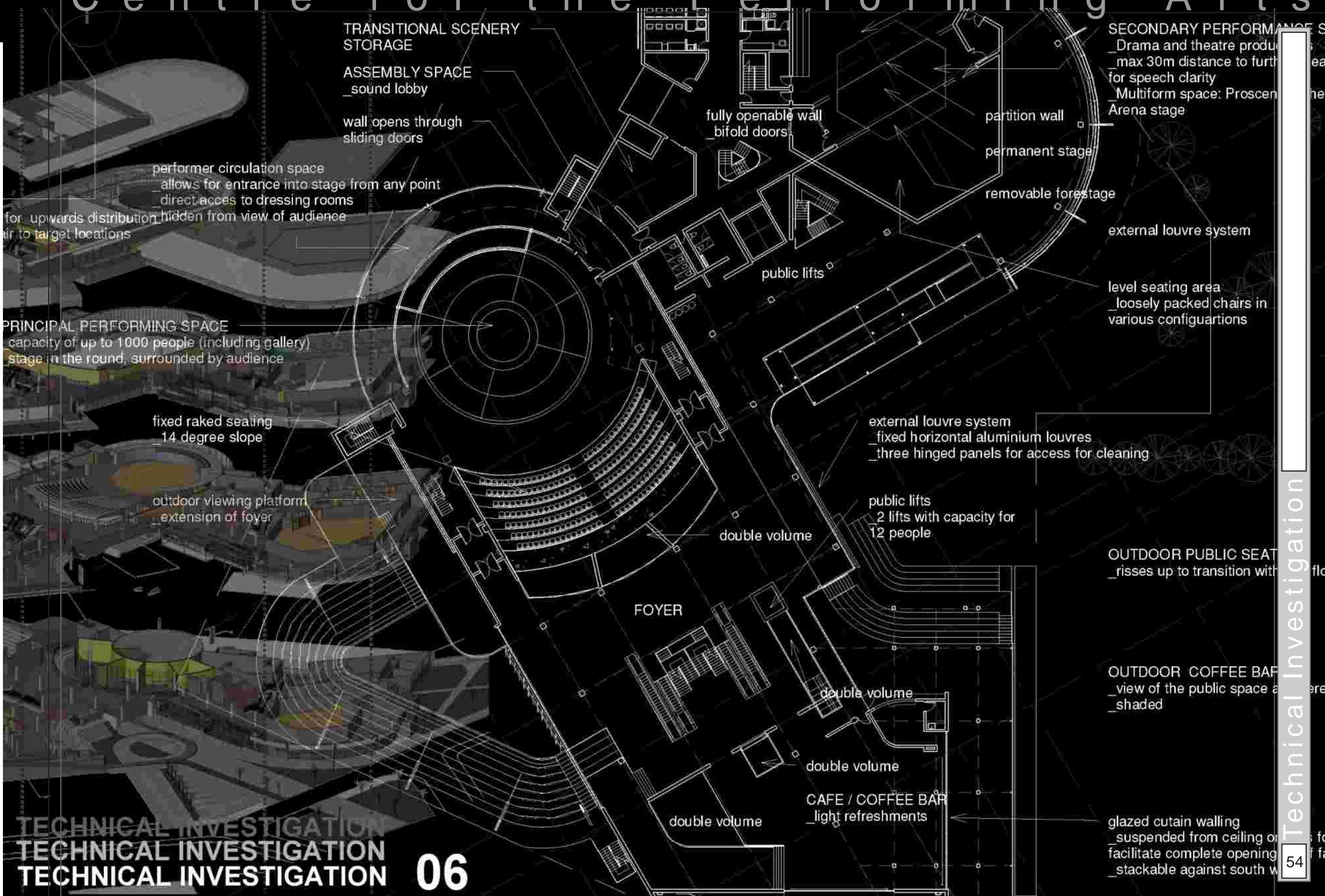


Centre for the Performing Arts



TRANSITIONAL SCENERY STORAGE

ASSEMBLY SPACE
_ sound lobby

wall opens through sliding doors

performer circulation space
allows for entrance into stage from any point
direct access to dressing rooms

for upwards distribution hidden from view of audience
air to target locations

PRINCIPAL PERFORMING SPACE
capacity of up to 1000 people (including gallery)
stage in the round, surrounded by audience

fixed raked seating
14 degree slope

outdoor viewing platform
_ extension of foyer

FOYER

double volume

double volume

double volume

CAFE / COFFEE BAR
_ light refreshments

double volume

fully openable wall
_ bifold doors

public lifts

external louvre system
_ fixed horizontal aluminium louvres
_ three hinged panels for access for cleaning

public lifts
_ 2 lifts with capacity for 12 people

partition wall

permanent stage

removable forestage

SECONDARY PERFORMANCE SPACE
_ Drama and theatre production
_ max 30m distance to further stage
for speech clarity
_ Multifunction space: Proscenium
_ Arena stage

external louvre system

level seating area
_ loosely packed chairs in various configurations

OUTDOOR PUBLIC SEATING
_ rises up to transition with floor

OUTDOOR COFFEE BAR
_ view of the public space and stage
_ shaded

glazed curtain walling
_ suspended from ceiling or
_ facilitate complete opening
_ stackable against south wall

7. Technical Investigation

7.1. Human Comfort and Climate Control

7.1.1. HVAC and Ventilation

The building will encompass a combination of cooling, heating and ventilation systems to achieve optimum indoor microclimate. Firstly, due to the contained and focused congregation of people and performer in performance spaces, these spaces are deemed to be serviced with dedicated air-conditioning systems. The system can be described as each auditorium having a separate Air Handling Units of constant volume with modulated temperature control system for ventilation (Bearg, 1993: 21).

The heating, ventilating, and air-conditioning (HVAC) systems for Auditorium space is sized and zoned to accommodate varying internal loads, which are a function of audience sizes, performance lighting loads, and projection equipment (McQuiston, 1994: 14). Air handling units with increased cooling capacity are zoned separately, with separate zones for auditorium, lobby and projection spaces, as well as separate zone for stage area from audience seating. Air supply is to be ducted through wall vents with ducted ceiling return air vents in auditorium and lobby. Other spaces to have ducted ceiling supply with return through the air ceiling plenum. Transfer ducts are specified at all acoustically rated partitions.

Humidity levels for auditoria are required to stay constant at approximately 45 to 50 %, plus or minus 5 percent for design purposes. A humidity control based on relative dew-point is required, maintained by determining absolute humidity in the return air lines, outside conditions and the treatment plant (National Institute of Building Sciences, 2005: www.wbdg.org/).

Internal temperature is required to be maintained between 23 to 25 degrees Celsius, with an air change rate of 2,2 degrees Celsius per hour (ASHRAE standard 55 – 66 recommendation) (Lawson, 1981: 205).

Fresh air intake from the outside is brought in at ground level. For reasons of acoustic insulation and accessibility, the central plant room is positioned at basement level. It is in this position that access for delivery of parts, maintenance and delivery is most convenient for vehicles of the stature of goods trucks. The AHU is to be elevated off the ground on bolted hollow section bracing structure. Contact between this structure and the concrete floor slab is to be transitioned by a flexible suspension system, consisting of steel coils wrapped in polyvinylchloride sheathing. This is to eliminate possibility of structural noise – noise conduction through the structure of the building – from interfering in the proceedings of all areas of the building. This central air handling unit is strategically positioned to be situated at the centre of the building. It is from this point whereby vertical piping could be directed to equally distance itself from key areas in need. Specifically speaking, air supply into the principal performance space is to be administered through and along the northern bounding wall, at ceiling level of the first floor. The events gallery will receive ducted supply through floor vents. Exhaust air in both shall be accommodated through the ceiling plenum. Exhaust air shall be centrally discharged through the roof above the ancillary space core.

Areas deemed to receive air-conditioned air are: the Principal and Secondary Performance Spaces, the Studio Theatre and rehearsal spaces on ground level, the dance studios on second floor level, the offices on ground floor, and dressing rooms on both first and second levels. The rest of the areas, mostly public foyers and lobbies shall receive natural ventilation by exploiting prevailing wind conditions specific to the base of the Salvokop hill (predominantly south to north), as well as by creating pressure differentials in order to siphon air through open spaces. The problem with a building of this nature is that typically a high pressure system is created on the inside due to the number of bodies in occupancy as well as temperature differentials between outside and inside. Air conditioning usually ensures that there is more air coming into the building than going out (McQuiston, 1994: 50). This is optimal in cases of complete air conditioning, but this is not the strategy for this building. It just so happens therefore that opening all the doors is not enough to get ensure optimum interior ventilation and air-change rates. Due to the vertical nature of the building, many double volumes have been provided between levels to allow warm air to escape to higher levels whereby they may be mechanically extracted through the roof and louvres windows. This induced stack effect will contribute to lowering the atmospheric pressure on the interior and ensuring an optimum air exchange rate.

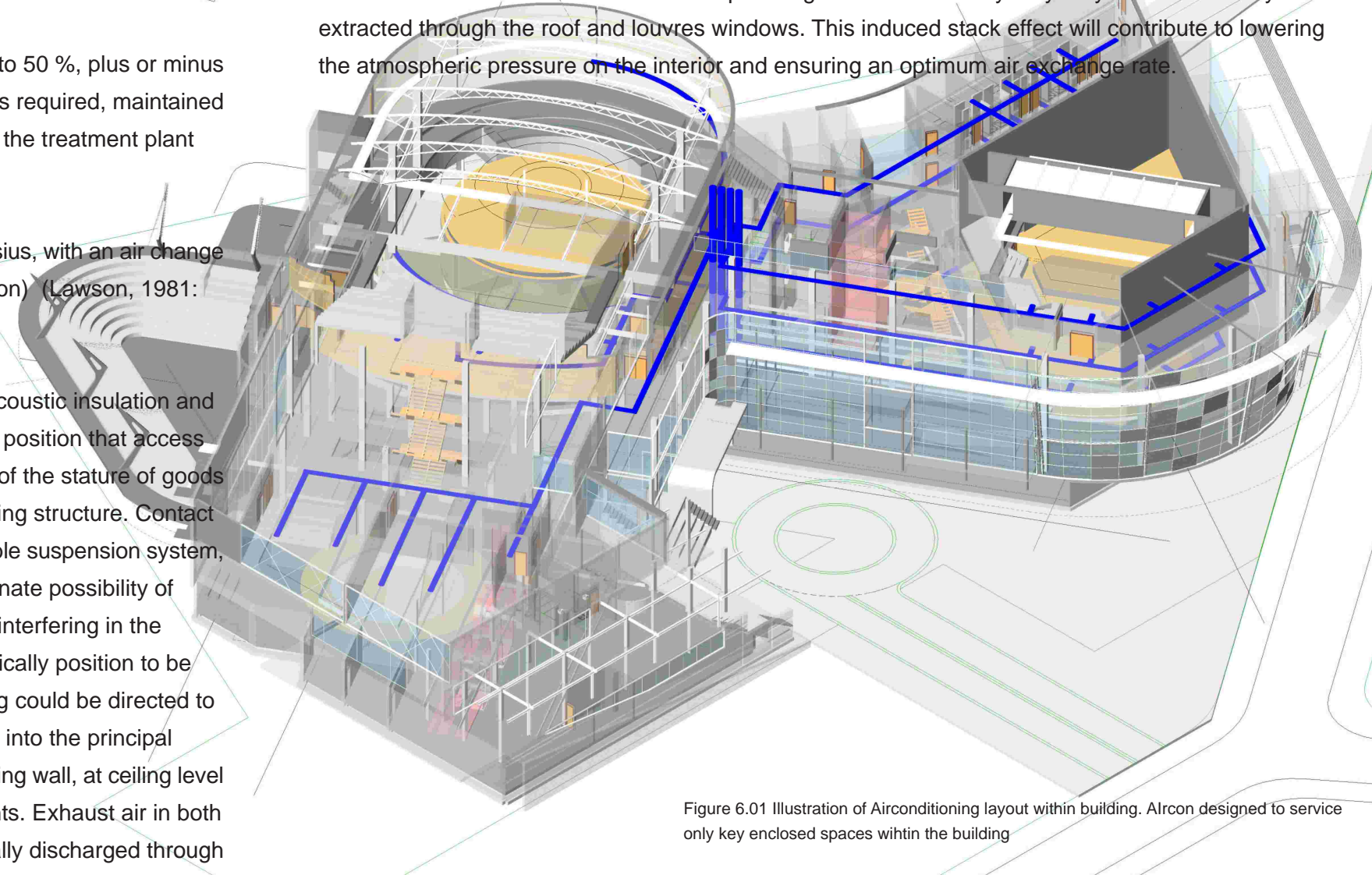


Figure 6.01 Illustration of Airconditioning layout within building. Aircon designed to service only key enclosed spaces within the building

7.1.2. Solar Gain and Incidence

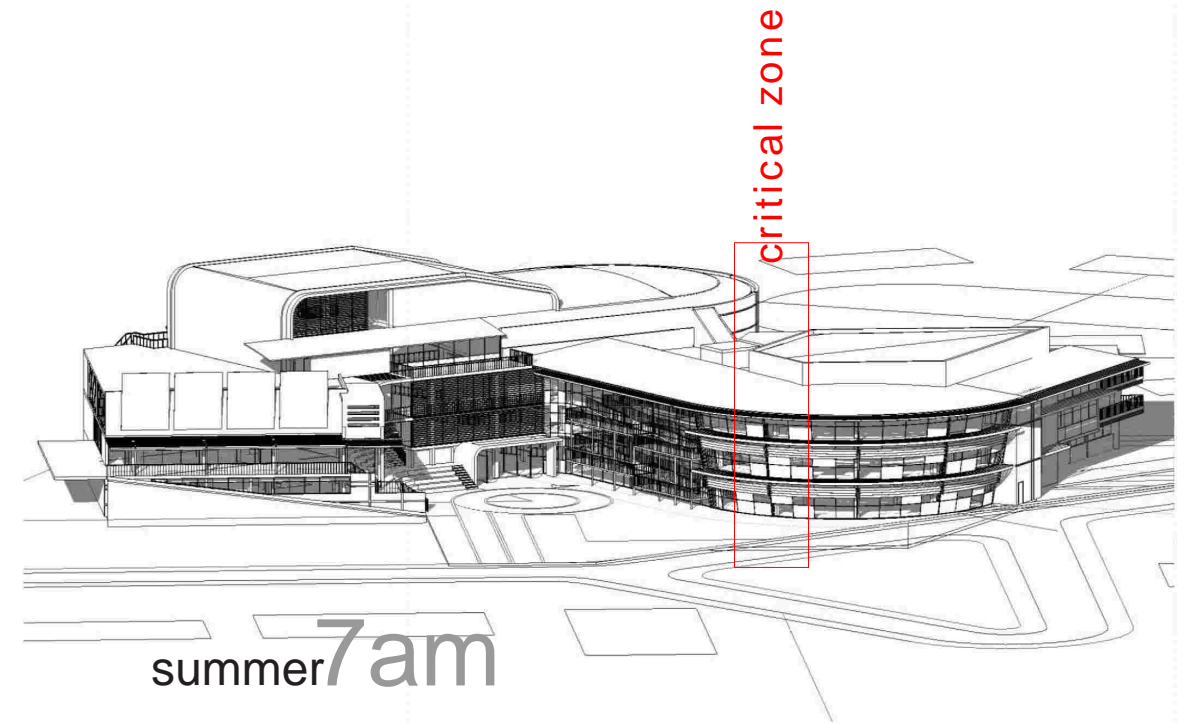
Solar gain is also an issue in matters of a building with prominent glass facades. The building itself, in a bid to connect the interior with its surroundings and reveal the full extents of itself to the passing public, has called for glass frontage on the north and eastern facing facades surrounding the public open space from which it derives its main entrance. Solar radiation in its raw form can be described as being short-wave in frequency. This direct radiation impacts upon a surface, and depending on the thermal mass and density of that material, is re-radiated after a time in the form of long wave radiation (Givoni, 1969: 208). When short wave radiation impacts upon glass some of it is reflected, some of it is absorbed into the mass of the glass and most of it travels through the glass in the form of long wave radiation (Givoni, 1969: 208).

Long wave radiation cannot escape back through the glass, resulting in the 'greenhouse effect' (Ruck, 1989:). It is thus imperative that, in the case of glass facades, the glass be kept shaded from direct radiation so as not to increase the temperature of the interior uncomfortably. Three techniques have been applied to adequately shade the glass during critical periods of the day: overhangs, horizontal and vertical placement of louvers where no overhang exists, and placement of reflective and insulative paneling.

Utilising the structure of the building in certain instances, more than adequate overhangs have been created to eliminate direct solar incidence, as in the case of the external balconies formed from the pedestrian ramps on the eastern façade of the building. Further louvers have been applied in a somewhat reactionary technique to shade the surface of the glass. The distinctive curved glass feature on the north eastern corner of the building has been applied with such louvers. Fixed vertical louvres run horizontally at the change in levels, providing good shade during all times of the day, even during midday in summer thanks to a generous overhang of the roof. Adjustable louvres are positioned one above the other at the same vertical angle to the curtain wall, hiding glass louvres at a high level in the curtain panelling whereby natural ventilation is able to penetrate the building. Further more, as previously mentioned, this glass façade has been inclined to increase the angle of incidence during periods of occupancy within the building, therefore reducing solar gain and glare significantly. With this angle it can be seen that solar incidence in summer after approximately 8 am is greater than 60 degrees, reducing solar gain by 70 percent (Everitt, 1970: 221).

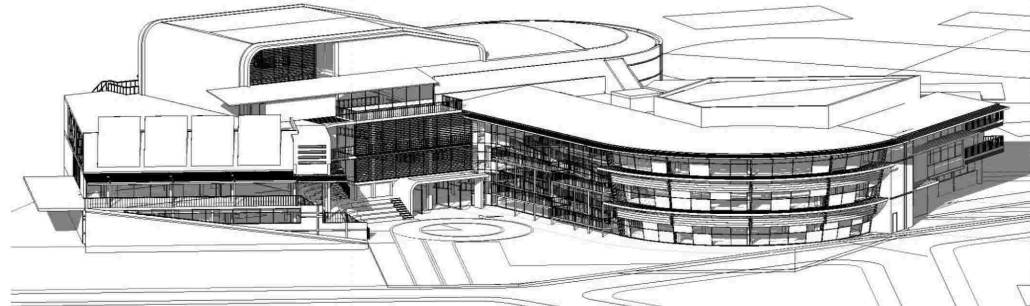
Solar gain is greatest when the angle of incidence is perpendicular to the surface of the glass panel (Button, 1993: 158). With the slope in the glass façade this can never happen. The greatest chance of solar gain is therefore at the earliest times in the day, when the sun is just rising and impacting the glass below the level of the louvers. By plotting the position of the sun during its seasonal movements, as well as taking into consideration the positioning of various medium to high rise structures surrounding the building, two key areas of critical exposure are identified. In these zones a ratio of 50: 30: 20 for reflective glass: insulative opaque panelling: clear glass is instituted. Beyond these zones the angle of incidence breaches 60 degrees (horizontal angle) and is negated in critical influence (Givoni, 1969: 220).

Critical Zone: Point of contact upon glazed surfaces where angle of incidence of direct solar radiation is nearest to perpendicular



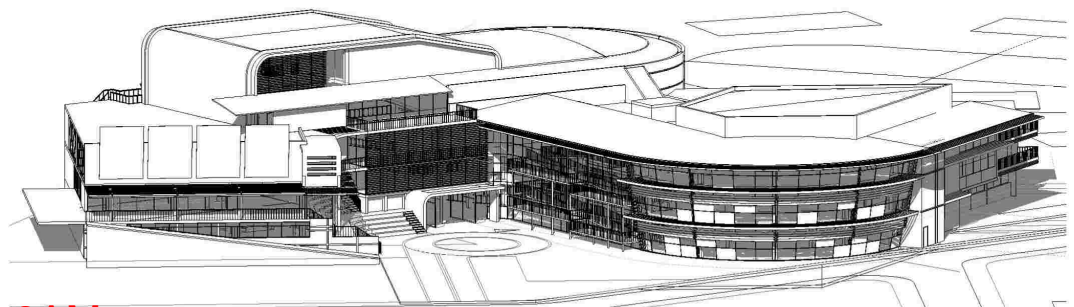
Figures 6.02 to 6.03. Critical zones as determined by perpendicular angle of incidence of sunlight during early hours of day. Occupation does not occur till 9 am.

SUMMER SUN INCIDENCE - EFFECTIVENESS OF SHADING DEVICES



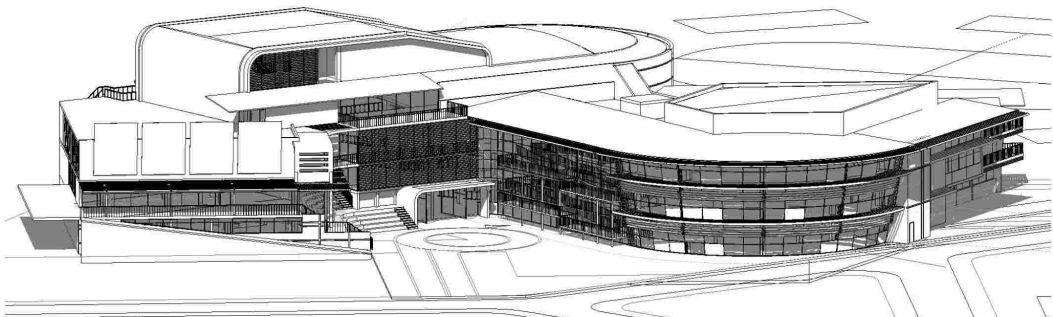
SUMMER 7AM

Period when sun is at its lowest and angle of incidence of light on glass is closest to perpendicular. It is observable that the only area of glass in position of discomfort is area of curved curtain wall previously described as **zone of critical influence**.



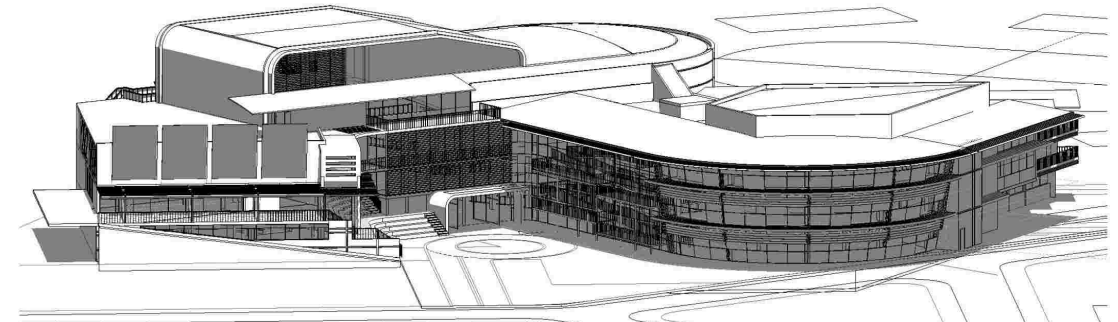
SUMMER 8AM

Interior predominantly shaded, light ingress of approximately 1,5 meters. More than two thirds of glazed surfaces under shading. Latent heat likely to dissipate before primary period of occupancy at 9 am.



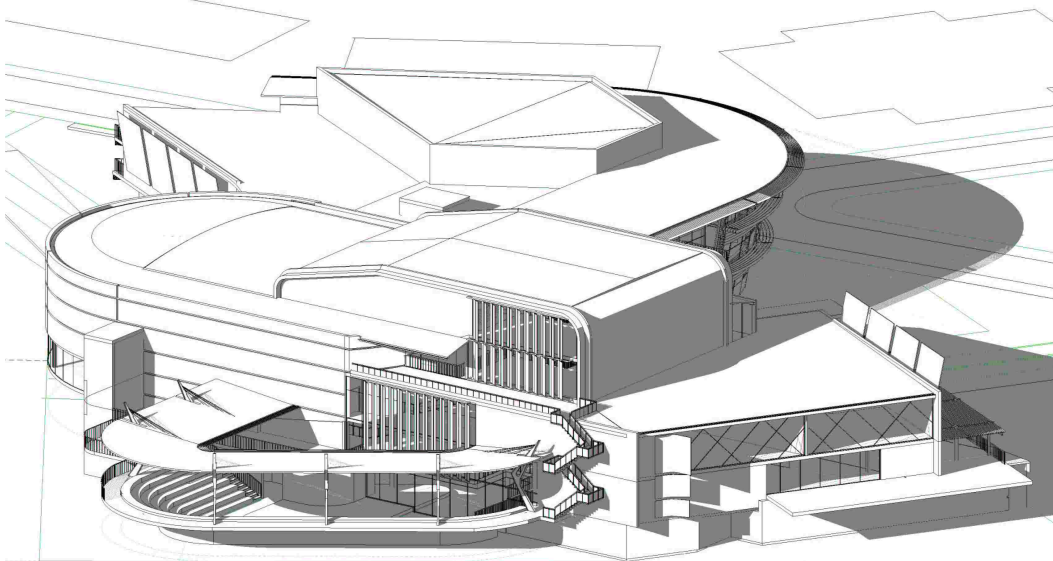
SUMMER 9AM

Period of primary occupancy by public. External glazing completely shaded and not in a position to jeopardise the internal micro climate



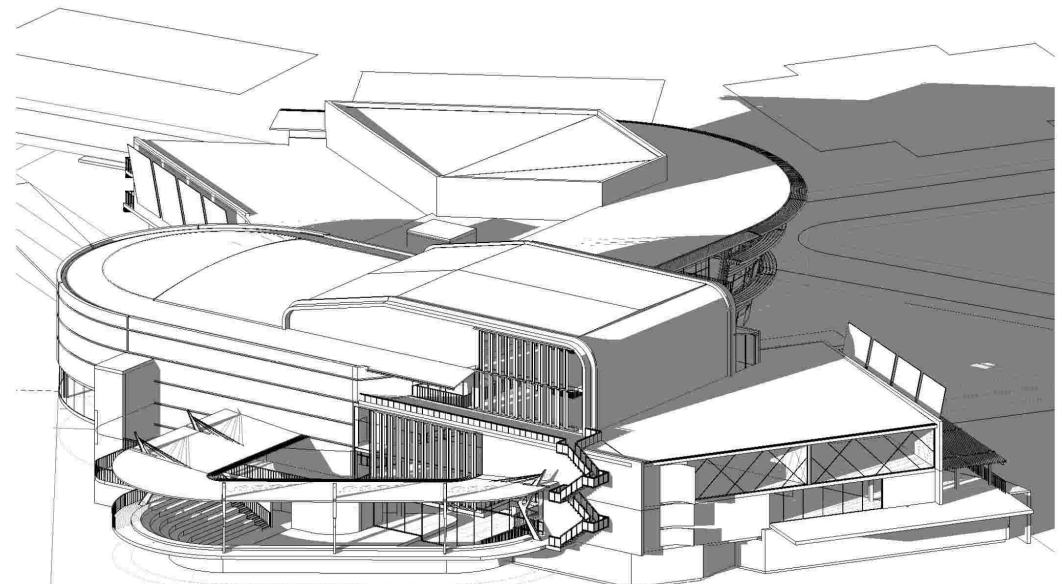
SUMMER MIDDAY

Time of greatest solar radiant intensity. All external glazing protected by overhangs and effectively shaded



SUMMER 5PM

South facade of building under threat. Glazed areas are effectively protected by adjustable vertical louvres which are orientated to obstruct direct impact of solar rays onto surface of glass yet retain views south to Freedom Park from within building.

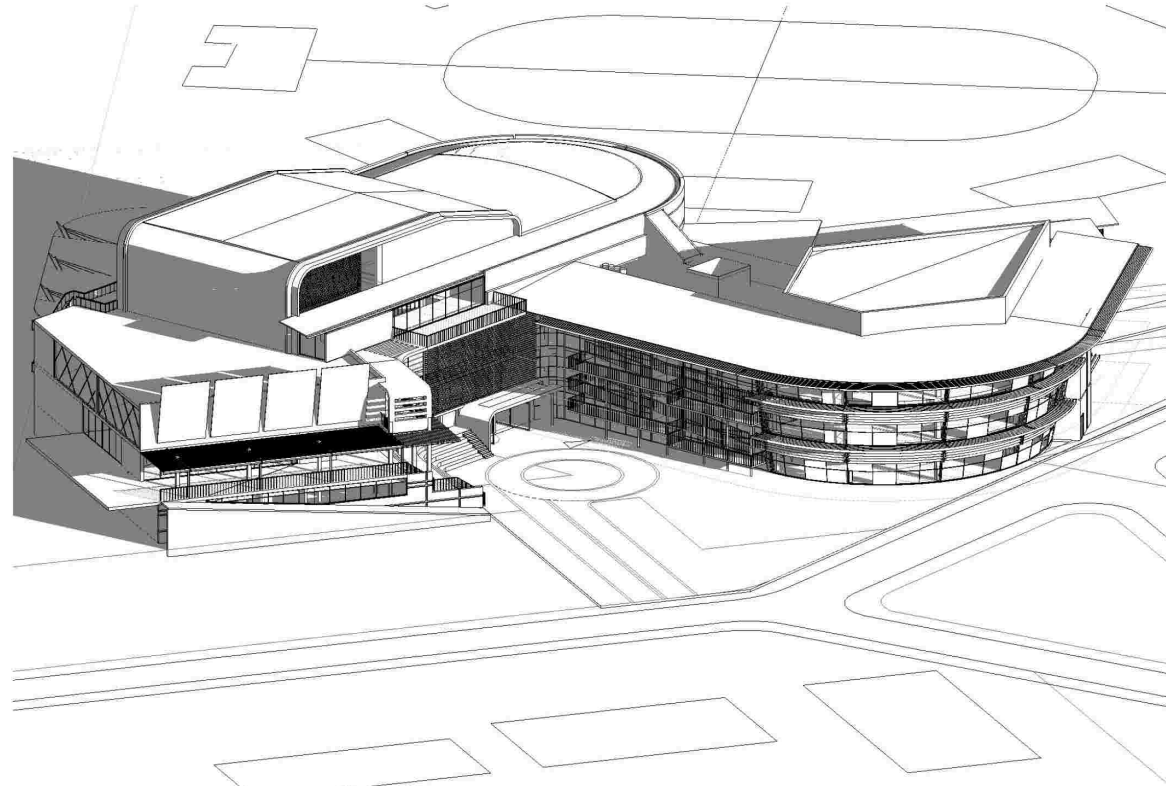


SUMMER 6PM

Period when sun is at its lowest with regards to impact on building (position of Salvokop hill obstructs light from this point onwards). Glazed surfaces still shaded and internal glare minimised.

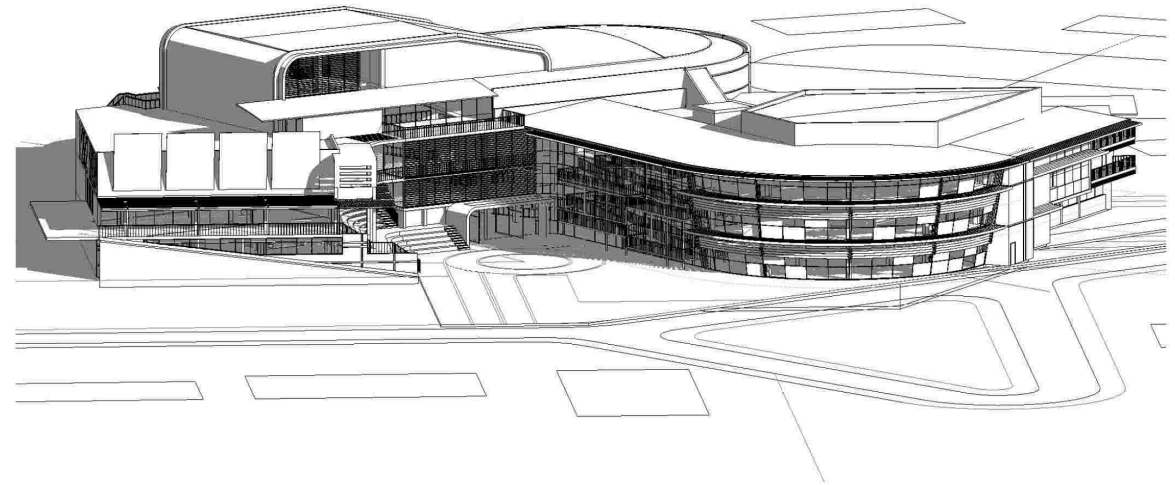
Centre for the Performing Arts

WINTER SUN INCIDENCE - EFFECTIVENESS OF SHADING DEVICES



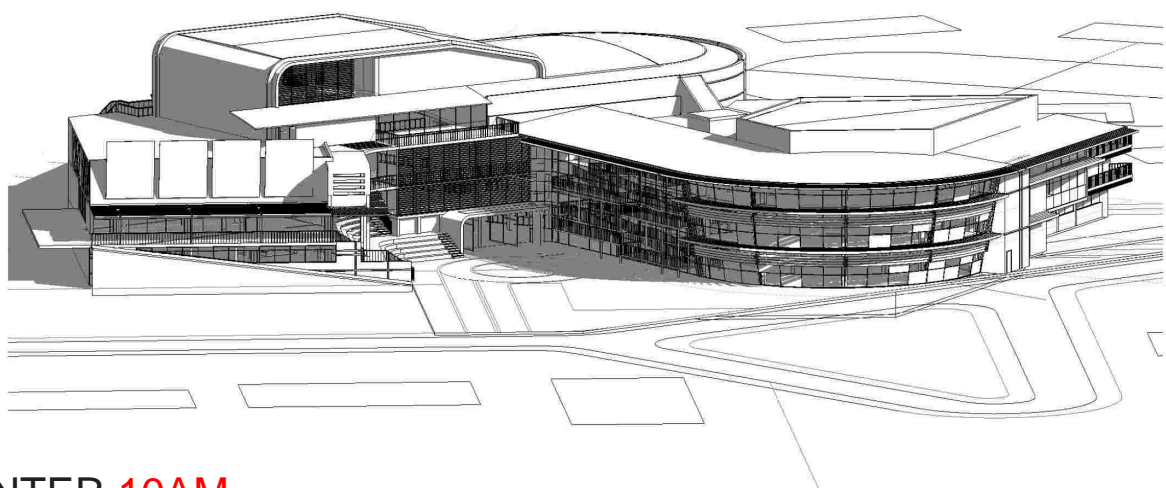
WINTER 8AM

point of maximum internal exposure. Two thirds of Glass on curtain wall facade under direct impact from sun.



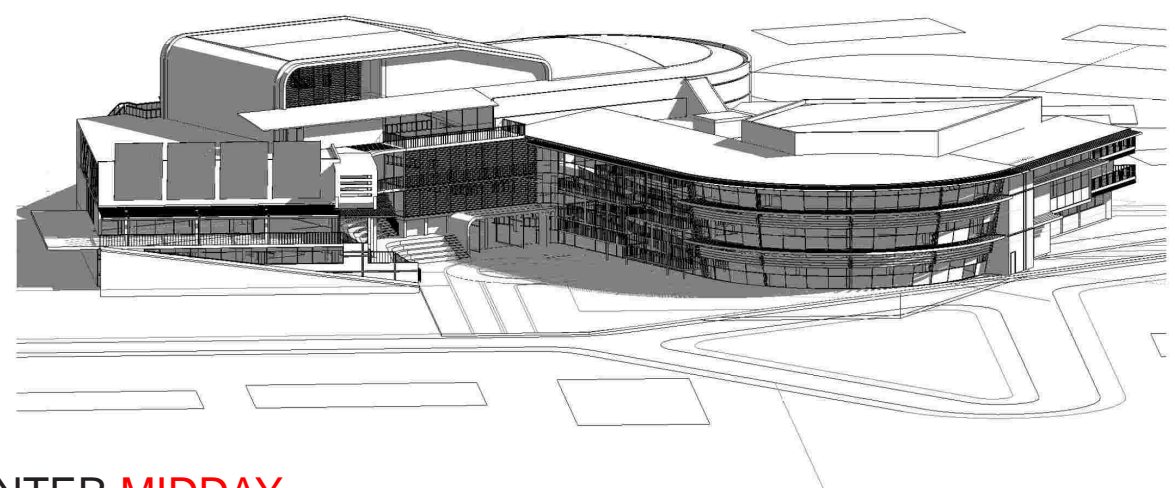
WINTER 9AM

Period of first occupation. Glass predominantly shaded. Internal ingress of light restricted to 1 meter. Aluminium opaque paneling absorbing radiant heat effectively due to positioning within critical zone of influence.



WINTER 10AM

Interior as well as external glass facades completely shaded by external louvres system and overhangs



WINTER MIDDAY

Glass facades remain shaded and free from heat absorption and transmittance into interior. Conditions for maintenance of an optimum microclimate without undue pressure on mechanical systems favourable.

6.2. Materials and Construction

The structure of the Centre is primarily a reinforced concrete structure, consisting of concrete columns positioned according to a regular grid, with floors of concrete floor slab construction. Masonry bricks with plastered finish are used in the construction of external walls where appropriate, as well as various internal partitions. External facades are typically treated with: off shutter concrete construction, glazed curtain walls, masonry brickwork (rendered). Roofing systems can be summarised into two categories: low-sloping concrete roofs, and steel roofing systems. These roofing systems are applied where most appropriate, depending on thermal and acoustical requirements.

This chapter addresses each of the afore mentioned construction and material selections, focussing on reasons for choice and relevant technical information for construction and substantiation of design decisions.

6.2.1. Reinforced Concrete Structure and Flooring

As stated previously, the main structure consists of concrete columns and slabs. It may be noted that not all columns share the same structural load, due to certain instances where beams are required to traverse greater spans than others. None-the-less, for sake of continuity, all columns are of the same dimension, 450 x 475 mm. Where columns are subjected to greater loads, these columns will be provided with additional steel reinforcing for strength. By maintaining regular column dimensions, the same shuttering may be used for all columns during construction, hopefully providing the means to accelerate and simplify the building process, if even only slightly.

The choice of an in-situ reinforced concrete frame, an in situ concrete floor cast in with the frame and designed to provide lateral rigidity serves the task of the building most optimally, as this permits the omission of beams parallel to the floor span.

Flat slab construction is economical for this heavy and uniformly distributed loading, which with normal beam and slab construction would require very deep beams. because of the smaller overall thickness, the total floor to floor height is increased by comparison (Foster, 1975: 211). Where heavy concentrated loads are carried, such as in the case of the sloping Principal Performance Space seating floor slab, a diagonal beam floor is selected in order to disperse the load throughout all column members of the grid, thus avoiding high stress and resulting in a reduction of beam depth (Foster, 1975: 212), set at this stage at 460 mm.

The flat slab construction is commonly used when the slab is intended to act as a membrane supported on columns without beams, in this case it is most pertinent since a high level of lateral rigidity is required (Foster, 1975: 205). In its simplest form, this method of construction often proves to be more economical than hollow block construction (Foster, 1975: 241). It provides maximum freedom in design on plan and section since it can be made to cover irregular shapes and varied in thickness depending

on load or span. It is a heavy floor but also highly fire-resistant. Since spans within the building structure are of roughly 6,5 m, two way spanning is used in which the reinforcing is designed to act in both directions, the proportion of load taken by each set of reinforcement is dependant on the ratio of long to short side of the floor panel.

Load paths are distributed through the use of reinforced concrete columns set to a regular grid, 6,5 x 7 m, as well as loadbearing masonry walls. these loadbearing walls are thus a permanent fixture and rigidify internal layouts. Where internal flexibility of space utilisation is required, loadbearing walls are not used and load paths are restricted to the columns structure, as in the case of the first floor coffee bar area and ground floor exhibition and archive space. load bearing wall on ground and first floor levels are 330mm in thickness in order to cope with compressive resistance requirements.

6.2.2. Curtain Walls

A curtain wall is any exterior wall that is attached to the building structure and which does not carry the floor or roof loads of the building. In common usage, curtain walls are often defined as thin, usually aluminium-framed walls containing in-fills of glass or metal panels (National Institute for Building Sciences, 2005: www.wbgd.org/).

The curtain wall system implemented in this design is that of a stick-built system. In this system of construction the curtain wall frame (mullions) and glazing panels are installed and connected together piece by piece. For this exterior glazing system, glass and infill are installed from the exterior of the curtain wall and are secured with glazing stops or pressure bar retainers, and require swing stage or scaffolding access to the exterior of the curtain wall for glass and infill repair or replacement. Typical infill panels for this building include vision glass insulating glass, metal panels (thin composite panels consisting of two thin aluminium sheets sandwiching a thin plastic interlayer), and other FRP (fiber-reinforced plastics).

Overall curtain wall thermal performance is a function of the glazing infill panel the frame as well as construction behind opaque areas. In the case of this build, mullion construction shall be of steel. It should be noted here that steel has a high thermal conductivity. It is common practice to incorporate thermal breaks of low conductivity materials, such as polyurethane and nylon, for improved thermal performance (Everett, 1970: 240). This system is designed to include "pressure bars", which are fastened to the outside of the mullions in order to retain the glass. This system includes gaskets that are placed between the pressure bar and mullions and to function as thermal breaks as well as waterproofing barriers.

6.2.2.1 Design of the Main Curtain Wall Feature

Whilst the curved glazed curtain wall on the north-eastern edge of the site has been designed as an aesthetic feature, reasons for its construction have their roots in the performance of glazed surfaces under direct contact from solar radiation. It was important for the aesthetic of the design to retain a transparent facade at this point in order to reveal the interior of the building to passers-by on what is to become the primary pedestrian route. Thus a strategy design a glass facade with northern and eastern orientation was required so as not to incur uncomfortable solar heat gain from direct solar radiation, as well as prevent uncomfortable glare and light reflections to the public.

The most obvious design decision to observers is the tilted glass surface that embraces the curve in its entirety. The tilt is set at 10 degrees to the vertical and is supported internally by steel columns that extend the full height of the curtain wall. This simple tilt provides a number of benefits. Firstly, the tilt provides the glass facade with the benefit of never being subject to solar incidence at a perpendicular angle. It is when sun impacts glass at a perpendicular angle that the majority of solar heat transmittance is experienced, as the angle of incidence is increased, however, the amount of solar heat transmittance

is reduced through an increase in solar heat reflectance. Furthermore, transmission becomes reduced to the point that it is classified as negligible when the angle of incidence reaches 60 degrees. In the matter of maintenance of internal microclimate in this temperate climate, it is essential that solar gain is kept to a minimum in summer months. It has been calculated therefore that in summer, the angle of incidence at nine o'clock in the morning, a time when the sun still breaches the external louvres shading devices, the angle of incidence is equivalent to 59 degrees. Therefore all solar gain that would have otherwise adversely affected the interior microclimate is significantly reduced.

The second benefit of the tilt is the reduction of external glare. External glare is caused through disruptive reflections of light from the sun. Due to the fact that the glass faced interacts with a busy intersection where cars are required to proceed with caution, disruptive and uncomfortable glare from the building would prove to be greatly problematic. The angle of construction therefore ensures that all light that impacts on the surface of the glass, no matter the angle, will never reflect beyond 2m from the footprint of the building and is therefore redirected away from direct line of sight.

The leaning support column of the curtain wall is loadbearing in nature and fixed to the ground by means of a 10mm base-plate and pivot joint. The column is kept in its 'leaning' position by means of bolted connections to the reinforced concrete floor slabs of the first and second levels.



Figure 6.05

Figure 6.06 Glass facade and treatment

6.2.3. External Glazing

In recent years, windows have undergone a technological revolution. High-performance, energy-efficient window and glazing systems are now available that can dramatically cut energy consumption and pollution sources. These glazing systems have lower heat loss, less air leakage, and warmer window surfaces that improve comfort and minimize condensation (Buttton, 1993: 163). These high-performance windows are featured in the build in the form of double glazing, specialised transparent coatings, insulating gas sandwiched between panes, and improved frames. All of these features reduce heat transfer, thereby cutting the energy lost through windows (Button, 1993: 161).

In the task of designing this building, certain window and glazing options must be evaluated. The issues earmarked for consideration include:

- Heat gains and losses
- Visual requirements (privacy, glare, view)
- Shading and sun control
- Thermal comfort
- Ultraviolet control
- Acoustic control
- Colour effects
- Day lighting
- Energy requirements

U-value indicates the rate of heat flow due to conduction, convection, and radiation through a window as a result of a temperature difference between the inside and outside. U-factors usually range from a high of 1.3 (for a typical aluminium frame single glazed window) to a low of around 0.2 (for a multi-paned, high-performance window with low-emissivity coatings and insulated frames) (National Institute for Building Sciences, 2005: www.wbdg.org/env_fenestration).

Solar Heat Gain Coefficient indicates how much of the sun's energy striking the window is transmitted through the window as heat. As the SHGC increases, the solar gain potential through a given window increases. The SHGC is a ratio between 0 and 1. SHGC = 0 means none of the incident solar gain is transmitted through the window as heat and SHGC = 1 means all of the incident solar energy is transmitted through the window as heat. Typically, windows with low SHGC values are desirable in buildings with high air-conditioning loads while windows with high SHGC values are desirable in buildings where passive solar heating is needed (National Institute for Building Sciences, 2005: www.wbdg.org/env_fenestration). In the example of this building, whereby the interior climate carries significant air conditioning loads, windows are required to be specified with a low SHGC value of less than 0.40.

In general, high Glass Visible Transmittance is desired, to a value of approximately 70% minimum, especially for the required internal day lighting applications and requirements. Spectrally selective

glass (high coolness index) has a relatively high visible transmittance and a relatively low SHGC (Button, 1993: 160). Low SHGC windows should generally always be considered for the east and west facing glazing as a means of controlling solar heat gain and increasing occupant comfort. In the case of the Centre, low SHGC windows are to be used on the east, north, and west facades. SHGC for the south-facing windows is not critical where solar incidence does not exist. The south-west glass façade (opening to the outdoor performance space) will require such specification due to its exposure to direct sunlight in the evening during summer months.

Direct solar radiation is categorised as “short wave radiation”, typically 0,4 to 2,5 microns (Givoni, 1969: 210). This short wave radiation is able to penetrate and transmit heat to the interior of building structure through external glazing. This heat is then absorbed by interior structure and furniture to be re-radiated to the interior. Once this solar radiation passes through the transparent layer of glass, it is transformed into long wave radiation of about 10 microns (Givoni, 1969: 210). This long wave radiation is not able to pass through glass, and is retained on the interior whereby internal temperatures can be expected to rise accordingly. This principle is known as the ‘greenhouse effect’ and is particularly undesirable in the temperate climate of South Africa. This effect can be countered and obstructed with the strategic positioning of external shading devices which shade the glazed surfaces of the building from the direct impact of the sun’s rays. It should be noted that re-radiated heat from the louvres systems will impact on the interior, but typically only 5 per cent of this heat is eventually transferred (Ruck, 1989: 133).

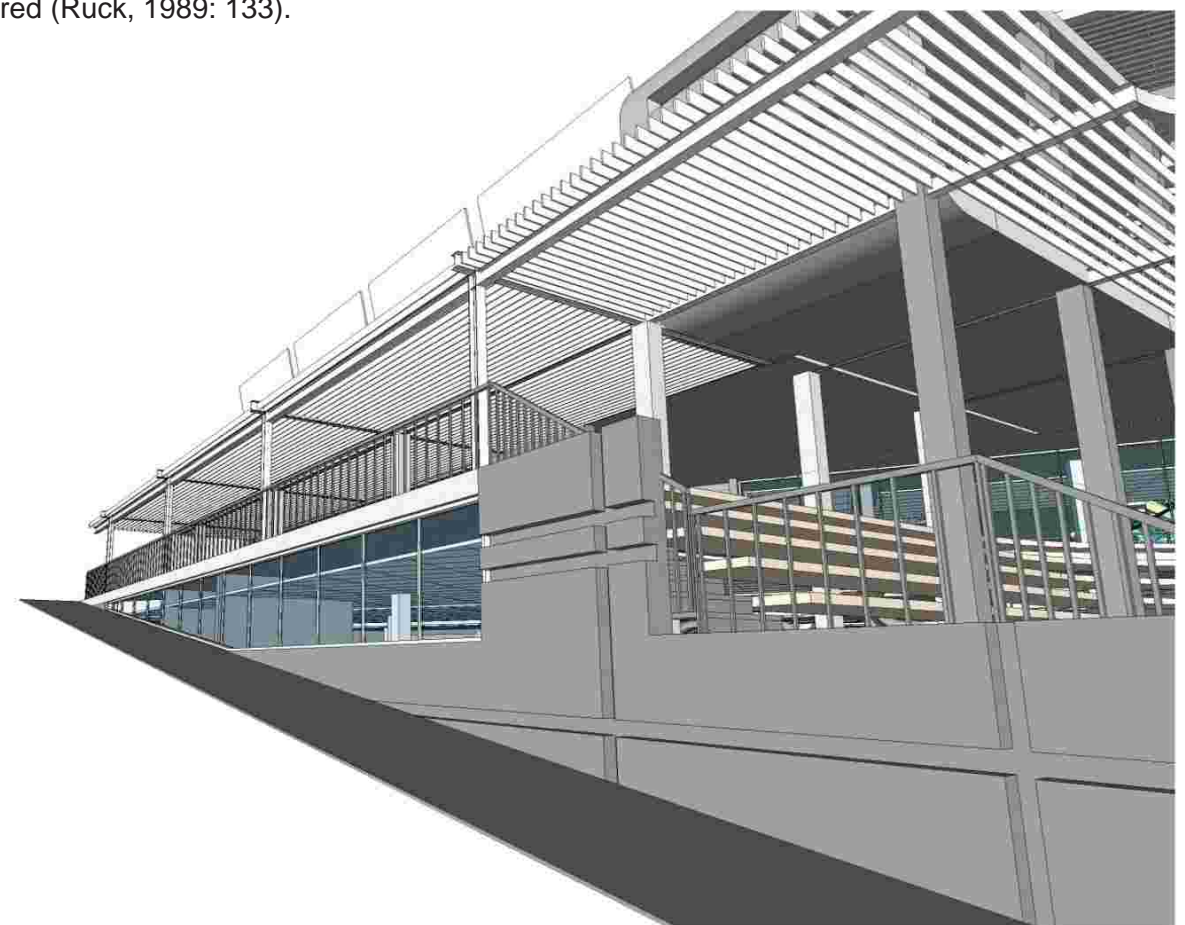


Figure 6.07 One of the forms of solar shading devices utilised in the design of the Centre for the Performing Arts

6.2.4. Roofing Systems

Before specifying roofing construction materials and methods, the following considerations must be taken into account:

- system durability
- material availability
- maintenance intensity
- aesthetic considerations
- technical considerations
- cost
- implications of sustainable roof design

In the case for utilisation of a steel profile roof over the public foyer areas of the Centre, galvanized roof sheeting must be specified in order to obtain greater corrosion protection in the event of roof leakage. It is also recommended that screw-attachment be specified in favour of welding, due to the fact that generally screws provide a more reliable attachment (King, 1971: 394). A highly reflective surface will aid in alleviating solar heat gain on the interior, especially in the areas such as the foyer spaces where passive techniques of cooling and ventilation are sought to be applied. Rigid board insulation is to be used in these low-slope roof assemblies, and therefore this insulation has sufficient tensile resistance to support the roof membrane. This insulation will provide the roof with substantial thickness, under which a suspended ceiling is to be attached.

The second form of roof construction to be used in the Centre is that of a low-sloping concrete roof structure, flat slab construction. Falls are strategically mapped in order to facilitate effective water distribution to common discharge points. The slope is obtained by laying a low density cement-sand screed to a fall of 1: 40. The exterior surface is thus treated in order to make waterproof, provide thermal insulation and, where appropriate, provide a robust surface upon which to walk and install services. The surface of the roof is treated with a Modified Bitumen structure. Modified Bitumen membranes exhibit general toughness and resistance to abuse. This finish is composed of pre-fabricated polymer-modified asphalt sheets. Polymers are added to bitumen to enhance the various properties of the bitumen (National Institute for Building Sciences, 2005: www.wbdg.org/env_roofing). The quality of Modified Bitumen products is highly dependent on the quality and compatibility of the bitumen and polymers, and the recipe used during the blending process. The modified bitumen is to be specified in the form of Atactic polypropylene (APP). APP polymer is blended with asphalt and fillers. The mixture is then factory-fabricated into rolls that are typically one meter wide. The prefabricated sheet, commonly referred to as a cap sheet, is then reinforced with fiberglass. The sheets are applied smooth and embedded with mineral granules of a suitable colour (Foster, 1974: 164). To avoid surface cracking, a field-applied coating (such as aluminium-pigmented asphalt), is specified. APP MB membranes are typically composed of a base sheet and an APP cap sheet. The cap sheet is heat-welded (torched-on) to the base sheet (National Institute for Building Sciences, 2005: www.wbdg.org/env_roofing).



Figure 6.08 Example of roof treatment: Application of Bitumen to roof surface



Figure 6.09 Example of roof treatment: Application of a modified bitumen cap sheet, torched on

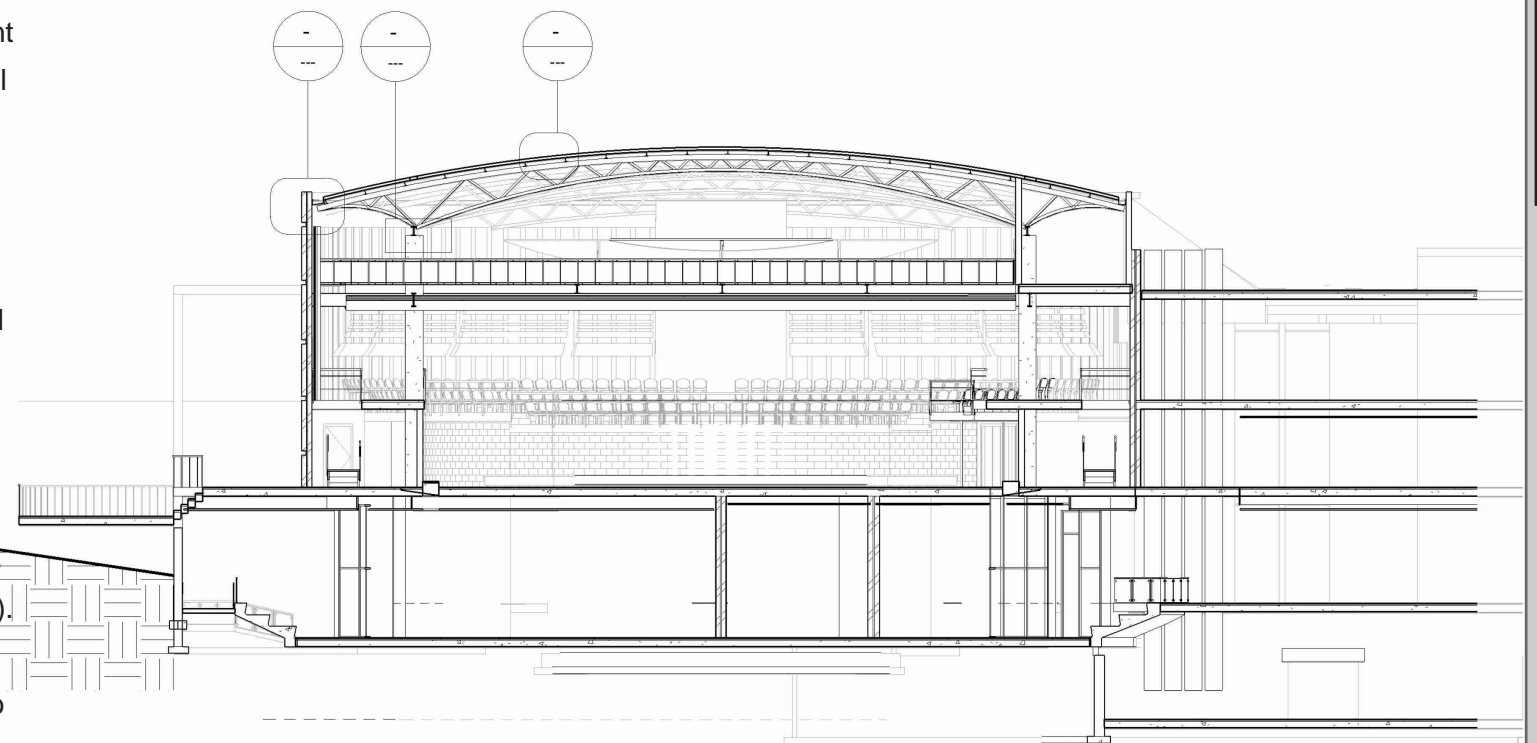


Figure 6.10 Section through Principal performance space
Illustrates simply the nature of roof construction, span of curved trusses and discharge point to box gutter for rainwater discharge

6.3. Acoustical Considerations

6.3.1. Noise Control

External vehicular noise is of most concern to this building. It is important that the quality of sound and performance be maintained in each of the performance spaces, outdoor spaces included. Transport noise, especially, is estimated to reach a level of approximately 75 to 80 dB during peak traffic periods (Ariba, 1971: 140). This is particularly relevant since the site is lying directly adjacent to the soon-to-be most utilised road in the area. It is not clear as to the frequency and consistency of this noise, but it is assumed that this noise shall not be regular and will fail to classify as ambient noise, which is not of a distracting and detrimental nature. Pedestrian noise is also of concern since the Centre for Performing Arts is designed to incorporate public spaces and activity. Pedestrian noise is estimated to reach levels of 65 to 70 dB (Ariba, 1971: 140).

Specific sound considerations are required for the various areas (Lawson, 1981: 71, 88, 170):

- The performance and rehearsal spaces for concerts, drama and dance recitals require an ambient noise level maximum of 30 dB.
- The exhibition space and multimedia archive is slightly more forgiving with a noise range restriction of 35 to 38 dB,
- Offices and dressing rooms restrict noise to a level of no higher than 50 dB.

In order to isolate the performance spaces from such external noise influences, the performance spaces have been literally enveloped by the more forgiving public spaces. The Secondary Performance Space, in which performance shall orientate itself towards performances of a more theatrical and dramatic inclination requires its internal environment to be silent except for the words of the actors. Clarity of speech is essential, and so the performing space does not have one perimeter wall placed within direct contact to external noise influence, except for that which may occur within the centre itself. An extended foyer space wraps itself around the performance space on three sides, while the fourth is bounded by the partition wall separating the ancillary spaces for performers from the performance space. Noise control utilising the structure of the building itself is thus integral in achieving optimum acoustical standards. By buffering the target areas for noise control with the service spaces and corridors and rooms of limited use, much acoustic insulation is given to the space on the other side of the wall as sound is presented with a dual layer of structural mass. Air is of course a weak conductor of sound, so it can be noted that cavity construction is means for superior insulation. It should also be noted at this point that the best insulator of sound is high mass material. The thicker the wall, the less sound and noise penetration. Rule of thumb states that a typical rendered 110mm masonry wall reduces noise by approximately 46 dB, whereas a 220mm thick wall has more success by reducing noise levels by 55dB (Lawrence, 1989: 120). Cavity walls are further implemented to increase noise insulation, after which the next step is to introduce acoustic insulation layers in the form of 50mm glass wool to achieve greater results.

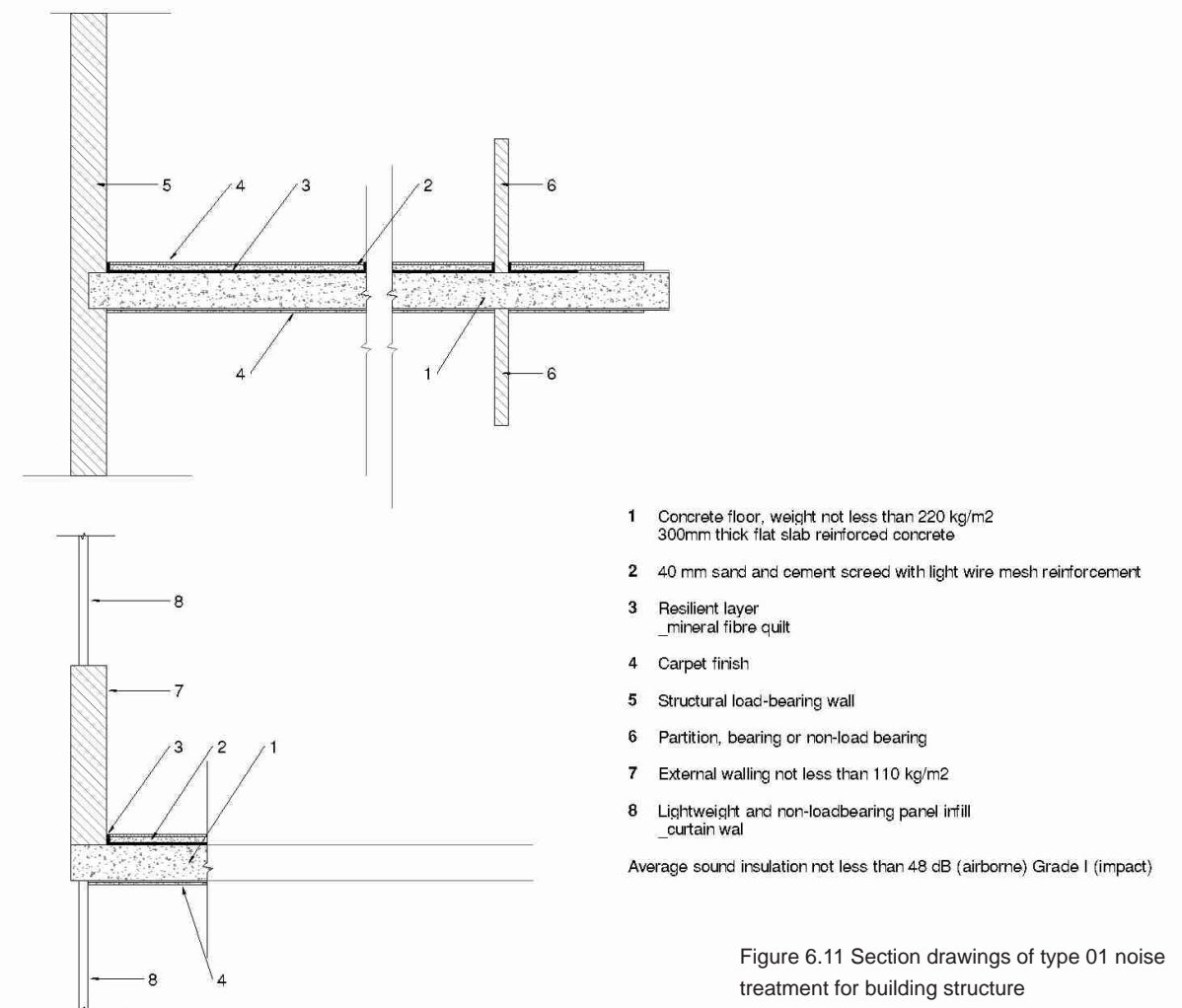


Figure 6.11 Section drawings of type O1 noise treatment for building structure

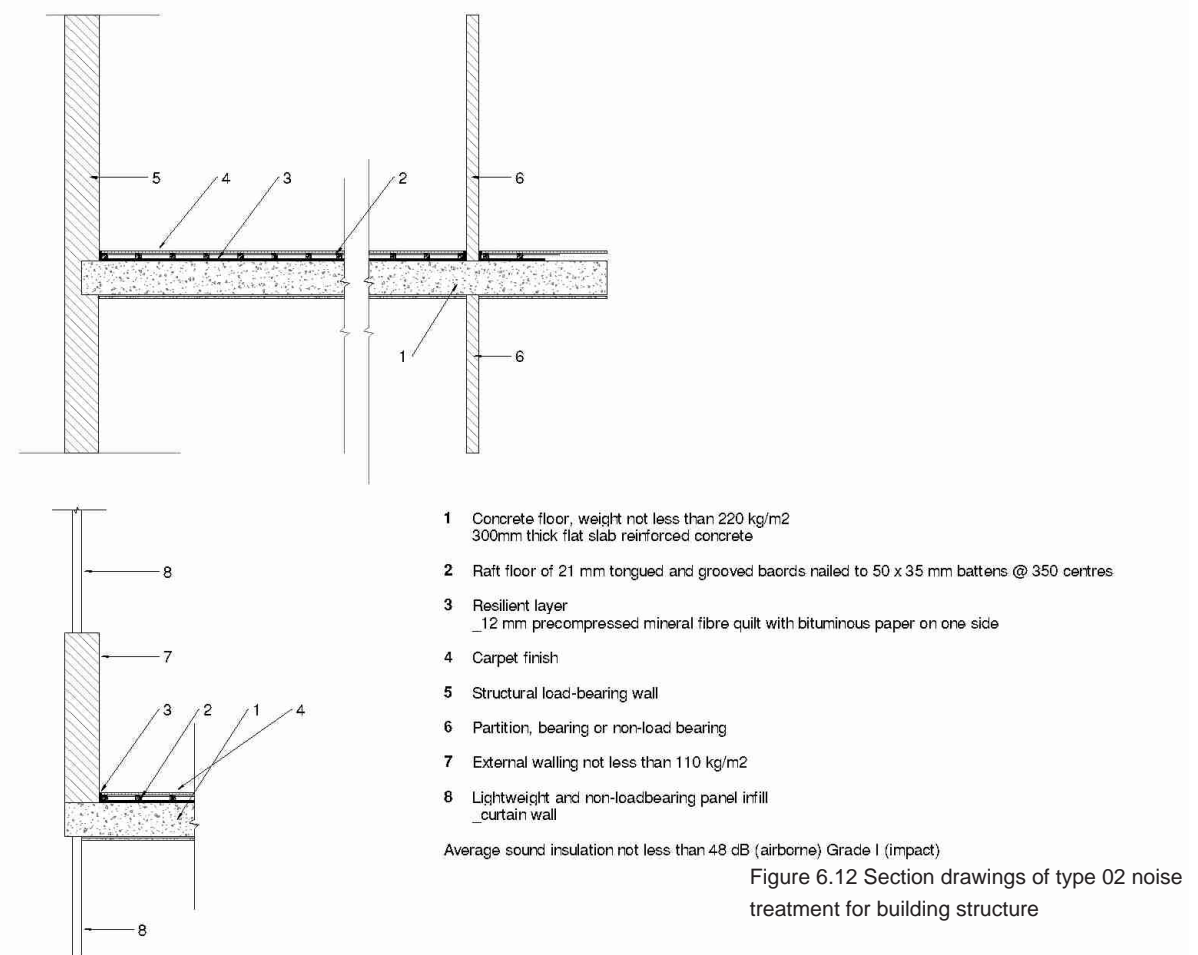


Figure 6.12 Section drawings of type O2 noise treatment for building structure

Reduction in sound through doors is also of concern. This is without doubt the weak link in what would otherwise be a sturdy and dense wall partition. Where walls of high mass provided excellent insulation, it may be noted that in these situations flanking noise ingress becomes concern. Separating walls typically have a sound reduction index of approximately 35 dB maximum, but sound has many routes that it can take before it becomes a problem (Lawrence, 1989: 122). Doors do have a habit of deforming over time, and a door is only good for insulation if it is able to achieve a perfect seal. In order to accommodate for the potential problem the sound lobbies for performance spaces are typified by double door configuration, creating a large cavity in the form of a transition space between foyer and performance space. This lobby creates a plenum that restricts sound and noise escaping or intruding into or from the auditoria. In order to achieve maximum results, auditorium doors shall be specified to be in the form of solid core 50mm hardwood veneer double doors 1868mm (w) by 2134mm (h). Doorframes will be a minimum 14 gauge metal frame construction. In thinking of safety and evacuation requirements, these public doors will be hardware to contain panic release locksets with bush bars and levers constructed with concealed vertical bolts as security measure.

With regards to the ground floor rehearsal spaces, the question of sound insulation though glass is raised. This glass is positioned within aluminium mullion framework, due to the ability to achieve tight seals, integral for appropriate sound isolation. Laminated safety glass consisting of 5mm segments shall be used, positioned upon 10mm thick neoprene float strips to compensate for irregularities in the mullion construction. This glass has a sound reduction capacity of up to 33 dB (Ariba, 1971: 138).

6.3.3.1. Noise Implications of the Gautrain

Due to the nature of the Centre for the Performing Arts as a building that requires carefully maintained acoustical levels on the interior, specifically the performance spaces, the effects of a potentially disruptive underground train system need to be considered. Adverse noise effects can be categorised as air-borne and structural noise. It is accepted that structural noise is essentially coupled with equally disruptive vibration.

According to the Noise and Vibration Report of the Gautrain Environmental Impact Assessment of 2002, measures are currently in existence with respect to the construction of such tunnels that would effectively negate the disruptive effects of this transport system on the internal environment of buildings above. "Following the success of high-speed trains in Japan and France in the 1980's, many countries have improved their rail commuter services with new generation faster trains and upgraded operating service during the last two decades" (Gauteng Department of Transport EIA, 2002: 12 -1). Careful designs of modern systems with an emphasis on reducing wayside, station and coach interior noise levels have created systems with considerably less noise impact on the surrounding communities than the older generation trains.

There are numerous factors and sources that contribute to propagation of train related noise and vibrations. These factors are further complicated by variations in train type and operating conditions. The generation of noise depends largely on the method of locomotive propulsion system, the related auxiliary equipment - such as compressors, motor generators, and brakes -, the interactions of wheels and rails, the noise radiated by vibrating structures, the speed and length of the train, and for high speed operations aerodynamic noise may also become significant (Gauteng Department of Transport EIA, 2002: 12-10). At present it may also be noted that there are no South African noise standards related to railways and their operations, resulting in a trial and error scenario whereby the construction of this project will serve to highlight and develop railway construction strategies for the future.

Due to the fact that the train is planned for sub-surface conveyance at a depth of between 10 to 12m, airborne noise is impossible. The approximate density of the soil as well as concrete and steel construction of the tunnel support system and structure result in a scenario whereby the acoustical mass of these obstructions effectively negates the propagation of direct sound waves. Potential airborne noise does arise from the sections in the tunnel and those in cut-and-cover construction in the event of the position of a ventilation shaft (Gauteng Department of Transport EIA, 2002: 12-12). These ventilation shafts will be positioned externally to the Centre for Performing Arts, and are no more significant in noise intensity than the super-surface vehicular noise generated by the motorcars of the Ceremonial Way.

It is thus assumed that a foundation base of high density and mass is most convenient for the Centre for Performing Arts in order to provide significant acoustical insulation and structural stability. The bulk of design decisions and construction choices is however needed to occur in the fabrication of the tunnel and choice of train in order to remain sensitive to the super-surface structures in its vicinity. Recommendations according to the Crossrail Noise and Vibration Report for the Channel Tunnel Rail Link (Crossrail, 2004: 4) are thus provided by this dissertation as measures for noise and vibration reduction:

- the introduction of 'resilient' track design to eliminate ground-borne noise
- noise limiting measures such as noise barriers
- continually welded rail to be used as much as possible to avoid noise of train wheels on joints
- ventilation systems and other services must be designed to avoid noise and vibration impacts
- smooth running trains must be specified

6.3.2. Performance Spaces: Auditorium Acoustics

Upon determining form for the main performance spaces, a rough initial estimate of audience capacity was required. It is from this estimate that an approximate volumetric assumption may be drawn, already providing certain dimensions and form to the space. Typically musical performances require a greater volume of space per person than for speech. Musical performance requires a volume of roughly 6 to 9 cubic metres per person, while theatrical performances require 3 to 4 cubic metres (Rettinger, 1968: 245). This is a contributing factor in the determination of reverberation times. It must be noted that different performances require different acoustic settings. Musical performances thrive on an imposed echo of limited proportions (approximately 1,14 seconds reverberation time), while speech is better understood and intelligible through an instantaneous audible reception (approximately 0,3 seconds reverberation time), and an echo in this setting would cause interference (Lawrence, 1981: 120). Thus two options are presupposed: one is to create completely flexible interior layout which could accommodate itself to either scenario; the other is to limit the main scope of the various performances to interior spaces that are more suitable to various and diverse spaces within the same building.

Since it is already stated in earlier chapters of this investigation that a large variety of performances are to be housed in this development, it is clear that each performance space will have to lend itself to any environmental setting as required from it. The Principal Performance Space is one such space. Since it is likely that speech as well as music shall be housed within its walls, the interior acoustic setting needs to be accommodating. In order to achieve appropriate reverberation times in performances of an acoustical nature, it is far better achieved through electronic augmentation than by any other process (Lawson, 1981: 185). Thus reverberation time may be systematically predetermined at the start of a performance, and electronically operated speaker systems embedded within the ceiling plenum discharge sound at a favourable rate and volume. It has been widely acknowledged that this form of musical augmentation far surpasses the 'traditional' theatre and concert hall principles of bouncing sound off walls and ceilings. The accuracy and quality of such electronic interventions guarantee a manageable acoustic environment (Rettinger, 1968: 356). This of course does not mean that planning and calculating absorptive and reflective capacities within these performance spaces must not be carefully and accurately performed. This does however require a change in attitude. For now it is the aim of this project to design a space within which little reverberation time exists, a setting that would otherwise be conducive to intelligible speech at a distance of 20 meters without augmentation (Lawson, 1981: 171). In this way the setting is primed to be receptive to all manner of electrical augmentation and induced reverberation of up to 1,2 seconds depending on the performance.

In the case of curved walls, acoustic design principles stipulate that the perpendicular angles of convergence of sound reflections should not be positioned above the audience at any point (Rettinger, 1968: 245), as they do not in this case. These walls are to be acoustically dampened to absorb all sound to inhibit the return of echo. Wall panels of a curvilinear nature distribute remaining sound vertically that has not yet been absorbed. Since the stage is in the round, a reflective curved suspended ceiling in

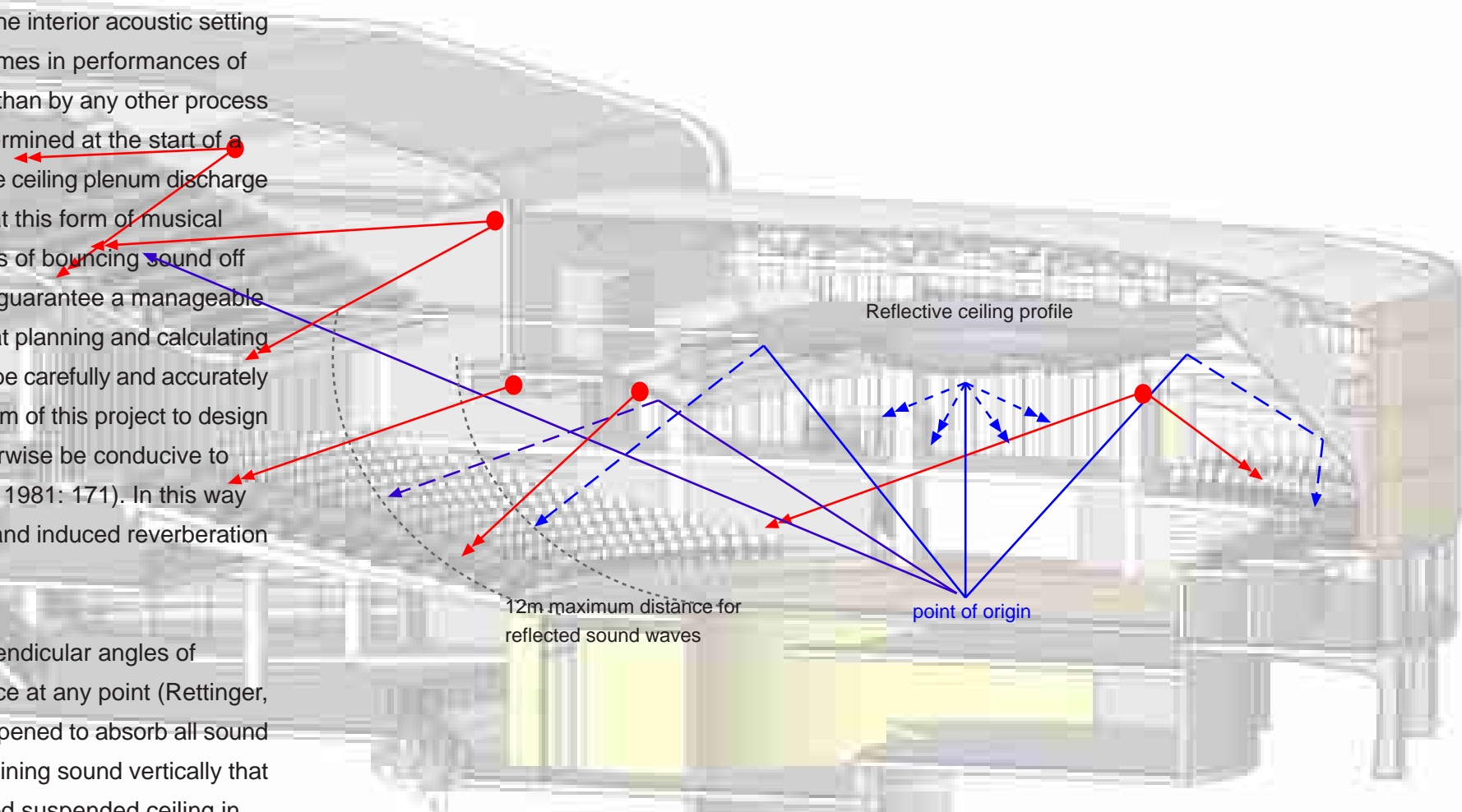


Figure 6.13 Schematic representation of patterns of travel of sound
Blue lines indicate natural paths of sound and reflected sound
Red lines indicate electronic augmentation and sources of transmittance

the shape of an inverted dome (convex) is hung above it. All sound coinciding with its surface is reflected in all directions towards the audience. This reflective ceiling shall be the only practicable reflective surface within acceptable limits of the stage. All other reflective surfaces will lend their properties not to the direct sound from the stage, but rather to that of the electronic augmentation in the form of diffuser panels. Diffuser panels are those that are angled at a minimum slope of 4 degrees to prevent stationary sound waves from forming in the pursuit of creating what is known as flutter echoes (Rettinger, 1968: 87). These diffuser panels encourage the lateral perception of sound to the audience member, especially in cases of a musical performance, but are retractable into the ceiling void. These diffusing panels should be sheets with low absorption and with a mass per unit area of about 5 kg/m². Diffusers of an area of 0,8m² to 3m² are recommended (rettinger, 1968:). These sheets shall be slightly curved and randomly orientated throughout the room.

Recommended noise criteria (NC) rating for auditoria of this nature ranges from NC-20 to NC-30 with recommended sound transmission class (STC) rating ranges from STC 40 to STC 50 (National Institute for Building Sciences, 2005: www.wbdg.org/). This translates into positioning of combination Type II vinyl wall covering and fabric covered acoustical wall panels. The stage area is to be surrounded in Type II vinyl wall covering, while Orchestra (audience) side walls are to be Type II vinyl wall coverings for 1/3 of the front and fabric covered acoustical panels for 2/3 of the back. The rear walls are to be fabric covered acoustical supawood panels bolted to the wall with a rubber spacer and air gap of 20mm.

The shape of the Secondary Performance Space is conducive to being appropriated in a variety of configurations. Hexagonal in nature, by instituting the planned central partition an interior 'fan shape' is formed. This fan shape is most sought after in the design of spaces in which intelligible speech is a requirement. While electronic augmentation is available in this space, the dimensions of this performance space have been designed to ensure that no seat is distanced at more than 20m from the source of sound. This is a distance requirement for the audible reception of speech in performances of a dramatic nature (Ham, 1972: 36). This sound shall be further more supplemented by reflective panelling suspended from the ceiling, always making sure that the reflected travelling distance of sound through the air does not exceed 12m, due to undesirable attenuation and inaudibility (Ham, 1972: 37).

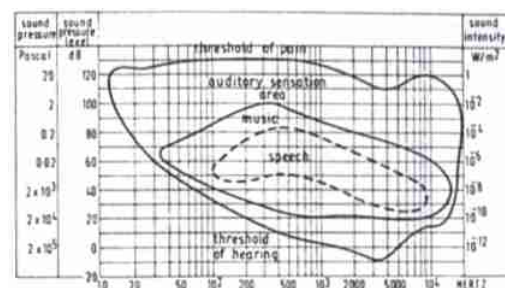


Table 6.01 Human auditory sensation area showing typical spectrums for human voice for music (Lawson, 1981: 173)

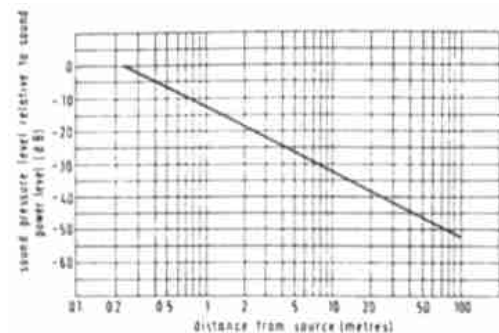


Table 6.02 Effect of distance on sound (open air condition). In a room or hall average reductions range from 5dB to 3dB each time the distance is doubled (Lawson, 1981: 173)

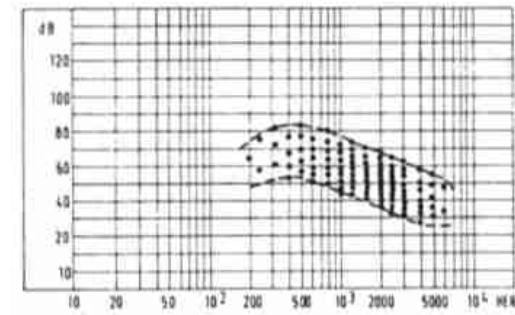


Table 6.03 Contribution to intelligibility from frequency bands, each dot represents 0,01 contribution to the articulation index (Lawson, 1981: 173)

Principal Performance Space - Unoccupied

	125	250	500	1k	2k	4k	
Side walls, plasterboard and plywood, 13mm on studs (10mm gap) 750m ²	0,29	0,10	0,05	0,04	0,07	0,09	
Side walls, open jointed brickwork	0,07	0,38	0,21	0,15	0,25	0,31	
120 m ² Back wall, 50% micropore construction 60 m ²	8,4	45,6	25,2	18,0	30,0	37,2	m ² Sabin
Stage back drop, light, 300gm/m ² , straight, on wall 80 m ²	0,12	0,67	0,48	0,52	0,66	0,64	
Floor, heavy carpet on foam	7,2	40,2	28,8	31,2	39,6	38,4	m ² Sabin
600 m ² Stage flooring, wood floor	0,03	0,04	0,11	0,17	0,24	0,35	
176 m ² Ceiling, plywood over 10mm gap with cork tiling 800 m ²	2,4	3,2	8,8	13,6	19,2	28,0	m ² Sabin
Ceiling reflective profile, linoleum finish 160 m ²	0,08	0,24	0,57	0,69	0,71	0,73	
Unoccupied upholstered seats Audience of 670	48,0	144,0	342,0	414,0	426,0	438,0	m ² Sabin
S=670 m ²	0,15	0,11	0,10	0,07	0,06	0,07	
A = Sa	26,4	19,4	17,6	12,3	10,5	12,3	m ² Sabin
S total 5625,2m ²	0,28	0,22	0,17	0,09	0,10	0,11	
a- = Sa/S	224,0	176,0	136,0	72,0	80,0	88,0	m ² Sabin
V = 5400m ³	0,02	0,03	0,03	0,03	0,03	0,05	
0,164V = 885,6m ³	3,2	4,8	4,8	4,8	4,8	8,0	m ² Sabin
Sabine R _r	0,19	0,37	0,56	0,67	0,61	0,59	
reverberation time	1,4	1,2	0,9	0,9	0,8	0,8	

Principal Performance Space - Occupied

With audience of 670	0,39	0,57	0,80	0,94	0,92	0,87	
S = 670m ²	261,3	381,9	536,0	629,8	616,4	582,9	
A = Sa	798,4	890,1	1136,7	1225,7	1279,0	1300,3	
Sabine R _r	1,1	1,0	0,8	0,7	0,7	0,7	
reverberation time							

Suitable for Speech and Drama without electronic augmentation, Successful implementation of intended reverberation time to cater for a music hall with electronic augmentation and mechanical reverberation assistance as proposed by Centre for the Performing Arts

Table 6.04 Simplified version of reverberation calculation used to prove successful application of internal surcae finishes in order to achieve desired acoustical environment, one where reverberation time is kept minimal in order to accommodate effective use of electronic supplementation of performance sound