WEBB YATES ENGINEERS

Structural Statement

J4565 Highgate Cemetery

Ref: J4565-S-RP-0002

Revision: 01

Status: S3

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DOCUMENT CONTROL

Document number:	J4565-S-RP-0002		
Status:	Stage 3	**Reason for issue:**	For Information
Date:	23/10/24	**Revision:**	01

Author:	A Alderson	**Signature:**	
Reviewer:	C Newmann	**Signature:**	
Approver:	C Newmann	**Signature**	

REVISION HISTORY

Date	Status	Revision
11/10/24	Stage 3	DRAFT
15/10/24	Stage 3	00
23/10/24	Stage 3	01

1. INTRODUCTION

Webb Yates Engineers (WYE) have been appointed to provide Civil and Structural Engineering design services for proposed works at Highgate Cemetery, London for the Friends of Highgate Cemetery Trust. The project involves some new build construction, some re-fit and reinstatement of existing buildings, demolition of others and some public realm developments. The overall works are split into a number of smaller projects, which are listed out in the table and image below.

1.1. Scope of Works

The overall works are split into the following projects. Figure 1 indicates the location of each Project

Project No: Title	Description	WYE Input
Project 1: East Side Building	Community & Education Building. New building with basement on the site of the existing gardener's compound in the East Cemetery.	Yes
Project 2: West Side Building	Visitor & Operations Building. New building extending from the existing colonnade, incorporating operations accommodation, visitor ticketing, shop, and café.	Yes
Project 3: Chapel Buildings	3.1. Dissenters' Chapel Internal Refurbishments - *Interpretation & Archive Space, Funeral Break-out* 3.2. Anglican Chapel MEP - *Anglican Chapel* - Contemplative space, used for funerals and evening events. 3.3. Dissenters' Chapel Internal Refurbishments - Interpretation & Archive Space, Funeral Break-out 3.4. External Works to Chapel – involving reinstatement of original elements to the chapel building such as the cupola, pinnacles and domes.	Yes
Project 4: Courtyard Store	Utility Block New small scale single storey building.	Yes
Project 5: East Side Sentries	East Side Sentries New single storey kiosks at entrance to East Cemetery from Swain's Lane and Chester Road.	Yes
Project 6: East Side Mound Building	Gardener's Building. A new building in the East Cemetery providing office and welfare accommodation and storage for gardening vehicles and equipment.	Yes
Project 7: Public Realm (GPB)	7.1. Courtyard & Access Control	Limited

	7.2. Swain's Lane	
Project 8: Landscape Conservation (GPB)	By others	No
Project 9: Lodges	9.1 North Lodge - Gardener's Tea Point 9.2 South Lodge - *Visitor WCs*	No
Project 10: Conservation & Repair	10.1 Funerary Structures and Roofed Mausolea. By others	No

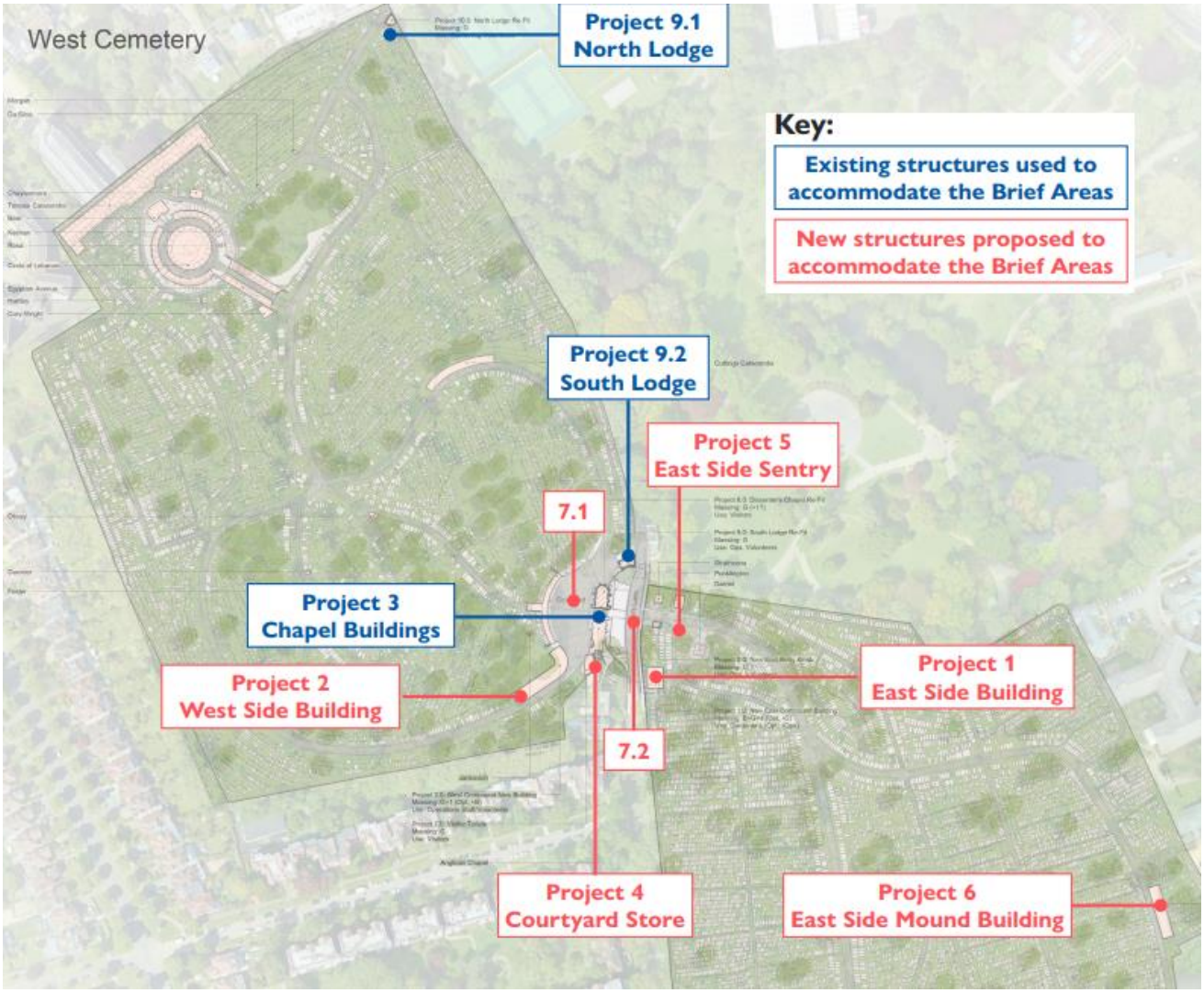

Figure 1. Masterplan sketch by Hopkins Architects providing an overview of the Project locations (Hopkins Architects)

2. STRUCTURAL SCHEME

The following sections summarise the principles of structural design for each project.

2.1. PROJECT 1: Community & Education Building

A new education and community building is proposed in the East Cemetery to replace the existing Gardener's East Compound. Works involve demolishing and rebuilding the existing single storey building and enlarging the existing basement.

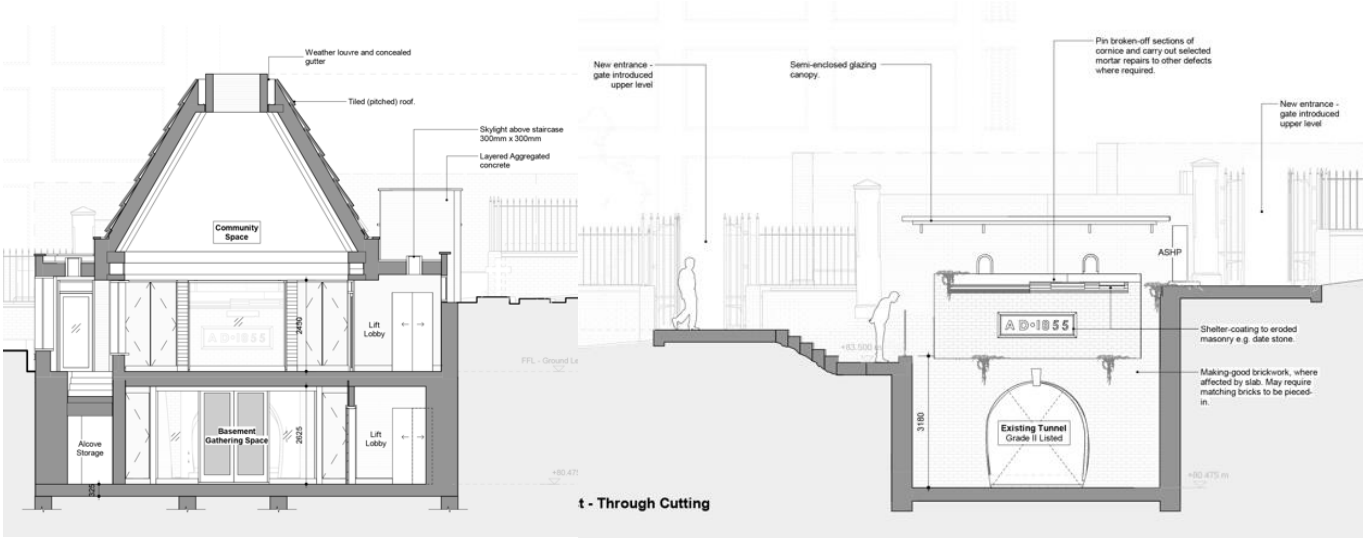

Figure 2. Extract of Hopkins Architect's section drawings of the Community Building

2.1.1. Superstructure

The structure proposed is to include a large vaulted pyramid roof over the ground floor space. The superstructure will be timber framed with reinforced layered concrete external walls. Layered concrete describes concrete poured in layers with varying pigments and aggregate to create visual texture. The vaulted roof will be timber framed roof clad with stone roof tiles. The ground floor will be a reinforced concrete slab. Around the main ground floor area are small peripheral poche spaces, these also are proposed to be constructed from layered concrete. The flat roofs over these are to be timber joisted supported on the external concrete walls.

2.1.2. Substructure

The substructure consists of a basement with poche spaces around the main square space, formed with concrete piled retaining walls. There is an existing basement for part of the footprint, however new retaining walls will be needed to extend the basement space. Consideration should be given to replacing large parts of the existing basement structure due to the difficulties involved in interfacing with the existing fabric and providing a watertight structure. Open excavation will not be suitable due to the constrained site. Embedded retaining walls, such as secant piles, can be used instead to allow for excavations. The depths of these will need to be carefully controlled to avoid disturbing any burial sites, so temporary works sequencing should be considered by the contractor.

There is an existing disused tunnel which leads to the Chapel and runs under Swain's Lane. The entrance to this will be visible from a glazed canopy connected to the Community Building. The interface with the existing walls will be sensitive to the historic nature of the tunnel. Any connections that are required will minimise drilling or cutting into of existing masonry.

2.2. PROJECT 2: Operations & Visitor Building

This project encompasses the creation of a new building for visitor ticketing, café, and shop, as well as office accommodation. The proposed building is adjacent to the Grade II listed Colonnade and opposite the chapels in the West side of the cemetery. There are currently containers in this location on site; these will be demolished and removed prior to works starting.

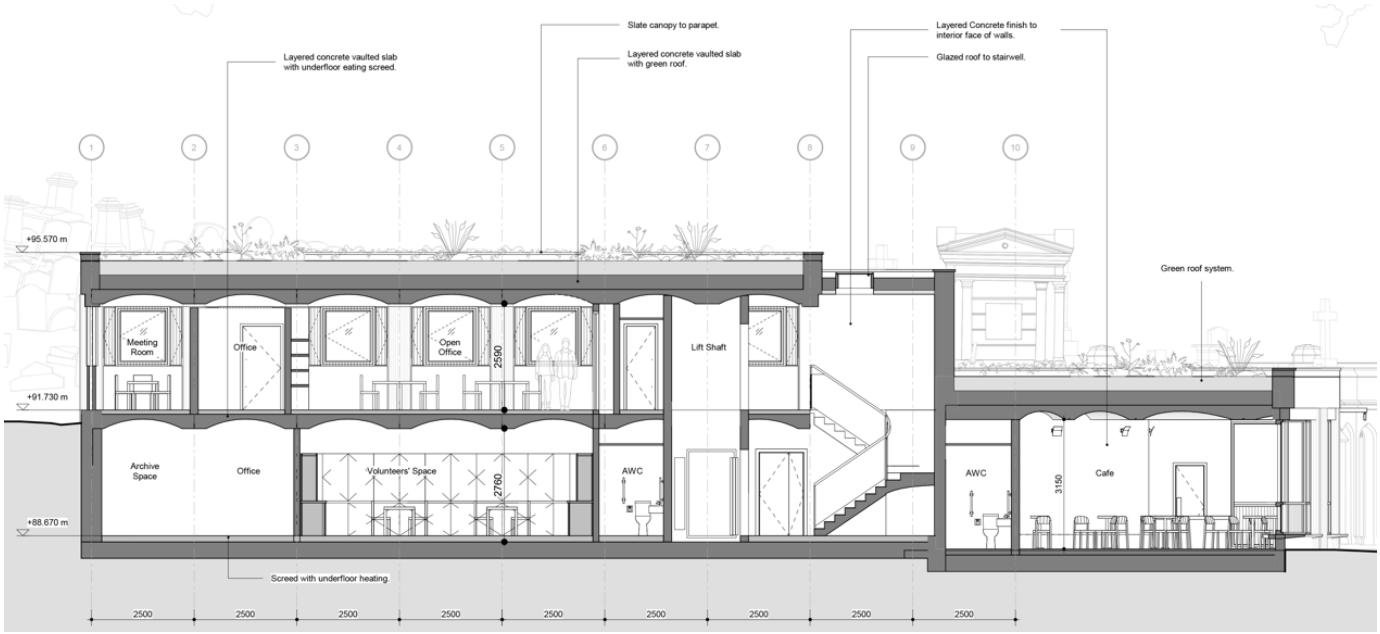

Figure 3. Extract of Hopkins Architect's section drawing of the Operations and Visitor Building

2.2.1. Superstructure

The building proposed includes a single storey café area and office accommodation over two storeys. There is a small ticketing booth adjacent to the Colonnade with a canopy roof.

The superstructure proposed is reinforced layered concrete columns with vaulted concrete arch floors and roof. The arches are to span between reinforced concrete beams at the deepest parts of the arches, within the slab depth. These arch elements could be produced either on-site or cast in-situ off-site, and the choice of construction methodology will inform details developed at the next stage. Manufacturing these units offsite would allow use of concrete with a lower cement content (and therefore longer curing time). This type of concrete is less practical when using in-situ methods but can reduce the embodied carbon of the structure. Offsite manufacture of the arches could also allow for a layered concrete effect on the arches, as it can be poured in different directions.

Architecture layouts show large piers at ground floor level. These will be constructed using the layered concrete and a cavity construction method to allow them to be exposed both internally and externally without creating a thermal bridge. The outer layer would be tied to the inner column for support.

2.2.2. Substructure

Ground levels slope across the site so that the building is partly set into the ground and will therefore require a retaining wall along two sides of the ground floor level. To allow for the retaining wall to be built within the constrained site, sheet piles are proposed be used along the back faces. These cannot be driven deeply into the soil due to the likely presence of burials and heritage fabric below, the positions of which are currently unknown. Therefore, the sheet piles will require temporary propping during the retaining wall construction. These temporary works will need to be carefully considered and sequenced.

A concrete raft slab will form the ground floor and be used to distribute the structural loads evenly, replacing the need for deep foundations. The ground floor slab will step to align with the ground levels of the Courtyard & West Carriage Drive.

2.2.3. Entrance Canopies

The canopy soffits will be finished with slate or stone, using either post-tensioned stone or steel beams to support the canopy cantilever. Posts will be used in walls to support the canopy beams where required.

2.2.4. Future Considerations

In the next stage, the concrete arches and cavity columns should be prototyped and tested, as well as the chosen finishes. The canopy design over the ticketing booth will also be developed further. Results of additional ground investigations will allow more detailed analysis of the raft foundation slab and retaining walls to be carried out.

The abutment of the new building to the existing Colonnade will be sensitive to the historic and listed nature of the Colonnade. The new building will not be connected to the historic Colonnade or use the structure for support in any way.

2.3. PROJECT 3: Chapels

Structural works to the chapel building are focused on the reinstatement of original external features. Proposals are developed with West Scott Architects and are detailed with consideration to maintaining, and minimising interventions to, existing structure where this is suitable. The sketch below from West Scott Architects shows the structures in red that are intended to be reinstated. See also photos in Section 3.2.2 that show these original features. Additionally, updates to the interior of the Dissenters' chapel have been developed with Hopkins Architects.

Figure 4. Sketch from West Scott Architects showing the pinnacles and cupola.

2.3.1. Dissenters' Chapel Alterations

A new mezzanine structure is to be provided within the Dissenters' Chapel, replacing an existing mezzanine that was installed in the 1980s. The existing mezzanine floor will be taken down, and reuse of the existing joists will be considered depending on their size and condition.

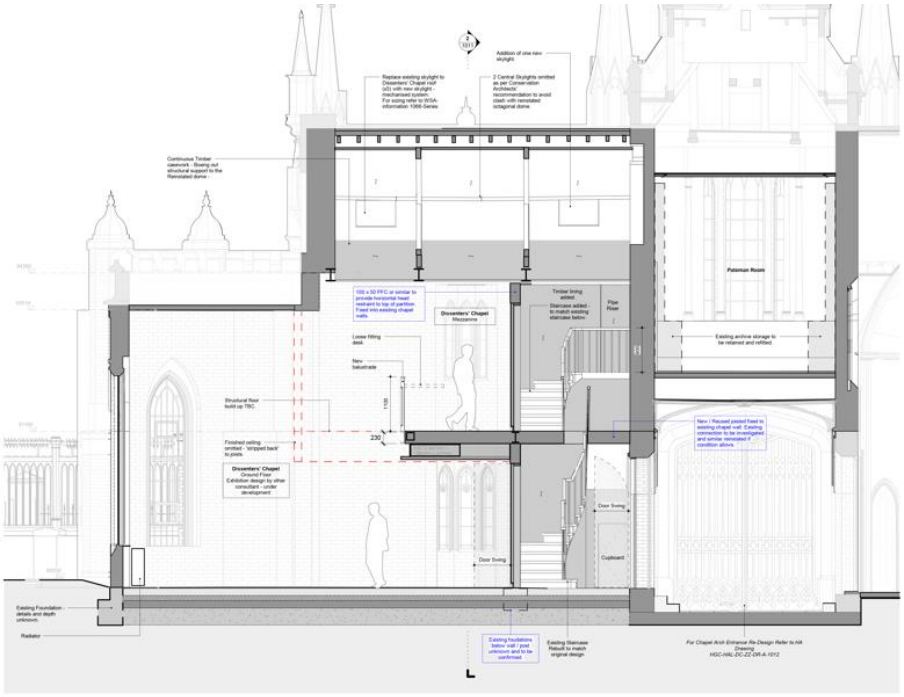

Figure 5. Extract of Hopkins Architects' section drawing of the proposed Dissenters' Chapel with mezzanine

New steel beams spanning between existing masonry walls will be provided to support timber floor joists. The existing walls will require some investigation to confirm condition to support the new beams. New load bearing posts or walls may require new foundations to support loads from the mezzanine and staircase. The existing ground floor slab of the Dissenters' Chapel is likely to need to be replaced with a similar new slab, due to its poor condition.

2.3.2. Cupola

The cupola is the large central structure that sits above the carriageway roof and would have originally held the chapel bell. A new timber frame structure is proposed to be reinstated, protruding approximately 6m above the current roof ridge, and will replace modern dormer windows. Support to the new timber frame has been carefully considered. An existing timber truss frame is located within the roof space, this currently holds the bell and it is believed that this would have originally supported the cupola. WYE have visited site to view this existing structure and it was noted that some structural interventions have been made over the chapels' history, most notably the presence of steel beams that are spliced to several original timbers. See site photos below.

Figure 6. WYE site photos of existing timber truss within central chapel roof

WYE have carried out an assessment of the existing timber frame based on available survey information, see figure below showing GSA analysis software outputs. This assessment showed that the existing truss would likely be able to support the new proposed cupola if all elements were in good condition. However, several unknowns remain (i.e. condition and grade of existing timbers, details, and condition of existing connections) that may lead the framing to be unsuitable for reuse. Further intrusive and extensive investigations would be required to confirm these unknown factors and establish if the frame could be reused. It was ultimately decided by the deign team that an intervention scheme should be proposed at this stage, as it not yet possible to obtain such investigation results.

New steel beams are therefore proposed to provide support to the new timber frame cupola. These are intended to bear onto existing stone and masonry walls. The approach will aim to minimise the loss of historic structure. Some investigations will be required to confirm the bearing detail and strength of walls below to take these new loads.

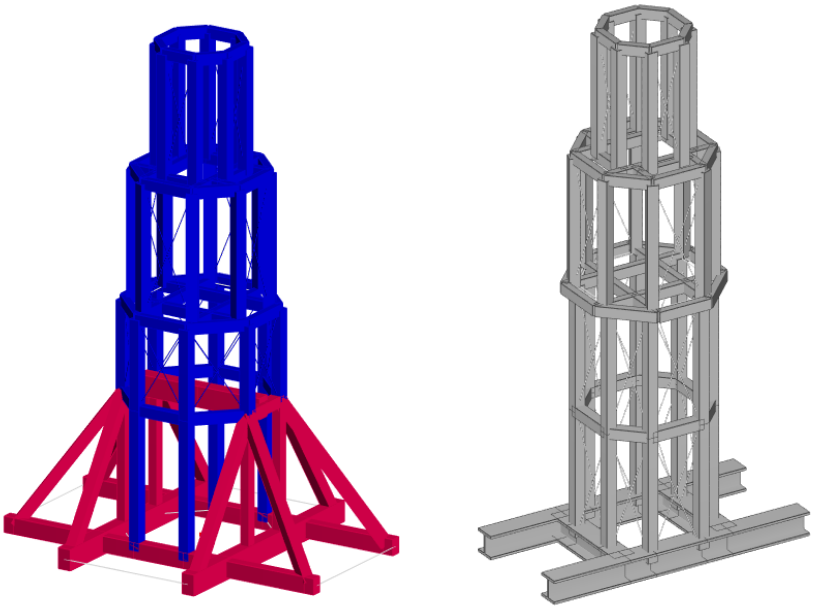

Figure 7. WYE analysis model of new (blue) and existing (red) cupola frame [LHS]. WYE analysis of the new cupola structure with new steel beam supports [RHS].

The new octagonal cupola structure is to be formed from timber posts and beams with some timber infill flooring at levels changes. Diagonal steel bracing is required to provide lateral stability and transfer horizontal wind load back to the supporting structure. The timber frame is considered external, as louvres will be used in cupola openings. Timber types and grades have been discussed with West Scott Architects with regards to durability, but a decision will be needed at the next stage in order to finalise the design of the framing.

2.3.3. Ogee Domes

Smaller octagonal ogee domes are also to be reinstated to original locations. Some concrete or stone plinths are still present and will be considered for reuse to support the new structures. The new domes are proposed to be constructed of stone blocks and will be partially supported on masonry walls below and partially on a new beam spanning between existing timber roof trusses. See image below.

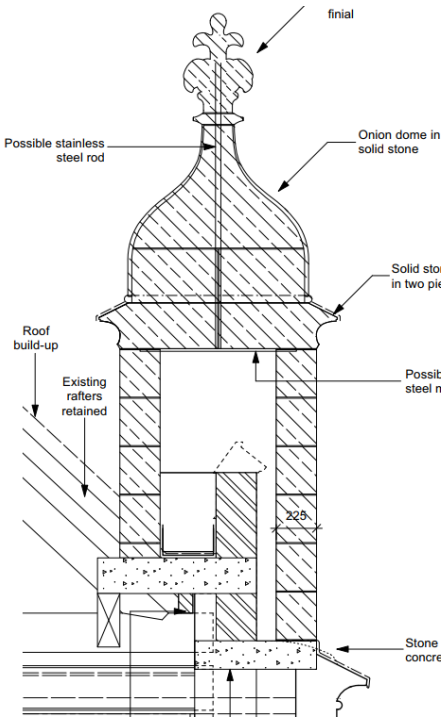

Figure 8. Extract of West Scott Architect's sectional drawing of the ogee dome

WYE have considered the stability of the new domes, and it will be necessary to tie the stone structures to the new concrete base slabs and the existing walls below to prevent overturning. It is also proposed to use steel dowels between coursings of stone blocks and to the solid stone capping pieces.

The type of stone chosen to be used for the domes is currently Oolitic Limestone, with Bath Stone deposits sourced from Hartham Park. At the next stage, testing of the chosen stone is to be carried out in order to confirm suitability, strength, and other properties.

2.3.4. Pinnacles

The pinnacles are tall stone spires that are located around the perimeter of the chapel roof. The new structures, again to reinstate original features, are proposed to be of follow stone form. The top pitched section of stone is proposed to be post tensioned off site and lifted into place in once piece. This will then be fixed down to solid stone walls that form the octagonal spire. These walls will be reinforced with steel bars to the centre of the blocks and tied down to the new concrete base slab and again to existing masonry walls below.

The new pinnacles, circa 6.5m high, would be detailed to match the original ones and checked to ensure that they are stable when installed. We believe that the existing plinths and structure will have the capacity to support the pinnacles as it supported them historically. Careful attention will need to be given to the connection interface at the bottom of the pinnacles and the plinth.

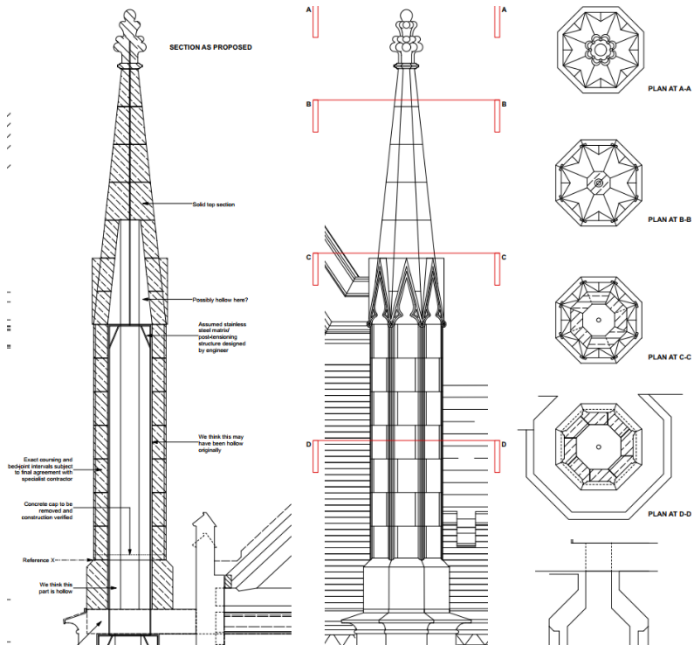

Figure 9. Extract of West Scott Architect's drawing of the new pinnacles

2.4. PROJECT 4: Courtyard Store

A new single storey building is proposed to the south of the Chapel. An existing WC block in this location will be demolished. The new utility block is unheated and will use load bearing masonry walls on an RC raft slab with a timber joist roof. The building is sited over existing utilities which may require localised diversions, this should be given due consideration in Stage 4.

2.5. PROJECT 5: East Cemetery Sentries

New single storey entry kiosks are proposed at the Swain's Lane and Chester Road Entrances to the east-side of the Cemetery. The existing ticket booth will be demolished. The new structures will use simple structural timber framing with a layered concrete base on an RC raft slab, to suit the architectural proposals. The roof cantilever will be formed from cantilevering timber joists supported on timber posts. The timber structure will be in external conditions and is designed accordingly. Appropriate choice of timber species to suit these conditions will be made at the next stage. The roof finish proposed is a welded metal canopy with inlaid slate.

2.6. PROJECT 6: Gardener's Building

A two-storey building to house gardener's welfare facilities, vehicles and equipment is proposed in the East Cemetery. The site is located in an embankment just off a main footpath and burial zones are known to be present at the higher and lower levels.

The Trust has undertaken some exploratory works at the lower level to verify the existence of recorded burials. These investigations have confirmed that there are graves located under the proposed building footprint. The footprint of the building will be assessed once further investigative works have been undertaken to minimise the risk of the works disturbing the burials.

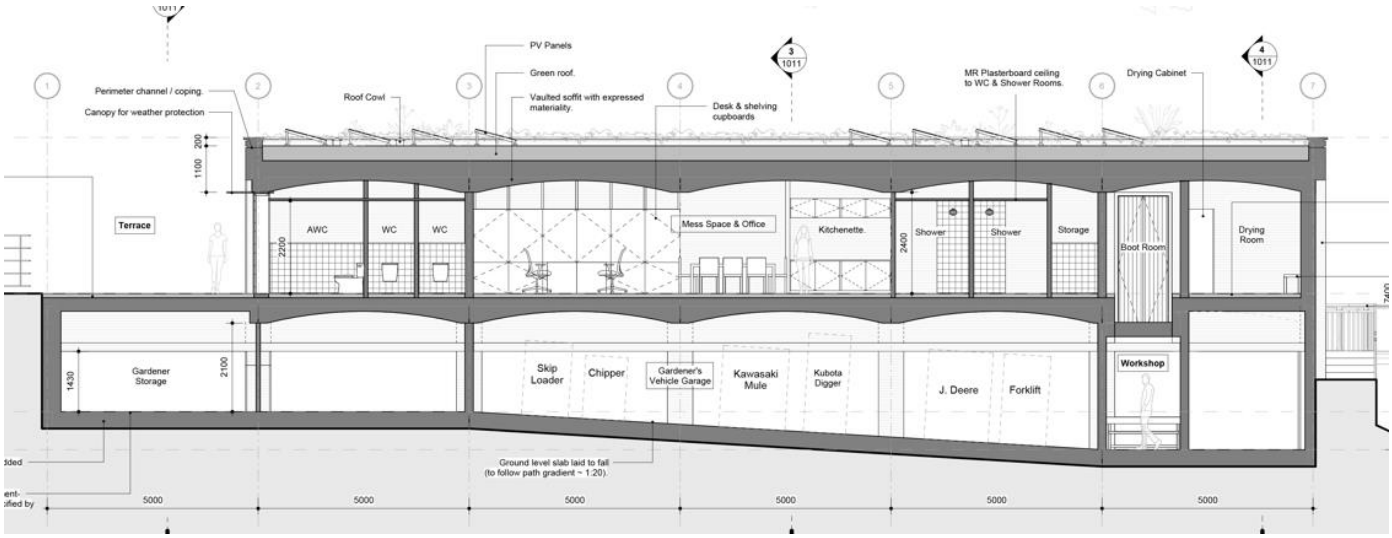

Figure 10. Extract of Hopkins Architect's section drawing of the Gardener's Building

2.6.1. Superstructure

The superstructure of the Gardener's Building is similar to the Operations & Visitor Building, consisting of reinforced and layered concrete columns and vaulted concrete arch floors. The arches are to span between reinforced concrete beams at the deepest parts of the arches, within the slab depth. These arch elements could be produced either on site or off site. Manufacturing these units off-site could allow the cement content to be reduced, minimising the embodied carbon of the concrete, and would also allow for the layered concrete to show visually as it can be poured in different directions.

Rather than using cavity columns, the Gardener's Building is assumed to use a monolithic layered concrete column, which is to be thermally broken from the arch slabs and beams above first floor level, using a proprietary thermal break system such as Schoeck, cast into the concrete. The columns could also be produced as precast elements with the thermal breaks already cast in before being brought to site.

2.6.2. Substructure

The Gardener's Building is to be embedded into the mound embankment at ground floor, so a retaining wall is required. The substructure should prevent any impact on the underlying archaeology and further investigations may be required to establish the presence of any burial sites or other interred structures. Consideration will therefore need to be given to sequential construction of the retaining wall with a propped sheet pile wall (similar to the Operations & Visitor Building). A concrete raft slab will also be used to distribute the structural loads evenly and replace the need for deep foundations.

2.6.3. Future Considerations

In the next stage the concrete arches and voided columns should be prototyped and tested, as well as the chosen finishes. The external staircase supports will also be developed. Results of additional ground investigations will allow more detailed analysis of the raft foundation slab and retaining walls to be carried out.

2.7. PROJECT 7: Public Realm

Works are proposed to improve the arrival area and provide step free access to Chapels. This would involve public realm works to re-level colonnade and courtyard. Minimal structural interventions are expected, and WYE will input as needed in the next stage based on proposals from GP+B.

2.8. PROJECT 9: Lodges

No structural modifications are proposed for the North and South Lodges.