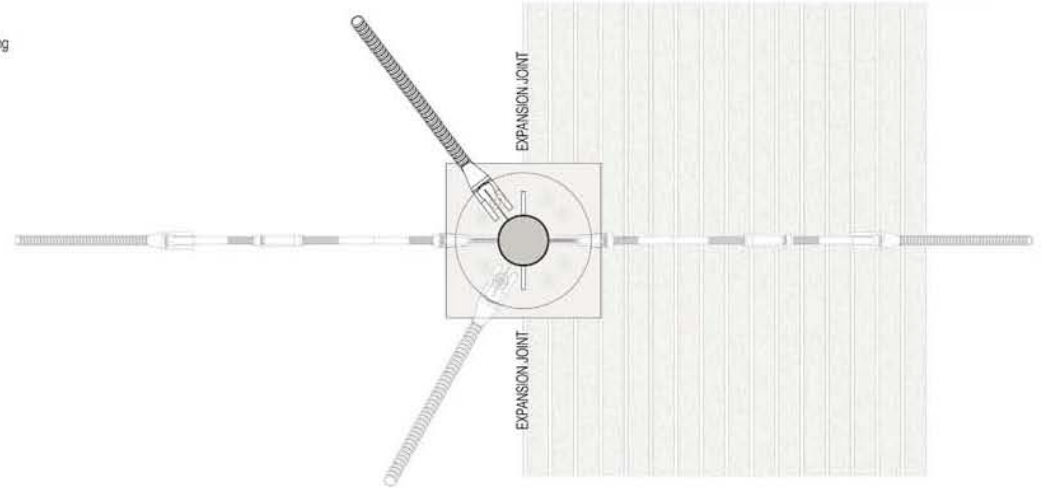
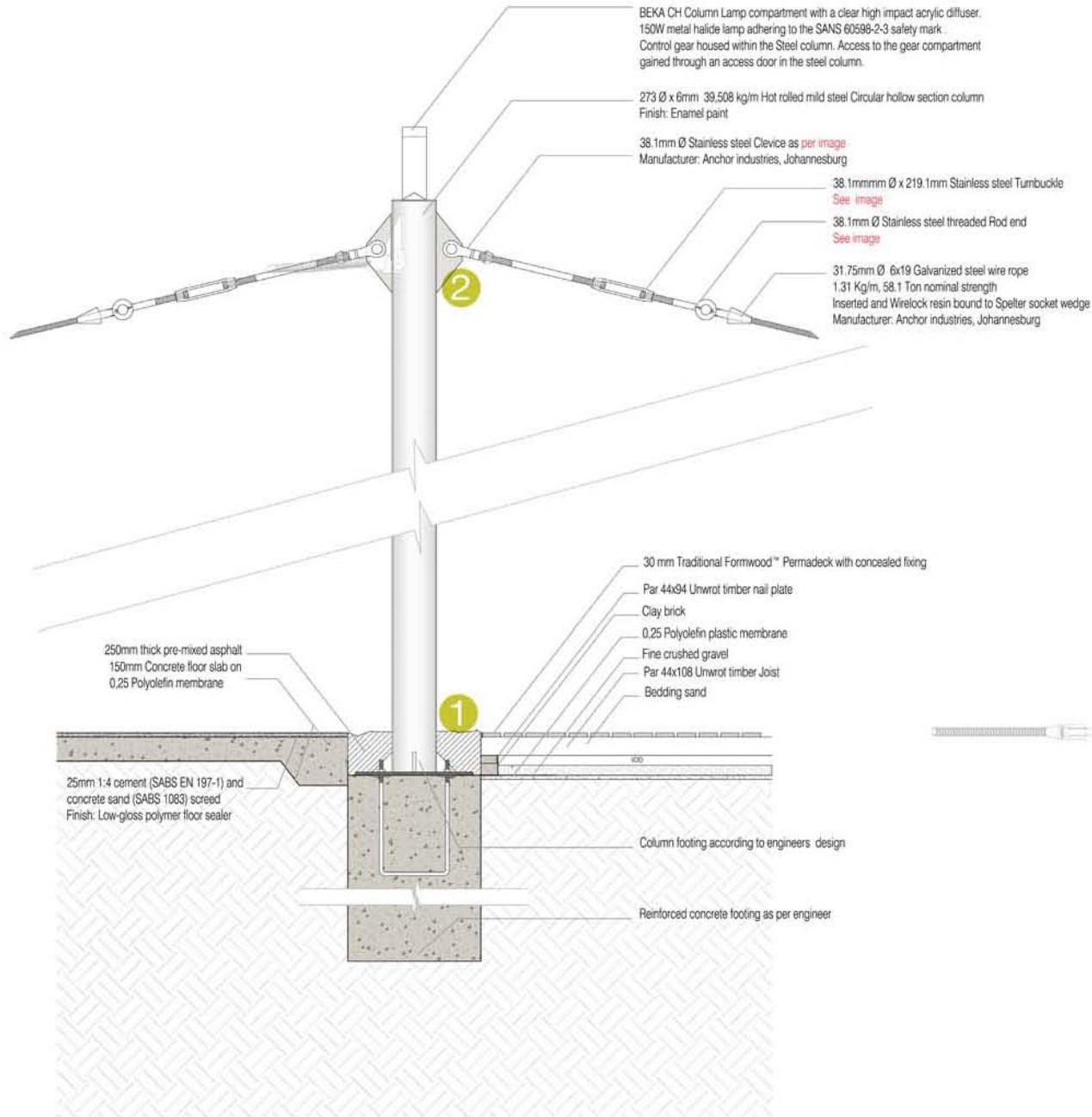
6mm Mild steel plate (Factory welded to circular hollow section with hot gass)

- 100x65x2 9.94 Kg/m
 Mild steel Unequal leg angle fixed to concrete with Epoxy adhesive
- 219 Ø x 6mm 23.805 kg/m
 Hot rolled mild steel Circular hollow section
 Finish: Enamel paint
- 300x300mm steel reinforced off-shutter concrete column as per engineer

- 1 Live loads and structure deflection:
- 2 Membrane infill - tent



7.4.4 Detail 4
 MAIN SUPPORT COLUMN 1:40



DETAIL 5: Primary support column

1 Concealed column footing

2 Force distribution and required connections for stability:

Figure 6.24 illustrates the hierarchy of forces that are dealt with at a critical node. From the main support the primary cable keeps the column stable by directing the forces into three appropriate directions, whilst the secondary cables and cable net evenly disperse forces caused by loads induced by the roof cladding across the area of the structure.

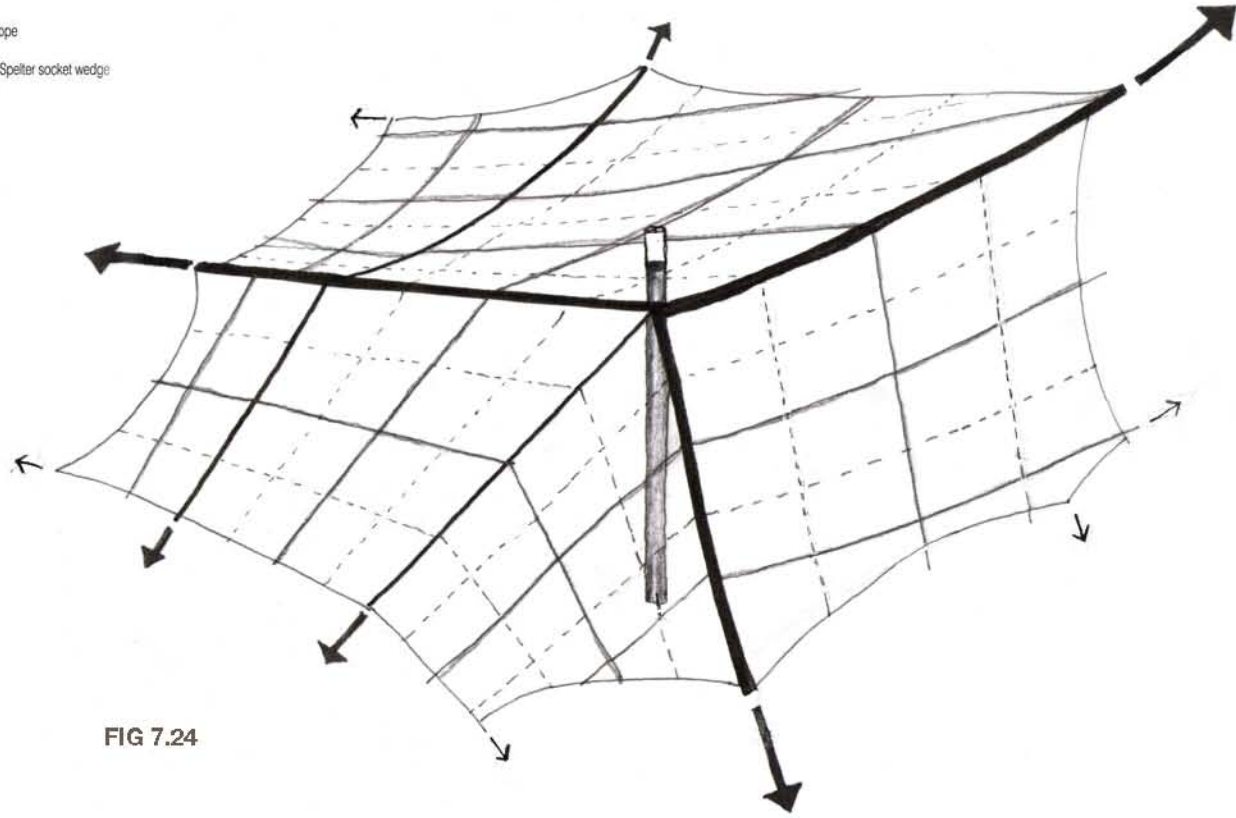
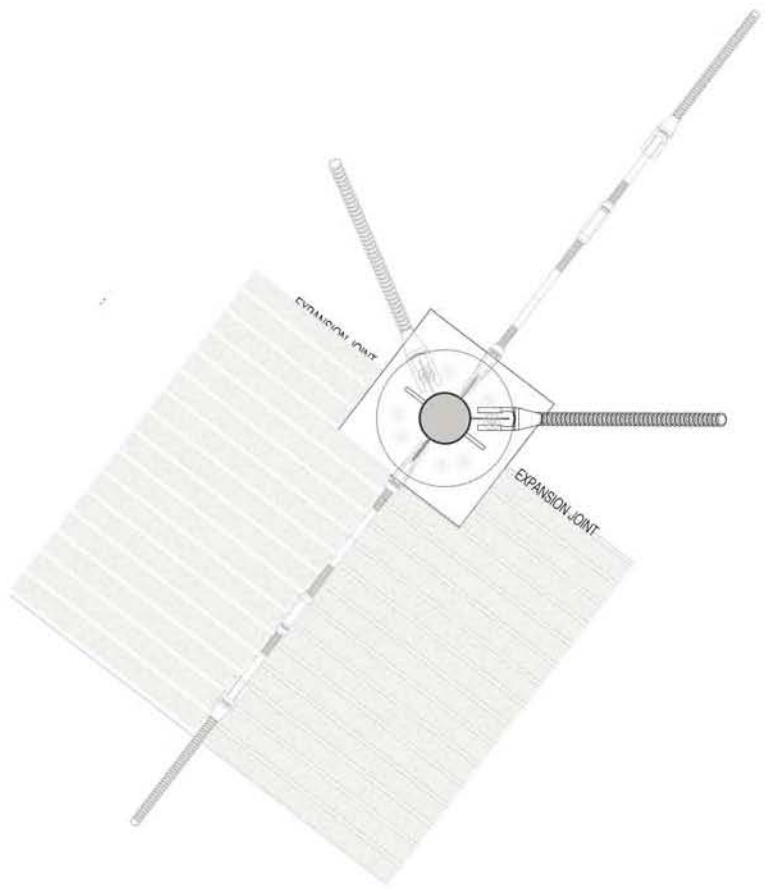
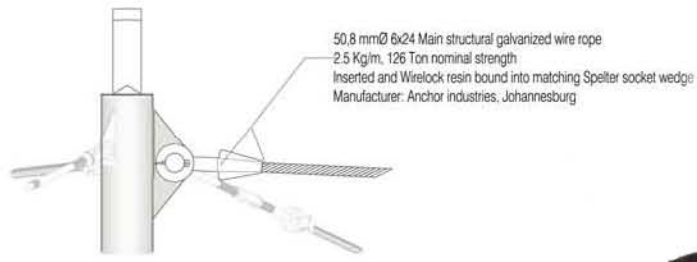


FIG 7.24

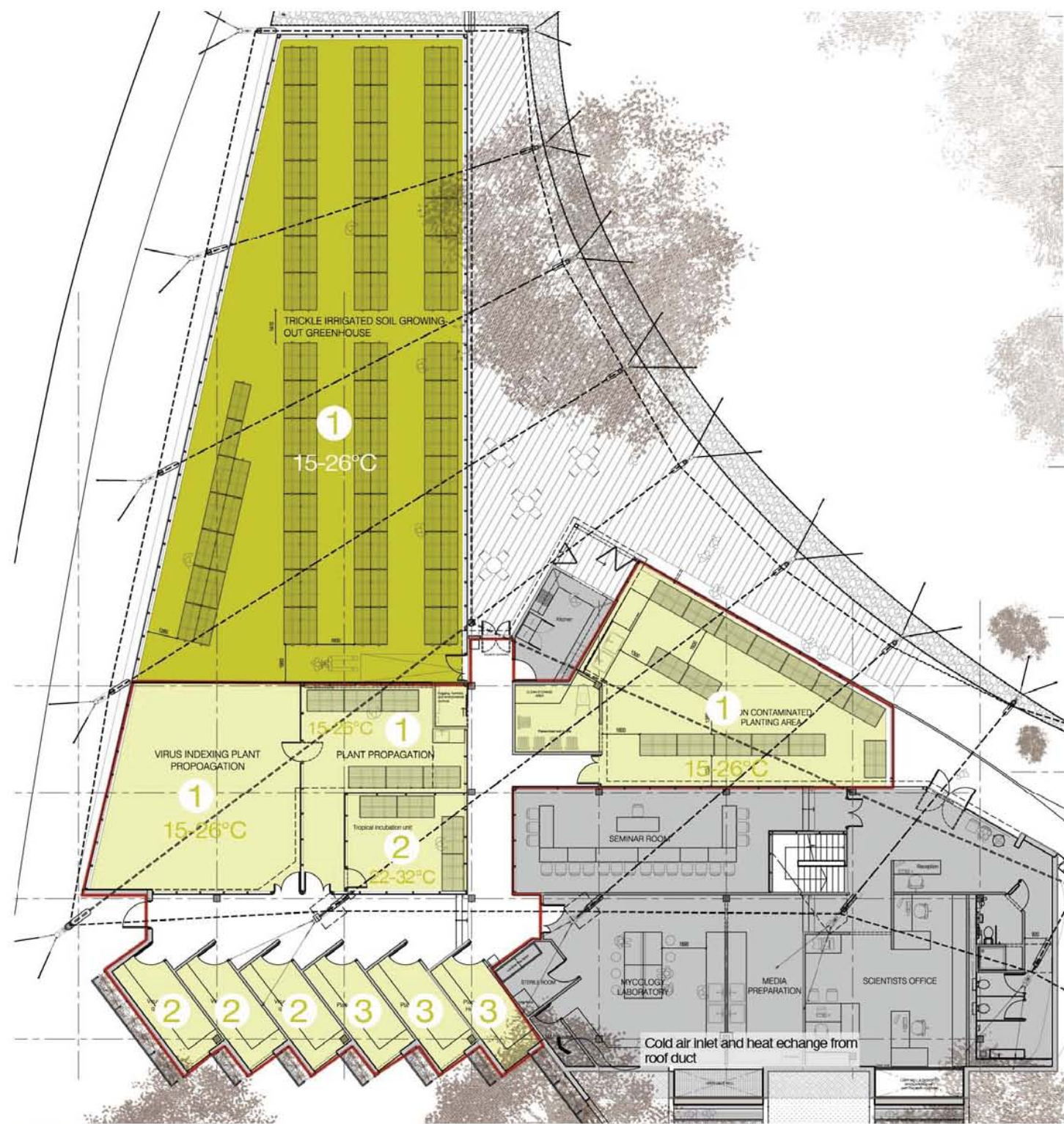


FIG 7.29 Ground floor growth rooms



FIG 7.30 Basement growth rooms

FIG 7.31 Natural cross ventilation in greenhouses

