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The organic nature of the built form required the selection of an exceedingly plastic and sculptural material. Rammed earth was considered, but the high shrinkage quality of the earth on the site raised the concern of brittleness. The sculptural ability of the concrete can be increased by adding super plasticizers to the mix. These negate the necessity for vibration, thus the achievable form was less limited.

The variability of concrete was also deemed appropriate to the scheme. The texture can be manipulated by exposing the aggregate, brushing the concrete and by the type of shuttering used. Pigment can be added to change the colour of concrete.

Curves can be achieved with radius wall shuttering. Cost for the shuttering can be maximized by limiting the amount of different radii used in the design.

Adding fly-ash to the concrete offers a more sustainable solution to a product traditionally considered environmentally unfriendly.

Copper is a natural material that changes its appearance over time. This indicates the connection to the natural environment that is at the core of the project.

The material is well suited to the organic form of the roofs as its pliability allows for different methods of fixing that is adaptable to the shape of the surface.

Although expensive, it is also a durable material that will last the lifetime of the building with virtually no maintenance needed.
6.3 Gridshell roof

6.3.1 Background

Gridshell construction is a timber lattice that is constructed on a flat plane and then lifted or lowered into the organic shape required. The structure has the ability to span great distances unsupported with the minimal use of material.

In order to generate a structurally sound form, a hanging chain model can be constructed. The hanging chain is an inverted representation of a catenary curve structural shape. The chain is in pure tension which translates into pure compression when uplifted, dispelling tensile and bending forces (Graefe 2009: 732). This method of form-finding was used in the past by Antonio Gaudi in buildings such as the Sagrada Familia, where the organic roof structure was conceived by a complex chain model which was then measured, drawn and directly built (Graefe 2009: 735). Today, some digital aids exist to generate catenary structural forms, that simplify the translation of the model to workable drawings. This simplifies the process, as an architect is now consuming time in creating detailed drawings and often inaccurate when translated into reality (Klas 2004: 1). The modelling of geometry and physics of the gridshell also minimises the occurrence of breakages in the timber lattice, the type of tool being unavailable to the author, the old method of a hanging chain model was built and measured to generate the organic form needed for the scheme.

6.3.2 Laminated timber

The laminated timber laths are layered into a double curvature and connected at the intersections with pinned joints. The connections allow for movement: the grid has the ability to skew into parallelograms to better transfer the load to the edges of the structure. The nodes are clamped by steel plates in between the laths and connected by threaded bolts.

The form of the Sagrada Familia by Gaudi in Barcelona, was generated by a hanging chain model.
6.3.3 Construction

The construction process entails the construction of the lattice system on a flat surface; after which, the form is achieved by lowering or raising the frame. In the case of the Weald Downland Museum, an adjustable scaffolding system was employed to lower the grid frame into position. The construction of the Mannheim Multihalle, however, entailed the grid to be raised with scaffolding towers, hydraulic jacks and forklift trucks. (Orton 1988:440) In this case, the structural supports and non-loadbearing walls will be constructed before the roof, the adjustable scaffolding constructed over the structure and the lattice lowered into place.

Along the edges, the laths are sandwiched between plywood layers and connected to a steel beam. The sizeable beam is constructed from hollow steel sections, factory constructed and connected on-site. This construction absorbs any lateral forces ensuring that only downforces are exercised upon the supporting columns. Further rigidity is achieved by cladding the lattice with plywood before the cover material is added.

6.3.4 Precedents

The first gridshell structure was designed as a temporary exhibition space for a flower festival in Dorset in South-West England by the German architect-engineer, Frei Otto. It consists of a lightweight structure that spans 60m and is covered by a PVC-coated polyester fabric. Being the first of its kind and built in pre-computer times, the breakages and physical prediction of the form were problems that could be improved on with contemporary computer technology. (Orton 1988:440)

The architects of this project, the Edward Cullinan Group, are known for a low environmental impact approach to architecture which is clearly visible in the scheme. The use of local material was later simulated in the Saville building where local timber from the park grounds where the building is located was used for the gridshell roof structure. The Saville Building, designed by the Glen Howells, compares to the Mannheim Multihalle at 90 x 25m and is supported by a steel tube rim. (annular.org 2006) The flatness of the gridshell roof blends into the surrounding landscape, as well as shading the interior and preventing the necessity of artificial cooling. (annular.org 2006)
6.3.5 Development of the gridshell roof
Copper sheet metal

The most appropriate cover pattern for the copper sheet metal is a diagonal flat seam system. Diamond shaped copper panels are folded along the edges to form flat seams. The diamond shape easily accommodates the irregular curved shape of the roof. Where there is a low roof pitch, the seams are soldered, while the seams of a greater pitch should be treated with sealant (copper.org)
Where flat roofs are used, there are various benefits to establishing vegetation.

The visual impact of a green roof when viewed from a higher vantage point is far less than that of a concrete flat roof. A vegetated roof also makes optimal use of the surface area, as it is possible to cultivate vegetables and herbs on a flat roof. Further, the thermal advantages of a green roof are possibly the most important. The thermal mass of the earth greatly improves the insulation value of a green roof.

Different types of systems have different requirements such as the depth of the substrate, the types of vegetation that can be planted and the maintenance required. All of these variables determine the structural requirements and cost of establishing and maintaining the green roof.

An extensive green roof type houses vegetation types that only need a shallow substrate, such as grasses. The depth of the substrate would generally be 150mm. The depth of the substrate increases when larger plants such as shrubs and trees are desired. An extensive green roof has a greatly escalated price due to the deep substrate and subsequent structural requirements, as well as higher maintenance and irrigation costs.

The vegetation of an extensive green roof can range from simple turf and sedum to a biodiverse roof that entails the relocation of growth medium from the relevant site to the roof garden. This is done in order to establish vegetation indigenous to the site as well as supporting naturally occurring ecosystems.

6.5 GREEN ROOF

TYPICAL VEGETATED ROOF SECTION

Tapered roof edge

Waterproofing

Screed

210mm Roof slab

Drip joint

200 x 400mm Incorporated slab

300mm slab

Geotextile

Waterproofing incorporating root control

Screed with a minimum fall of 1:50

Reinforced concrete slab

Substrate expanded with vermiculite

150mm for grass and sedum

300mm for small plant species

600mm for shrubs

Diagrams 266 to 268

Diagrams 269 to 271

Fig. 270

Roof positions

Fig. 271

Roof edge concept

Fig. 272

Roof garden scale 1:50

Fig. 273

Roof edge overview
6.7.1 Passive cooling

As Tswaing becomes very hot during the summer, an important design consideration is thermal comfort. The need for air conditioning should be kept at a minimum design goal in such a way that passive cooling is possible. The most important characteristic of passive cooling is constant air movement. This combats the build-up of heat in a space, while encouraging the cooler air to enter. Most strategies for passive cooling rely on the principle that when hot air rises and is removed, it is replaced by heavier cool air.

This can be seen in the commonly used cooling strategy called stack ventilation. The strategy depends upon high openings that expel rising hot air, creating an air void that is subsequently filled with cool air.

There are other methods that are based on the same principle, such as a trombe wall. The cavity is created with a dark wall on one side and a layer of glazing on the other. Strategic openings in the cavity regulate the flow of hot air, either into or out of the adjacent space thus alternatively heating or cooling the space.

Where the main objective is cooling, a similar but simpler solution is a solar chimney. This structure effectively vents air through the interior space. In this way, heated facades become an asset to the building instead of a problem.

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Air flow can also be influenced by the surfaces surrounding the building. Hard surfaces that are heated and reflect heat also cause air to rise, while planted surfaces result in a cool micro-climate. Thus, when these surfaces are strategically applied around the building, air flow through the building can also be encouraged.

Air flow can also be enhanced by the size of openings. Smaller openings should be provided where hot air rises, as this becomes a natural vent, sucking air from the interior spaces. Larger openings should be provided near cool areas to ensure the provision of cool air to replace the warm.

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6.7.2 Trombè wall

The massive concrete wall on the Northern and North-Western facade is articulated with sections of brick wall that act as Trombè walls, or thermosyphons. The design allows the sections to be orientated towards the sunlight for maximum efficiency.

6.7.3 External shading devices

Sizing calculations of the external shading devices establish the overhang, depth and spacing of the fins for effective shading according to the position of the sun.

**Northern facade**

Depth of overhang for 2000mm window shading

\[ w = \frac{D \times \tan(\text{solar azimuth} - \text{window azimuth})}{1 - \cos(\text{solar azimuth} - \text{window azimuth})} \]

\[ w = \frac{550 \times \tan(280° - 258°)}{1 - \cos(22°)} \]

\[ w = 222\text{mm} \]

**South-Western facade**

**Overhang**

\[ h = \frac{D \times \tan(\text{solar altitude} \times \cos(\text{solar azimuth} - \text{window azimuth}))}{1 - \cos(\text{solar azimuth} - \text{window azimuth})} \]

\[ h = \frac{550 \times \tan(50° \times \cos(22°))}{1 - \cos(22°)} \]

\[ h = 704.8\text{mm} \]

**Details**

**Trombè wall acting as thermal syphon**

**SOUTH-WEST FACADE OF STORYTELLING BUILDING**

**Scale 1:100**

**DETAIL 4 (rough)**

12:00 21 DECEMBER

Solar altitude: 87°
Solar azimuth: 44°

12:00 21 JUNE

Solar altitude: 41°
Solar azimuth: 19°

15:00 21 DECEMBER

Solar altitude: 50°
Solar azimuth: 280°
In addition to passive climate control, air conditioning systems may be necessary, especially during the warmest times of the day. Air HVAC systems are not very energy efficient, natural cooling such as an earth-coupled air cooling system can be considered.

The system relies on the fact that the temperature of the earth is much more constant than the fluctuating air temperature.

Different systems of earth coupling exist, the main categories being those that operate using water and those that operate using air. Ground-coupling water systems can be installed in a horizontal loop configuration and vertical loop configuration. However, these methods require the disturbance of large areas of the landscape and additional equipment such as a water furnace that greatly encumbers the cost of the system. As this is not desirable within the context of this project, a ground-coupled air system will be proposed.

The system consists of length of pipe laid underground with an intake a distance from the building. The air is pumped to the building with a normal air-handling unit. The air is cooled by the lowered temperature under the ground and then distributed to the building. A depth of 2-5m is recommended for a stable temperature. Piping laid underground is connected to air intake at the building at one end and connected to the air-handling system at the other end. This can be used to pre-heat or pre-cool the building and significantly reduce the mechanical cooling requirements.

The simple system can achieve a cooling effect of up to 36 W/m² at an outside air temperature of 28°C, a reduction of 11°C at an average temperature of 28°C (Pennycook 2008:36). The system can effectively pre-cool the building, requires very little maintenance and no equipment in addition to the traditional air conditioning system (Pennycook 2008:36).
The programme of storytelling hall involves a small theatre, a children’s nook, and workshop space in the semi-basement area. The theatre space contains fixed seating, casual seating and a depression in the floor with low seating. The programme will mostly entail dramatic performance, although small-scale musical performance may be possible. Thus, the acoustic performance of the building is an important design criterion. The main considerations are:

- The reduction of background noise
- “When a theatre is truly quiet, an actor can use his entire dynamic range from a shout to a whisper, and still be clearly understood.” (Brooks p.2) The art of storytelling has been explained to be a dynamic and interactive experience (chapter 5), and thus the importance of a quiet environment is reinforced by the specific programme of the building.

Historically, the main concern of the acoustic engineer and architect had been reverberation time. (Edwards 1984:133) Reverberation time is determined by the cubic volume of the room and the absorbing power of the room surfaces and contents. (Edwards 1984:133) However, little was known about the effect of the building form and the reason for alterations in the acoustic success of different building forms.

6.8 Acoustic Performance

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6.9 STORMWATER TREATMENT

In a climate such as Tswaing where parts of the year are dry and precipitation consists mainly of thunderstorms, infiltration should be enhanced to the ability of the landscape to retain water. During a thunderstorm, surface water does not infiltrate fast enough and a lot of runoff goes to waste. This also causes erosion, a real threat to the landscape or Tswaing. Therefore, measures should be taken to increase the infiltration rate and slow the flow of water down.

6.9.1 Grassed swales
A grassed swale is a landscape intervention; its design and size depend on stormwater runoff, as well as erosion control. (Maryland Department of the Environment 2000)

The vegetated parabolic channel system is constructed of replacing naturalized highly permeable soil and placing it on an embankment. (Metropolitan Council 2002) Further, the channel is designed with retention of material that slows the flow of stormwater. Vegetation should be selected for its deep root system, high stem density, and resistance to flooding. (Maryland Department of the Environment 2000)

Check dams can also be included in the design as attenuation structures where the slope exceeds 4 percent. (Maryland Department of the Environment 2000)

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6.9.2 Pervious Pavement
As the site plays host to many paths and potentially hard outside surfaces, methods of maximizing stormwater infiltration are employed. Hard surfaces increase stormwater runoff that can cause erosion and carry harmful pollutants into the water sources on the site. Retaining stormwater in the site allows improved conditions for landscape intervention as well as for gardens in service of the project. Existing paths are at risk of being damaged by erosion, especially since greater foot traffic is to be expected from visitors to the site. Treating the paths with pervious pavement not only stabilizes the earth, but does not cause the runoff problems that other hard surfaces do.

Different types of pervious pavement are used. The textured appearance and the use of gravel and grass in certain pavers may indicate transitional zones from the paths to the buildings and also echo the landscape in the built environment. These can effectively be combined with normal (pervious) paving and planted areas.
6.9.3 Rainwater Retention

Portland Water Pollution Control Laboratory

The sections are typical details of the stormwater solutions employed at the BES Water Pollution Control Laboratory in Portland.

In certain instances, where the design allows rainwater to cascade freely off a roof, or where water flows from scuppers at a height, the water may cause erosion around the buildings. To avoid a situation where hard surfaces are used to prevent this, large stones may dissipate the energy of the falling water and spread the water into the surrounding landscape. (Liptan et al 2002: 27). A gentle slope away from the building will serve as a vegetation filter. (Liptan et al 2002: 16). Check dams are constructed to slow the speed of falling water. These are constructed from non-toxic material such as stone, brick or old concrete and are a minimum length of 3000mm. The slope should not exceed 10%. (Liptan et al 2002: 25).

Planters with a pervious bottom are also beneficial to water infiltration. The reservoir of storage required can be calculated as follows: impervious area in square meter x 0.45 = reservoir in cubic meter. The minimum infiltration rate is 50mm/h. (Liptan et al 2002: 16).

The above interventions will aid the designer in creating cool planted areas around certain parts of the buildings. Microclimate can be manipulated to induce flow from cool environments to warm.

Section of a vegetation filter (not to scale)
Fig. 300

Section of a pervious bottom planter (not to scale)
Fig. 301
Having addressed black sewage disposal, one should consider the recycling of grey water. Bathroom and kitchen sinks, dishwashing machines and water points, all present on the site use enormous amounts of clean water. Grey water is defined as washwater. (greywater.com) Although grey water will become similar to blackwater if left untreated for a few days, it is a great source of minerals when used for irrigation quickly.

A grey water recycling system redirects grey water from different points to a central recycling unit, where it is filtered. The product can then be used for irrigation. (United States Environmental Protection Agency 1999: 1)

Managing the self-composting system is of the utmost importance, but simple. No specialist labour is required to maintain the system. Maintenance entails: the regular addition of bulking agents such as soil or sand to and the removal of the end product. (United States Environmental Protection Agency 1999: 6)