DANGROVE

Design & Construction 2014–2018

We acknowledge the generosity of Judith Neilson in sharing the knowledge of the people who designed and built Dangrove.

DANGROVE

Design & Construction 2014–2018



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Dangrove

Dr Judith Neilson AM



Seldom has a major building been completed with both the client and the architect looking back with absolutely no regrets. In this respect, Dangrove is unique.

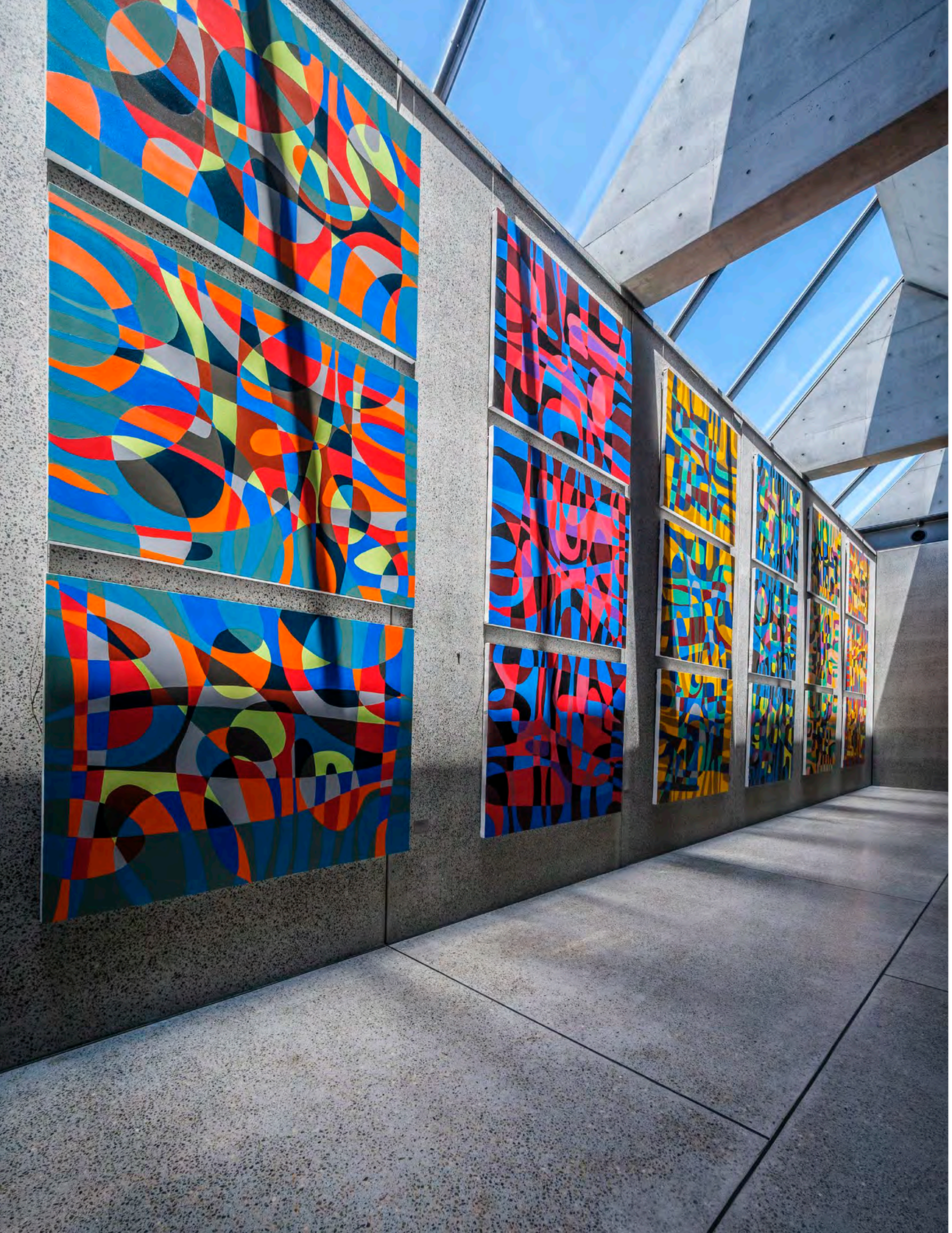
From its conception, Alec and I spent months in discussion and researching how we could create the very best art storage facility in the world. Only when both of us were completely happy and in agreement did work on the final design begin.

The brief for Dangrove was very specific as the art to be sorted there, and everything related to it, would never be reallocated. This building was to house The White Rabbit Collection for evermore.

Materials, spaces and functions were critical. The building had to be able to accommodate transport and deliveries in large trucks and containers; it needed a full-scale workshop, space for receiving and packing; rooms needed to be dust free and climate controlled; there had to be a photography studio, designated executive office space, state-of-the-art security, parking and a kitchen for events. Other key factors were spaces for conservation, a library and a large event space.

To accomplish such a significant build, experts were consulted at every juncture – everyone was aware that this building must last at least 100 years!

Dangrove is now a wonderful, working building and how we got to this incredible end is well documented. This book, I hope, will help those who don't know where to begin as well as anyone who wants to understand what is involved in putting a building together. I believe that all learnings we have from Dangrove's design and construction can be applied to any build.



SOLAR
WATER TANKS

Photography space
New works from recent trips
New show prepare.
Old show until re sent.
Unload
Boxes & packaging
Workshop.
Media/Video
Canteen
Laundry
Exhibition furniture
Lights
Painting
Photography – drawing - paper. GLASS FRAMED
Video
Installations
Sculpture
quarantine
THEATRE
SHOW SPACE for big install - INVITED GUEST

"DANGROVE"









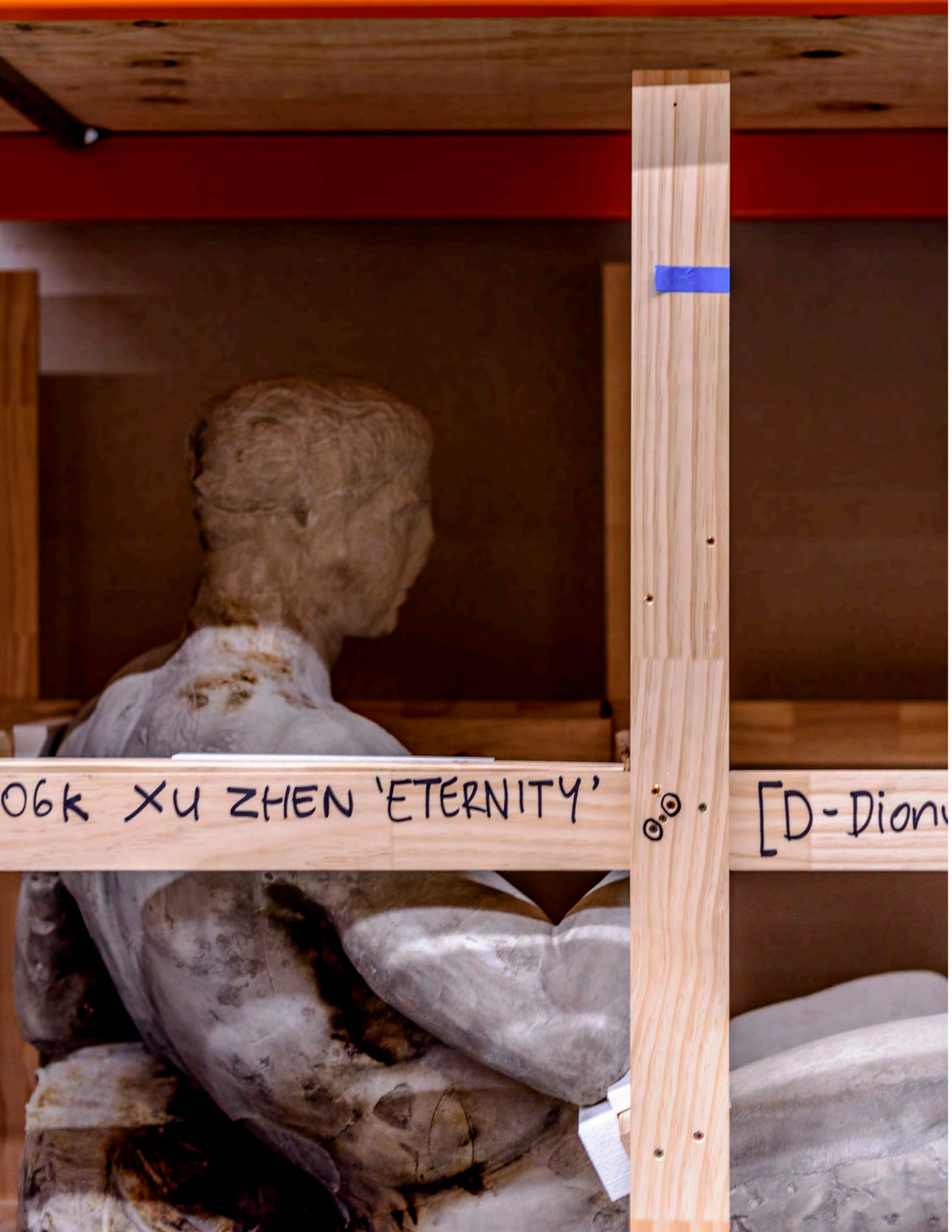

LIBRARY



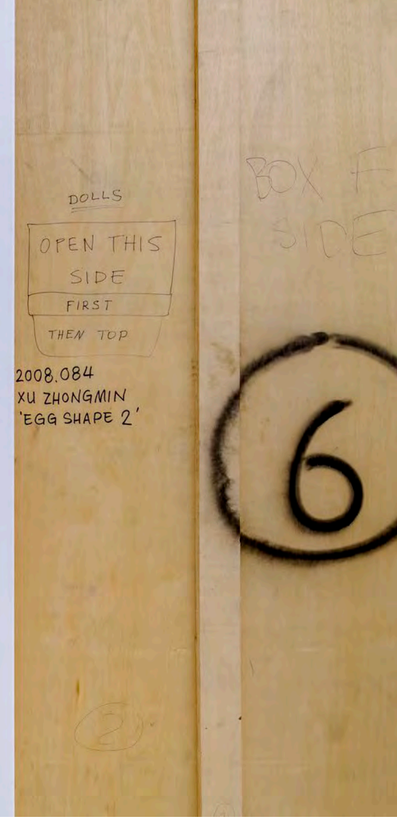





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Designing Dangrove

Alec Tzannes

Judith Neilson is a remarkable person and client for an architect. She deeply understands and values fine architecture as is evident by many of the buildings of national and international significance she has created in Sydney. Dangrove is just one of Judith's buildings – conceived as a storage facility for her substantial collection of Chinese art.

Before being commissioned for Dangrove, I was aware of Judith's inner-city home and White Rabbit Gallery, both designed by Smart Design, as well as commissions underway by Wardle and Durbach Block Jaggers Architects for the design of Phoenix, a private gallery and performance theatre. My first discussions with Judith about designing her storage facility in an industrial area of Sydney for the yet-to-be-named Dangrove seemed to me to be reasonably straightforward. Although relatively prosaic in function, I understood the facility to be designed was of critical importance to the future security of the collection.

Once commissioned, the brief turned out to be anything but prosaic. The brief is where the story about the design of Dangrove begins.

Dangrove was also to be designed for a 100-year life as well as minimise carbon emissions in construction and operation. In that context, storage for Judith was not to be a stand-alone function. Instead, storage functions were to be integrated with curatorial, conservation, administration and exhibition capability for all types of art. In addition, Dangrove was to provide the setting and technology for art, including performance art, to be featured at invited events.

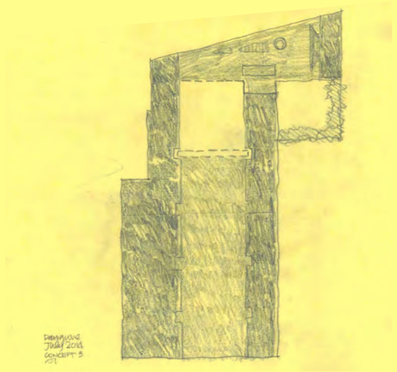
The art in storage was required to be viewed, assessed and experienced with ease and comfort. Art was to be easily brought into view or experienced within the storage compartments, and circulated with ease of movement anywhere within Dangrove. The entire range of functions and sequence of spaces were to be designed to enable Dangrove to function as the 'engine room' to service White Rabbit requirements and the increasing demand for art in her collection to be circulated around the world as part of exhibitions in other galleries and museums.

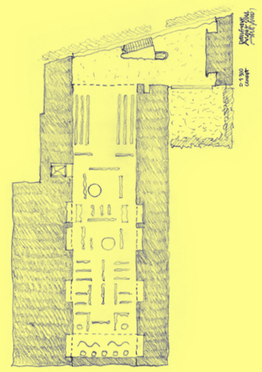
Within the brief, and at the core of her vision, was an essential idea that today may be considered to be of global significance in the area of art management, storage and the curation of art experiences within storage facilities. As a result of this brief, a design that was unlike all relevant precedents at the time was conceived.

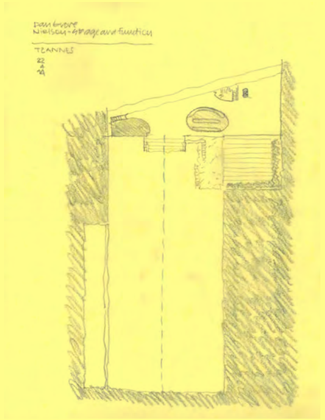
Addressing functionality as articulated in the brief was not straightforward from a design perspective. The management of art of scale and complexity involved many considerations beyond safe storage. Given the wide range of uses, the design of Dangrove was conceived from the outset as an attractive indoor environment for staff and visitors, optimising low-cost energy technology and with emphasis on movement efficiencies in all directions for the transportation of art throughout the facility. A focus of early design studies was on the technical capacity and requirements of the largest proprietary forklift truck and goods lift available in the world, as these would have to become the determinants of many critical space planning decisions and dimensions.

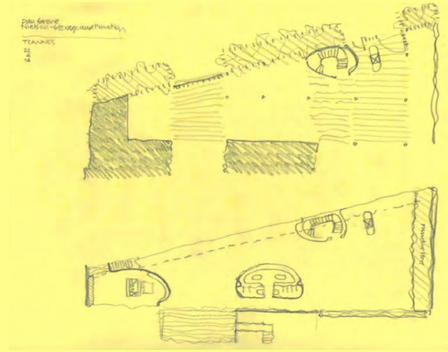
Given the size and rate of growth of the collection, another critical objective was to achieve optimum internal space within the constraints of the property for storage functionality. An early design idea was to place the fire egress routes at the perimeter of the property to optimise interior space and connectivity. This design proposition also provided a fail-safe double wall to enhance flood mitigation and waterproofing for the whole building.

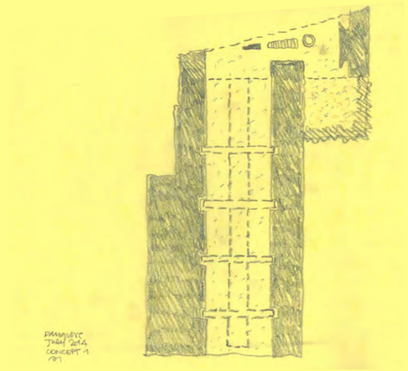
Along with easy movement of all art, comfortable walking between and inside each of the fire-rated storage compartments to view and manage the collection was essential and, as a result, has established a distinctive Dangrove experience.



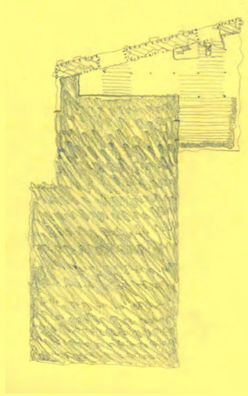


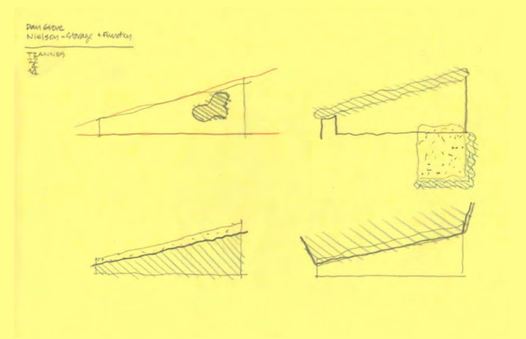


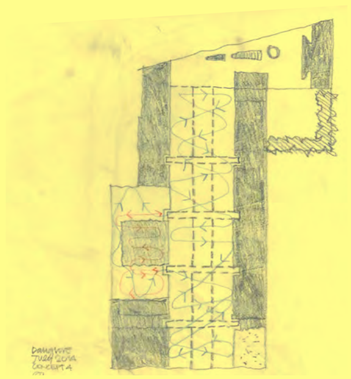


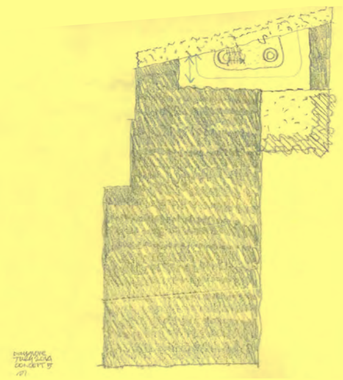




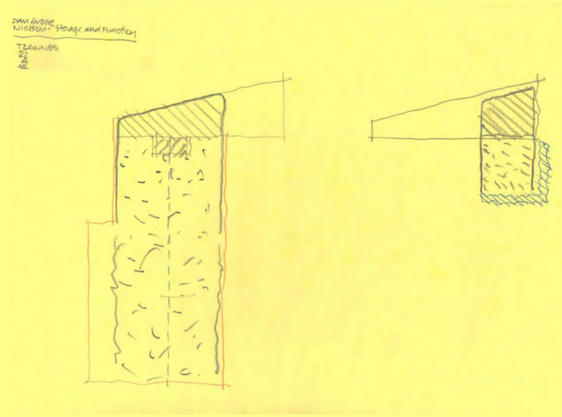












Concept sketches for Dangrove.

On a more technical level, the brief required Dangrove to be built to a budget with an expectation that tight design and construction management techniques were to be used to control cost and mitigate design risk.

Design research

After the design brief was issued, desktop research of precedents was undertaken. A visit with Judith to the Art Gallery of NSW storage facility at Rozelle, Sydney, was also arranged. During this visit, I was struck by how uninspiring the building was from many points of view, including its functionality and unpleasant working environment. I kept my thoughts to myself, not knowing Judith's assessment of the architecture.

When the visit was over and I was driving back to the studio, I took an unexpected call from Judith. It was a short conversation. She said that if I came up with anything like the building just visited, I would be on the wrong track.

The call confirmed what I had understood from discussions – the brief was 'open minded', embodying a serious commitment to rethink the nature of art storage. No more precedents needed to be examined as they could not be helpful, given Judith's design direction. From a design perspective, I was now confident that this commission envisioned a groundbreaking exploration of how art storage could be integrated with a complex range of specialised work and display environments.

The next area of research was into the potential adaptive reuse of the existing factory structure on the property. This building had a better-than-average exposed portal frame steel structure and open tread main stair as its only modestly positive attributes. The rest of the building was not of sufficient quality, size or functionality to be able to retain and adapt.

While keeping and adapting the structure and stair was desirable from environmental perspectives, three assessments made this prospect unworkable. The structure was far too small in its span and not suitable for a second storey. The stair went to a low mezzanine with non-complying treads and balustrades. The existing ground level was also subject to flooding with incapacity to deliver a secure new flood-free interior without compromising the main asset of the architecture, the steel portal frame design. And most importantly, I had already concluded that keeping the structure meant that a much more effective fire egress design could not be implemented. It was clear from the outset of my thinking that the most secure and efficient method for fire escape and flood mitigation was to design a perimeter double wall to address these technical requirements and deliver an enclosed area over the full dimension of the property to maximise the operation of primary functions.

All the demolished materials were subject to recycling priorities to offset the carbon footprint of new construction.

In parallel, examinations of the local planning requirements underway included a study of the development controls and site visits to the nearby industrial buildings. The objective was to fully understand the statutory and physical context.

Visits confirmed the property location to be in an uninspiring place from a pedestrian experience perspective, and ideal for the primary function of the brief – long-term art storage. Research and discussions with the City of Sydney indicated that the local environment was not likely to change in use in the foreseeable future given the intensive concrete manufacturing facilities and other substantial industrial investment on neighbouring properties. The statutory controls legislated by the City of Sydney were assessed and found to be based on sound environmental and economic principles with the aim of ensuring this type of relatively rare land use within the City of Sydney jurisdiction remained available for development.

The most important area of research was around understanding the scope and requirements of the collection, including its rate of growth per annum. Aided by data provided by Jim Strickland, who oversaw the collection including operations within the existing inadequate art storage facilities, schedules were prepared of all the types of art from large to small and in all media and mediums including video, film, digital, light or in composite materials.

Following this research, a new building was agreed upon by Judith as the only option to pursue.

The design concept

From the brief and research, the design concept was developed over a relatively short time period and with Judith's focused engagement.

George Korban, the design lead in the early stages of design process, checked my preferred design concept to determine whether perimeter fire escape routes met the mandatory egress requirements of the National Construction Code, also referred to as the Building Code of Australia. George confirmed that the concept technically worked, delivering optimum interior space and efficient functionality. Once the required fire escapes worked, I knew that establishing double-wall barriers for overall security, water control, flood protection and, potentially, an excellent plenum for services reticulation was a sound platform from which the architecture could develop.

In my mind, if plans were about optimising functionality, the 3-D experience reflected in the main cross-section was conceived to bring 'functionality to life' through the interplay of space, materials, shadows and light. The objective was to create an interior space for work and events with optimal amenity, excellent outlook and sense of movement from the skeletal shadows of the structure visible through the inner polycarbonate wall. The soaring space of the Great Hall complemented outlook to the north and the views onto the courtyard from the library, Ante-Room and upper-level reception area. Art in storage at Dangrove was part of an emotionally engaging spatial experience delivered by architecture that was conceived to not compete with or dominate the art. Instead, the architecture in soft grey, charcoal and white materials created a soft, protective setting that enhanced the distinctive characteristics of the art when displayed.

The ground floor optimises efficient movement between the main pedestrian and vehicular entry through security, to workshops, storage, the White Rabbit facsimile room and services. The loading dock is directly connected to the main connecting circulation pathway – a double-loaded corridor with linked vertical transport capable of moving all art throughout Dangrove with the use of forklift trucks.

On the upper level, storage compartments, conservation, library, security accommodation and administration are arranged around a sculpture courtyard and two major spaces for curatorial, exhibition and event functions. These two spaces were named during the design process as the Great Hall and Ante-Room to the Great Hall (and later renamed the Re-Drawing Room).

The upper level was conceived as the heart and soul of Dangrove. The experience of the courtyard and two major viewing and curatorial spaces aimed to create interiors that provided comfortable working conditions, encouraging collaborative and engaging work practices between the various skills and disciplines required to curate exhibitions and manage the art. The main spaces were aimed to create serene, contemplative feelings enhanced by a sense of the day unfolding by the play of light and shadow and outlook to views. The cathedral-like scale of the Great Hall was practical as it could exhibit major sculptures as well as display light and other forms of spatial art. The Great Hall is also conceived to allow curators to demonstrate the scale of the collection contributing a relatively neutral, light-filled space.

Dangrove is not 'showy architecture' – it is designed to safeguard the collection as well as to enhance the experience of the art when on view. The proposed monochrome material palette in grey, white and black and simple interior geometries ensure the art on display or in performance mode, and not the architecture, is the primary sensory experience.

Expanding on function, form and space

Dangrove's exterior character is designed to fit into the industrial precinct and disguise the significant interior experience. The triangular external form of the Great Hall can only be seen at a distance functioning as a landmark created by light through the double polycarbonate envelope terminating the major axis of Zetland Avenue.

The straightforward plans on both levels are complemented by three-dimensional spatial concepts that add varying sensory experience created by light, space and movement. These ingredients emotionally engage by adding intangible dimensions to the functionality of the spaces, including in performance and exhibition modes.

Level 1

The property's only street address provides the access for pedestrian, parking and an off-street loading dock for large container trucks. The street slopes to the lowest level of the property at the north-west corner. An elevated loading dock set out from the north-west vehicular access level established a practical level free from flood impacts for the ground floor. The large container vehicle safety requirement of 'forward in and out movement' set out the volumetric capacity for onsite storm water detention to ensure the required flood security at ground level. Other technical requirements including a substation, fire hydrants and meters for services were also safely positioned near the loading area and accessible from the street when required.

The loading dock connects to the main double-sided access corridor to service storage compartments, each designed to serve specific art requirements. The access corridor width accommodates 360-degree manoeuvres for large forklift vehicles and links workshops, the goods lift, storage areas and major plant rooms, including the stormwater tank, filter and recycling services.

Along with the storage compartments a special function space with the same proportions as the main gallery of the White Rabbit gallery enables curators to test potential exhibition ideas.

Dangrove's front door is located adjacent to the car park entry towards the north-east street boundary of the property on the other side of the truck access and loading dock. From there, a direct on grade route at flood-free level forms the pedestrian entry. Glass doors open to security from where pedestrians can continue on ground level or, more typically, up the stair or a smaller pedestrian lift to the main floor above. The security and adjacent administrative staff area is double sided, with comprehensive visual and camera control of the separate pedestrian/car and truck access points.

The pedestrian entry experience was first conceived as a distinct and more elaborate element of the architecture as evident in the first sketches. When cost became an issue, I suggested the current straightforward entry be developed, reasoning that as an industrial facility, it was appropriate and had the added benefit of creating context to deliver an element of surprise on arrival at the more spatially generous upper level.

The exterior expression on the street was simple. The architecture is designed to not draw attention to the purpose of Dangrove. The ground level treatment was conceived to be a high metal security structure behind the new street landscape, including Japanese maples. The upper level was expressed as a projected solar hood in concrete around full-width glazing with very large spans for each panel above the pre-cast concrete elements. The name 'Dangrove', chosen by Judith in memory of a childhood location, is cast into the concrete.

Level 2

Although Level 1 was designed with high floor-to-floor allowances at 5.92 metres to accommodate large objects and paintings, Level 2 was even more generous and spatially engaging being conceived as the main floor of Dangrove – the Piano Nobile, to use a Palladian or Georgian analogy.

On this level the primary function of storage was supported by administration, library, kitchen and other higher quality back-of-house facilities, conservation, residential accommodation for 24/7 security or guests, a landscaped sculpture courtyard and two interrelated multi-use spaces – the Ante-Room and Great Hall.

Arrival via lift or stair is to a lounge with a view of the sculpture courtyard. Adjacent to the lounge, out of direct view, are administrative offices.

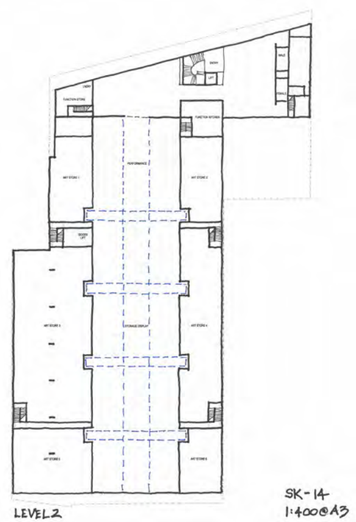
The Great Hall is designed to be concealed from view from the Ante-Room (or Re-Drawing Room) and only able to be accessed or viewed once an array of large doors connecting the two spaces are opened. One of the concept sketches shows a weaving movement between the storerooms and the Great Hall illustrating the intent for easy movement between these fire-isolated spaces.

The Great Hall was proposed at approximately 84 by 19.4 metres with a variable, stepped height ceiling aligned with the structural grid rising from 6.5 to 27 metres. Services, located outside the Great Hall envelope, deliver air control through a re-entrant steel band separating the precast concrete floors and walls from the triangular wedge of light entering above. Mechanical plant is located on the flat east and west roofs for easy maintenance and to operate without compromising the height or width of the Great Hall. Natural daylight entering at either end of the Great Hall was designed as a special threshold providing subtle contrast with the cool, ethereal light penetrating the double-layer polycarbonate clad walls.

The stepped ceiling over the Great Hall is designed to modulate space and provide differentiated articulation to the north and south interior vistas when viewed on axis.

Sketches by George Korban.





The ceiling panels have the capacity to support suspended art of significant scale and weight, as well as provide for light, laser, sound and video or film art for the space in performance mode. A retractable gantry superstructure, originally proposed to enable programmable installations over the whole space was deleted once it was determined that all art could be moved around anywhere and displayed without this mechanism.

Environmental design considerations also contributed to the three-dimensional form. The sloping roof is set at an optimal angle to harvest electricity sourced from photovoltaic technology and at the maximum allowable height defined by the development controls. The northern skylight 'scoop' is designed to minimise solar access during the summer to equinox periods and to slow water movement sufficiently to reroute as an overflow to the southern collecting drain connected to the ground level water tank and filtration technology. Dangrove's built form is shaped to optimise environmental performance and minimise the cost of maintenance in alignment with the technical aspects of the brief.

Development consent

A challenge in the development approval process was compliance with the City of Sydney Local Environment Plan Design Excellence Strategy and, in particular, clause 1.2 of the City of Sydney Competitive Design Policy 2012, which requires a design competition for properties of the size of Dangrove. Variance from this policy is permitted although rarely granted by the City of Sydney. The argument was made that the competitive design process could be replaced with a independent design review process overseen by the City of Sydney as the brief required an optimum layout which had been established and could not be varied. Consideration of Judith's proven track record for the delivery of excellent architecture was also given as a reason to have confidence in the design outcome from the perspective of the legislation intent.

The City of Sydney did not accept these arguments and requested the Development Application (DA) be withdrawn on the grounds that Design Excellence had not been demonstrated in the scheme submitted for development consent. Judith did not agree and proceeded by formally requesting the DA to be determined. This signalled to the City of Sydney a willingness to undertake an appeal in the Land and Environment Court as a consequence of a likely refusal of the submission. After more discussions, the City of Sydney proposed to delay determination until further visual material was provided, including a larger physical model to demonstrate the design proposition in more detail.

The City of Sydney reconvened after a number of months to review two new large physical models predominately crafted in recycled Huon pine material and along with new CGIs of the exterior and interior. The City of Sydney heard a new presentation with this material featured and determined that the Design Excellence provisions of the LEP were met, triggering the determination for approval of the DA.

Design from concept to construction

To get from concept to the Development Application for development consent in Sydney, especially for a complex building, is a lot of work, as most architects will testify. The next steps in the design process moving from development approval to undertaking design development leading to the consent to build is followed by detail design and the documentation required for pricing and construction. These stages of the design process are even more demanding for a project of sophisticated design intent. One aim of this publication is to chronicle, from the multiple viewpoints of the consulting team, the detail design and construction process, including the specialised design expertise required to address the web of interrelated design obligations in law.

Underpinning the design process was the clarity of the functional logic of the concept. Design development and detail design proceeded at pace without serious impediments arising out of the guiding conceptual design framework.

Jim Strickland, who together with Judith knew most about the operational side of the future facility, provided the detail required to ensure the design met or exceeded expectations from their perspectives. Regular meetings with Judith affirmed design milestones were being met and that design ideas as they developed retained alignment to expectations.

Along with water egress, managing fire risk was a paramount concern. Various options and technologies were explored to achieve 4-hour fire protection ratings. The eventual decision was to provide relatively simple fire-extinguishing technology within each storage compartment on the assumption that the fire brigade alert would contribute to the minimisation of spread to one fire compartment at most, without undue risk to human life.

Another contentious issue of significance was the use of the roof itself for stormwater reticulation and not sealed pipework to distribute water for collection, filtration and reuse.

The use of sealed pipework above the roof for the distribution of collected stormwater was unnecessary and unattractive when viewed from above. My preference was to redirect water from the northern skylight roof to the collecting rear gutter and downpipes over the main flat roofs. The double membraned and protected roof structure enabled overflow travelling by gravity to the oversized rear gutter and down pipe system (with safety using overflow spouts) for collection in the L1 recycling plant.

The structural design was influenced by very poor existing foundation material. The below-ground structure required friction pier construction with limited load capacity. One consequence with a positive outcome was the replacement of the proposed glass material enclosing the Great Hall with the much lighter polycarbonate cavity wall system designed to ensure maintenance and replacement could occur without risk of water penetration. The polycarbonate material improved UV filtration and created the interior cool, ethereal light experience.

The objective of a highly insulated and sealed external envelope, with redundancy to cover failure of primary elements, is the core reason for the minimisation of energy consumption. The large cavity between the double-wall external polycarbonate skins, the double walls to the perimeter and heavily insulated roofs all contribute to stabilising temperature variations with reduced dependence on mechanical plant and consequent energy consumption.

Photovoltaic technology was optimised with capacity to install battery back-up which, at the time of design and construction, was not at the level worthy of installation. This technology complemented a wide range of initiatives in the selection of high-performance, low-energy mechanical technology to deliver state-of-the-art, lower carbon design notwithstanding the general requirement to provide a stable indoor environment at 22 degrees Celsius and 50 per cent humidity within a narrow band of less than 5 per cent variation.

The design continued to evolve even as Dangrove was being constructed. Opportunities to enhance experiential and sensory qualities in the spaces were a guide to any change under consideration during construction. One example was the selection of the Magis Chair_One by Konstantin Grcic as occasional chairs for performance events. The design of this chair echoes the subtle skeletal silhouette of the portal truss structure between the polycarbonate wall with a similar triangulated structure providing a skeletal silhouette against the floor.

Design development and contract documentation

Architecture of substance is rarely conceived in short timeframes. Design development and contract documentation are both design processes of significance and usually take time, especially when innovative building techniques with unfamiliar materials are under consideration.

Following development approval, we were instructed by the project manager (Aver) that Dangrove was to be delivered using the mechanism of a guaranteed maximum price including a 'Design and Construct' type of contract as part of the suite of controls to manage risk. Value management was undertaken, and some design elements were consequently not progressed.

The rigorously controlled design and delivery process that is part of the Dangrove story did not take the 'soul' out of the architecture and the reason is clear. Led by Judith, everyone undertaking value management worked towards cost savings without undermining design intent. As the architect, we were able to voice the 'value proposition' associated with the cost of a design proposition and we were heard as everyone understood that Judith was committed to achieving longer-term design outcomes that were to the highest standards.

Delays in the approval process placed extreme pressures on the design development and the tender documentation phases of the architectural service. Aver instructed that the tender documentation process for the Design and Construct (D&C) type of construction contract be a mere eight weeks. The optimum level of tender documentation for D&C contracts where design is important, is a minimum of 70–80 per cent complete and preferably 90+ per cent, to give reasonable security of control over design during construction as this form of contract is weighted towards time and cost milestones for the builder and works against design quality.

Eight weeks was an unreasonable timeframe for the standard of research, design development and documentation required for any building of the complexity of Dangrove. Despite our arguments to convince Aver on this point, the program for tender documentation period was not increased.

Once the decision about the short documentation program was finalised, our approach was to assemble a larger-than-normal team led by Chi Melhem, an experienced director of the practice. Chi worked closely with me on every aspect of design development



and detail design. I also had the role of ensuring our developing design was effectively communicated through regular meetings with Judith and Aver. The outcomes of my meetings often led to direction fed back to Chi. In six weeks, Chi's remarkable team leadership and our internal workplace culture that includes remunerating appropriately for voluntary overtime, produced a level of tender documentation at about 90 per cent complete, to Aver's astonishment.

Aver further advised that we had the option to be novated to the successful builder and continue documentation in this arrangement or that we stay on the client side of the contract and act as the interpreter of the D&C documentation, providing independent advice to Aver and Judith on whether design intent was being achieved.

Of these two options, I decided on the more unconventional pathway by remaining on the client side of the D&C contract. As we had good documents for tender, I thought that staying as Judith's adviser on the builder's performance, based on these documents, was likely to give better prospect for a good outcome. I also knew that Judith and Aver understood and valued the design intent behind our detailed work. And we had the fees to provide continuing detail design advice equivalent to complete documentation services similar to the role when novated to the builder under D&C conditions.

A matrix of criteria was developed by Aver to select and evaluate the builders for tender.

Aver's list of builders included several we put forward for consideration on the basis that we had effective working relationships established from previous projects. An important criterion that Judith required to be satisfied to qualify for the D&C tender was that the person leading the building operation had to be heavily involved and have significant equity in the company.

We prepared and presented to all builders the ambitions of the project, design intent of the documentation, our role going forward and the way we expected to work to ensure 'we put the D back into D&C', as I sometimes said, to emphasise the project objectives in contract terms.

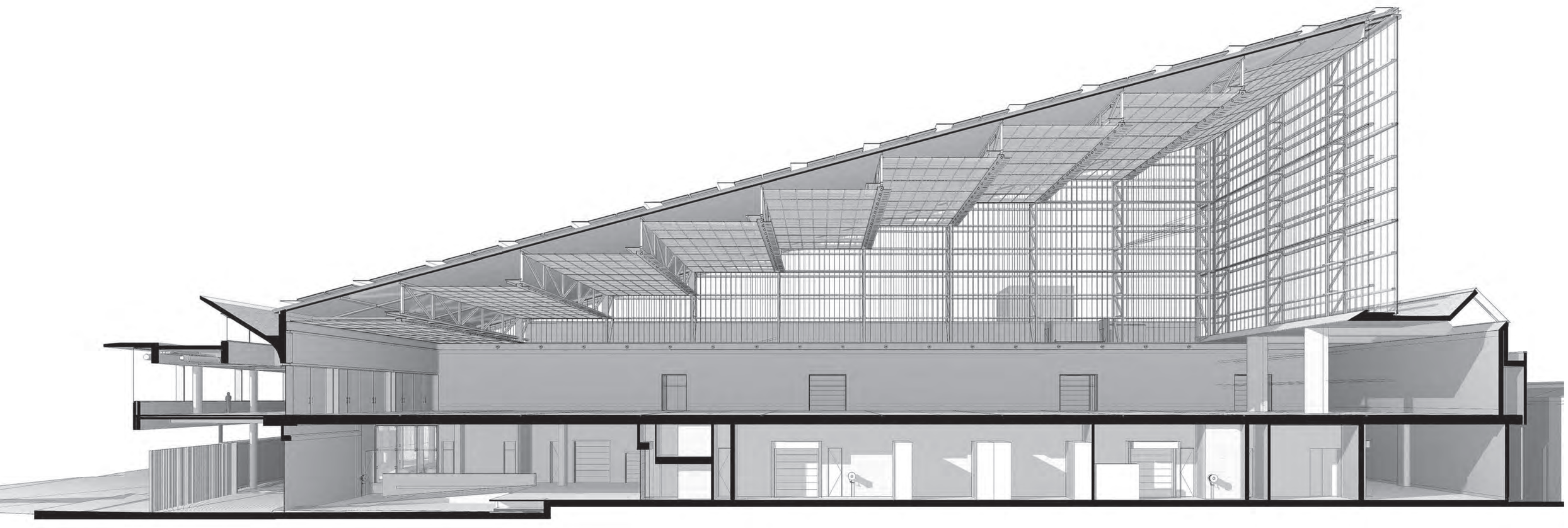
When Infinity was selected as the preferred tender, with Alan Yazbek leading the construction team, my confidence about the delivery of the design with integrity increased. Infinity was one of the tenderers with whom I had a long and successful working relationship. In recent years, Alan and his team had successfully completed more than ten projects of significance with our firm. Alan also had allowed Antoniades Architects in an executive role on his side. Before commencement we divided the remaining design documentation responsibilities between the two architects now on the project delivery phase of work, with all major remaining design elements to be led by our firm. We also established a Project Control Group team that included our attendance with Judith, as well as regular site meetings to address day-to-day concerns.

After selection, one of the first changes Infinity recommended was to the wall construction from concrete block to precast concrete. Infinity noted that although precast concrete was theoretically cheaper to build, design quality requirements meant that inevitable damage to the concrete blocks during construction would likely result in aborted work and ultimately, more cost risk than building in precast. Precast was also quicker to build with definite savings on program and therefore, cost. Infinity was not aware that precast concrete wall construction was my preferred material, rejected on the grounds of cost during value management in the design process. This value management decision was the only one I had grave concerns about during the concept design phases. On reflection, Infinity's request to change to precast wall construction in alignment with the original design is a major factor in the distinctiveness and success of Dangrove's interior experience – a decision made on cost grounds, somewhat ironically.

Another major change recommended by Infinity early in the construction process was the replacement of the Aramax roofing system and separate insulation installation with an integrated roof and insulation product that was also certifiable as a substrate to the photovoltaic structural fixing mechanism. Aramax required a bespoke and uncertified fixing mechanism to be designed. Aramax, we thought, had one remaining advantage over the alternative product proposed by Infinity, which transpired to not be practically implementable notwithstanding advice by the supplier during the design phase – the advantage that it could be installed in one length without a join. This was proven to not be feasible on this site by the builder.

These examples of design changes during the construction of Dangrove reflect an integrated design and delivery process involving a respectful re-examination of many design decisions we made during the design development and documentation phases prior to tender. The re-examinations led by Infinity had the benefit of expertise appropriate to each discipline, trade and artisan, that were unavailable during the design development and detail design phases due to the condensed timeframe allowed for this phase of the work.

Developed design.



Infinity with Antoniades Architects and their specialist engineers undertook rigorous independent analysis and assessment. This process could have easily debased the architecture, particularly under D&C arrangements. Instead, important changes that were made generally improved detail design, even though at times discussions were robust and judgement calls tight. Again, the clarity of the design intent, level of documentation and the knowledge that Judith expected design and construction excellence without 'corners cut' was at the core of the collaborative and mutually respectful D&C delivery process.

Dangrove was built to high standards within a compressed timeframe. Post-occupancy teething problems were mostly in respect to managing the machinery that controlled indoor temperature and humidity, with the problems being mostly addressed by Dangrove staff and involving the consulting and building team. To my knowledge, Dangrove functions well and continues to be valued by staff as an exceptional working environment and by visitors who have the opportunity to experience the collection.

Reflections about Dangrove

Judith's inspirational vision on how to safely store and enjoy, even in storage, her very substantial art collection was the driving idea underpinning the design process. Communications over design concepts with Judith reflected a rare level of alignment over a wide range of ideas, including the concept of the Great Hall as a multi-use place to support curation practices and double as an exhibition/performance venue. Judith's confidence in the design concept was 'from the heart', unfettered by preconceived solutions or precedent. Dangrove is a reflection of our alignment on what it could become – an architecture that functioned effectively and did not dominate the collection. For staff, Dangrove provides an exceptional indoor environment for the creative, scientific and practical work required to store, exhibit, curate and manage the collection.

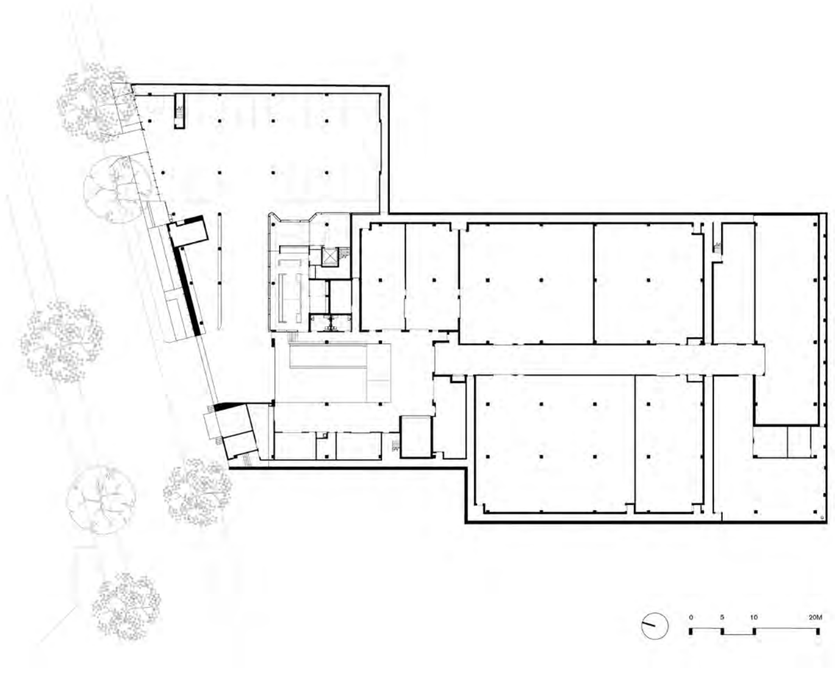
At Tzannes alone, twenty-five staff, including three in administration, using a total of 7427.50 service hours, were required to design and oversee the construction to completion. As architects, we are a fraction of the expertise required to design and deliver this building. Creating a culture where everyone believes in the outcome is a central, often unspoken role of a client and their architect. Dangrove demonstrates that a shared commitment to a design that is valued, combined with fair fee and contracting arrangements, designers as well as builders will do their best work achieving outcomes that exceed even high expectations.

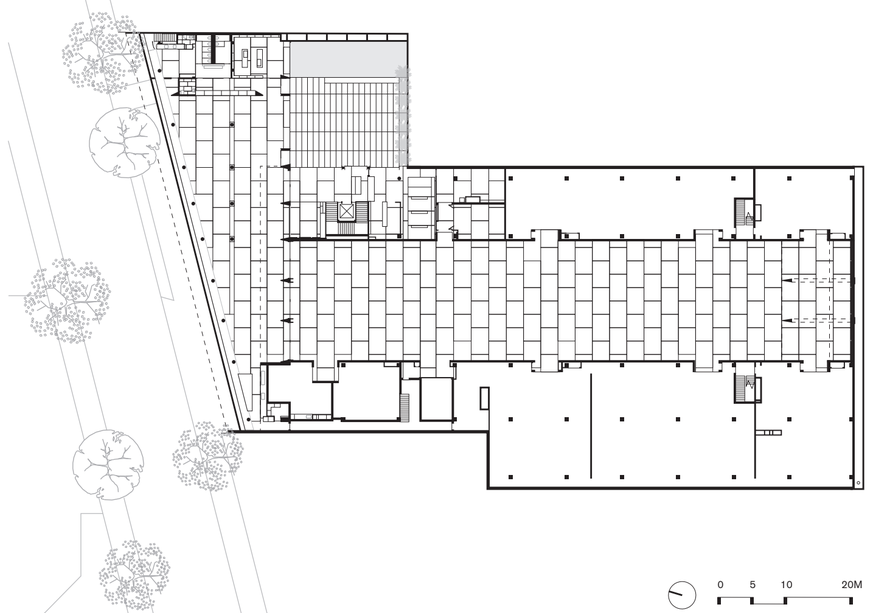
Dangrove developed, or at least contributed to the development of, a new typology for the storage, curation, conservation and exhibition of art, including multi-disciplinary performance work. Will Dangrove ever be open to the public to reveal the magnitude of Judith Neilson's contribution as an artist, visionary philanthropist, collector and patron of architecture? It is Judith's desire and part of her brief for this to never occur. Dangrove is destined to remain a private facility housing one of the most potentially important collection of artefacts that chronicle the socio-political and cultural era of China from 2000–2020 and beyond.

Biography

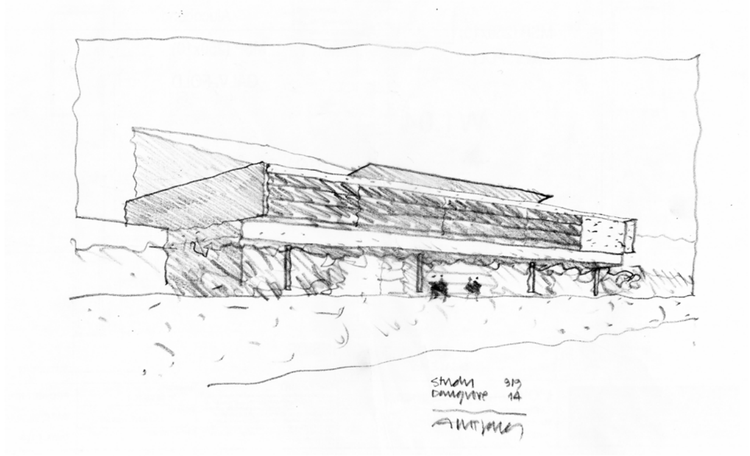
Alec is the founding director of Tzannes. He established the firm's design and working philosophy based on collaboration, ethical practice and the pursuit of design excellence. The distinctive, place-specific design culture at Tzannes has been instrumental in the firm's global recognition as leaders in a wide range of design disciplines centred around architecture, urban and product design.

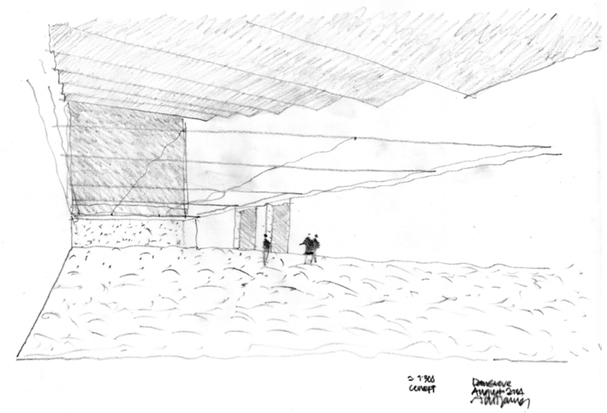
Plans of levels one and two.

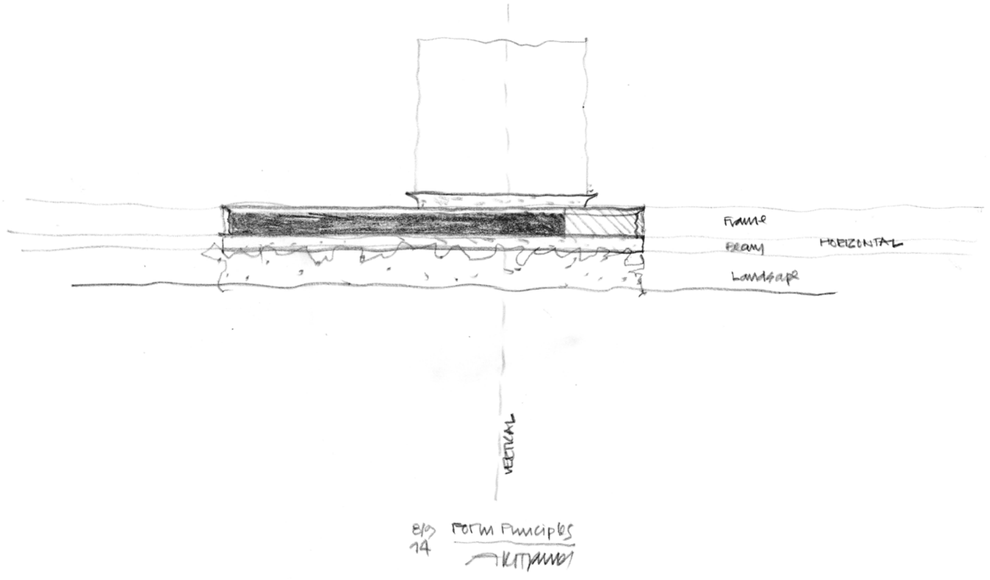


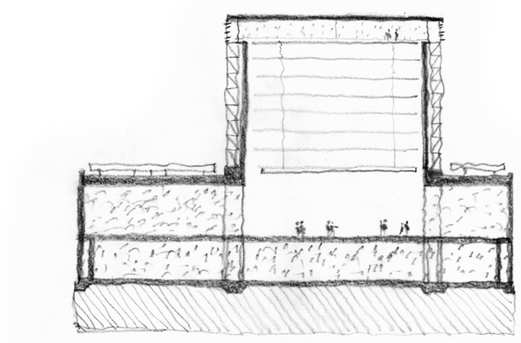


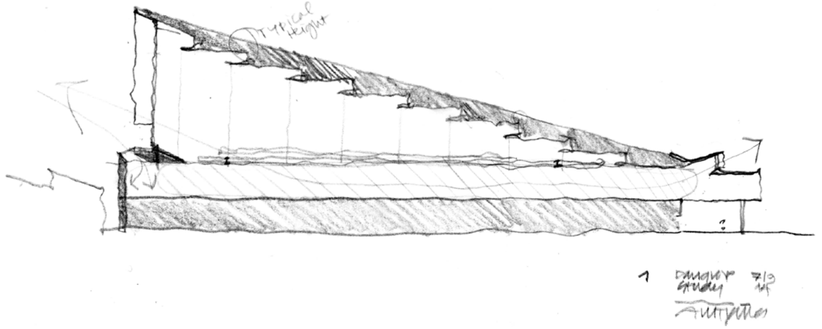
Concept sketches for Dangrove.

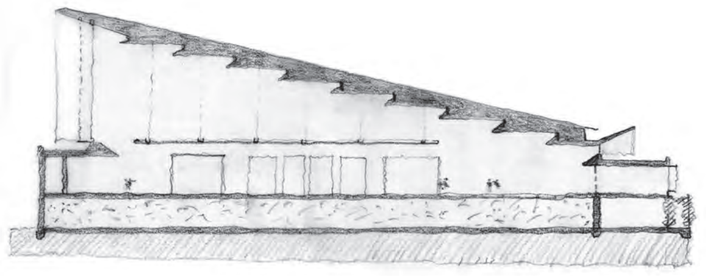














02

Design to Construction

Chi Melhem

Dangrove embodies a seamless integration of craft and function. This technical chapter is an insight into how complex and unique buildings such as Dangrove are both designed as well as delivered. It recognises the wholistic process of a project which integrates many disciplines and experts across all stages in the making of a building.

Design as a continuous process

There are often discussions around when the creative design process should finish in order for the technical delivery stages to start. For many, this may be reflected in the way a conventional project can be broadly divided into stages of work – concept design, development application, documentation, tender and construction. However, it is important to understand that managing a workflow is not the same as managing design. Design, in fact, never stops and the technical understanding of how buildings are built underpins design decisions from the start.

Dangrove is an example of how considered architecture comes from this continuous and integrated process. At the inception of the project, a clear design ambition was established alongside a robust technical brief. These created a set of criteria which allowed the evolution of the design and delivery to be continuously assessed.

The functional brief

The functional brief was divided into four key considerations which guided the design and delivery of Dangrove.

1. Curated storage – practical and efficient, a new way of experiencing art in storage.
2. Integration (whole of art process) – delivery, workshops, conservation and curatorial activities.
3. Exhibition – test and curate for White Rabbit Gallery.
4. Performance – evolving the brief to include exhibition, performance and private events.

From this functional brief, three key design criteria were established.

100-YEAR LIFE

- **Longevity** of materials which were prefinished to reduce ongoing maintenance, robust to withstand the activities of a working facility, durable to last the maximum life cycle possible.
- **Integrity** of design elements which accommodated multiple functional requirements to maximise its use.
- **Accessible** to ensure it could be easily maintained, repaired, replaced and accessed at all times with minimal impact to other building elements.
- **Sustainable** in its assembly and use to reduce energy consumption.
- **Flexible and adaptable** to provide a multi-functional use and provide opportunities for the future adaptive reuse of either the element, space or building itself.

PERFORMANCE

- **Security levels** for all modes, including visitors, staff and maintenance access. Layers of spaces needed to be provisioned to ensure Dangrove could continue to operate without disruption.
- **Fire protection** strategies which avoided sprinklers but included the most appropriate technology to protect the artwork and the volumes of spaces to be created.
- **Waterproofing** which eliminated the risk of any water ingress to the artwork through multiple fail safes, building layers and zones.
- **Temperature control** to keep the storage areas and exhibition areas in a stable environment and reduce the reliance on mechanical intervention through thermal mass, insulations and zoning.

CRAFT AND PRECISION

Each space was to be curated as an expression of its use. It had to address multiple functional requirements and embody design ambitions around volume, light and scale.

Collaboration

There are many hands and minds involved in the making of buildings. Individually, each member of the team contributes as an expert in their own discipline to inform how the various elements of a building performs and functions. Collectively, when each discipline is able to consider the broader ambition through a collaborative process, the interdisciplinary contributions and diverse perspectives can often challenge and push the design of buildings to unexpected outcomes.

This approach to collaboration was established from the start of the design process for Dangrove and continued through to completion. It invited a collective ownership for the stewardship of the project, from the project manager's steady hand through to the team of consultants who were interested in thinking outside of the box, and to a passionate builder who wanted to deliver the highest quality building possible.

The rigour of the Dangrove team culture exemplified how effective collaboration underpins successful design and construction outcomes.

The design delivery process

Design development and value engineering

Following the approval of the development application by the City of Sydney Council, a focused period of design development and review was undertaken. This led to a few elements not proceeding for a variety of reasons.

The gantry

The original design allowed for a hatch and gantry to lift heavy objects from the loading dock through the floor of the Great Hall and slide along the hall for placement as required.

The gantry itself was fixed at approximately 6 metres high to account for the datums set by the springing point of the roof and the bridge spanning the hall. Once the structural depth of the beams and rails were accounted for, the height clearance of objects reduced to 4–4.5 metres.

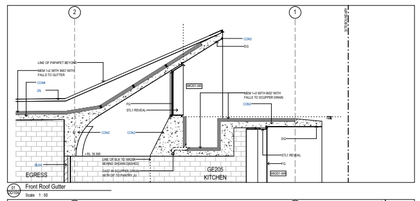
The complexity and cost of this system made the team question whether the loading and lifting of objects could be achieved through a simpler process. In reviewing the operational requirements, it was clear that most objects could be adequately moved from the loading dock to the Great Hall by the 6 tonne service lift adjacent to the loading dock. Heavy-duty forklift trucks could then move the objects through the Great Hall and be lifted in position with spider cranes.

The deletion of the hatch and gantry resulted in a simpler design which improved the spatial experience of the Great Hall without compromise to the movement of large works and resulted in significant capital and operational cost savings.

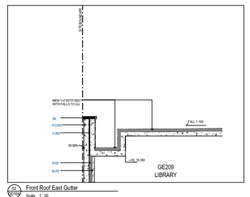
DA material that guided the design development and documentation.



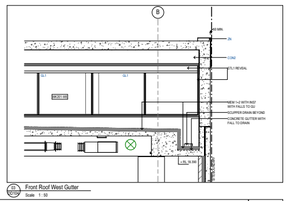




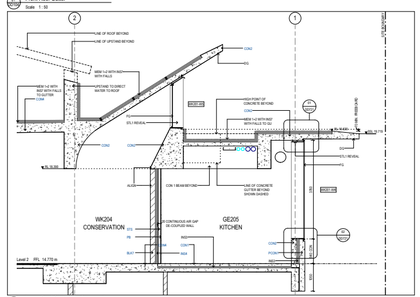
Front Roof Gutter
Scale 1 : 50



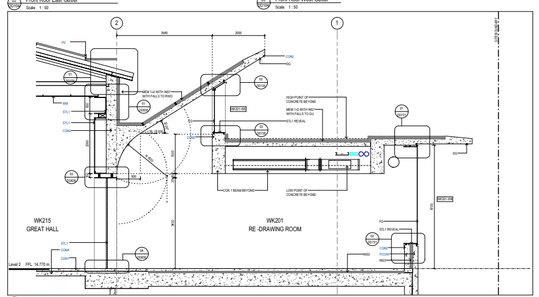
Front Roof East Gutter
Scale 1 : 50



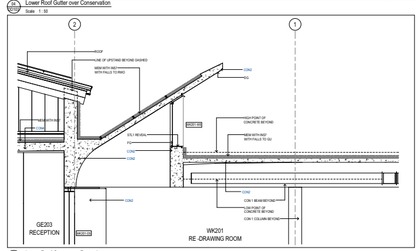
Front Roof West Gutter
Scale 1 : 50



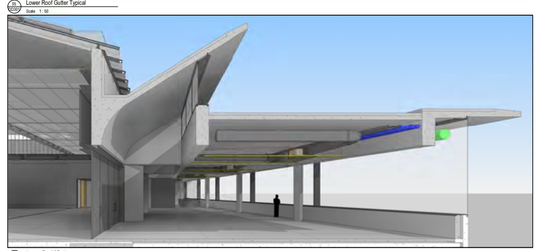
Lower Roof Gutter over Conservation
Scale 1 : 50



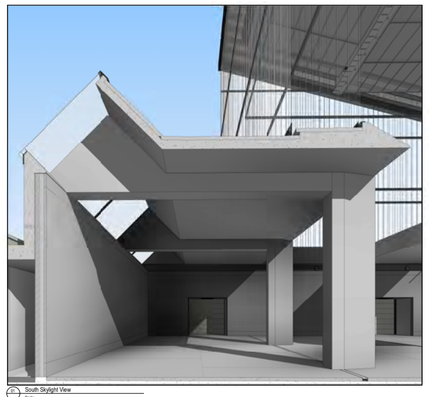
Lower Roof Gutter Typical
Scale 1 : 50



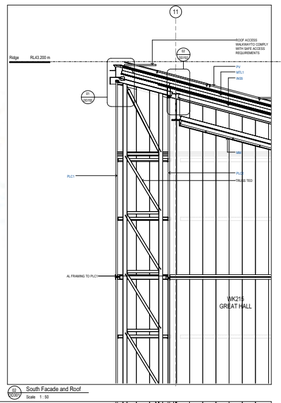
Lower Roof Gutter over Reception
Scale 1 : 50



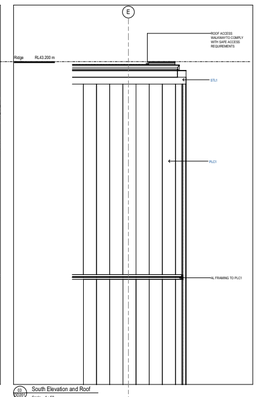
Lower Roof 3D view
Scale



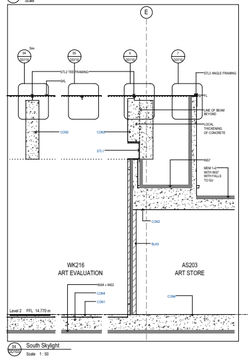
South Skylight View
Scale



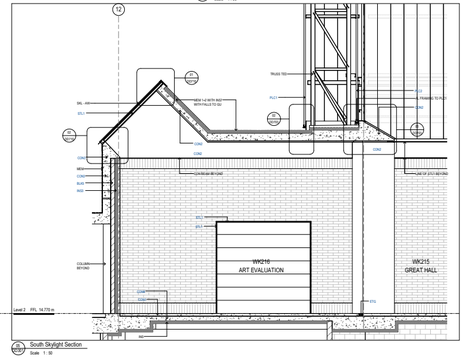
South Facade and Roof
Scale 1 : 50



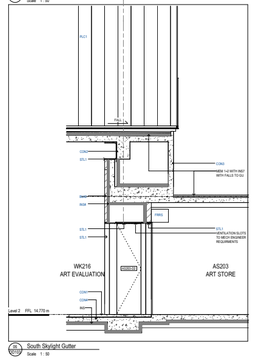
South Elevation and Roof
Scale 1 : 50



South Skylight
Scale 1 : 10



South Skylight Section
Scale 1 : 10



South Skylight Gutter
Scale 1 : 10

Northern and southern skylights.

Fire protection

Extensive research was undertaken to assess fire safety systems that would not result in the damage of artwork. Through consultation with our fire engineer and leading industry fire services providers, the following were explored and not progressed.

- **Sprinklers** – would result in water damage.
- **Gas suppression** – required significant storage space and the force of the gas being released would potentially damage some of the art. The air change rates required by the mechanical system impacted the requirements for the gas suppression to have a sealed room.
- **Hypoxic** – the reduction of oxygen levels would not be safe for the operation of heavy machinery in the working facility. The continual access to the storage rooms impacted the ability to maintain the low oxygen levels.

In the end, an early warning system (later refined with Infinity to a VESDA system – Very Early Smoke Detection Apparatus) was selected. This connects to the building management system, allowing early notification of a fire event. In combination with the fire rating and limited size of each compartment, the proposed risk mitigation system was considered acceptable.

Cost review

Progressive cost plans were undertaken to monitor design development. At 75 per cent documentation, costs had reached a $10m budget overrun. To meet the budget, the initial cost savings proposed were as follows:

- Delete the bridge with the option to reinstate if required.
- Delete the glass internal wall and replace with polycarbonate, thereby reducing structural loads and material costs.
- Delete the precast concrete walls in the front of house areas and replace with a honed blockwork wall.
- Delete the northern skylight.
- Delete the southern skylight.

The first three items were accommodated. The skylights resulted in a savings of approximately $2m or less than 4 per cent of the overall budget for the works. Although not an insignificant amount, the benefits of the skylights to indoor amenity were considered by the client to outweigh the cost.

The building contract

Selecting the building contract was critical to informing how the tender documents would be produced.

Due to the bespoke nature of the design, Tzannes believed that a managed contract with early contractor engagement would deliver the best outcome. The project managers favoured a fixed lump sum Design and Construct (D&C) contract in order to manage cost risk.

Robust discussions to assess the benefits and risks of each contract were undertaken. These discussions led to a modified D&C contract aimed at providing a more balanced administrative process to achieve quality and retain cost and time benefits during construction.

This modification of the D&C contract involved the following key principles:

1. Tzannes to remain a design consultant to the client.
2. Tender documentation completed to 90 per cent.
3. Rigorous design review and confirmation of the design intent process by Tzannes was written in the Principal's Project Requirements (PPR) which formed part of the contract.
4. Design principles were written into the PPR which provided design standards for the overall building as well as each individual space.
5. Any variation to design intent was to be discussed with the client by Aver, Infinity and Tzannes, with the client as the final decision maker.

The decision on the scope of work in the contract provided a clear framework for the design documentation. We were able to move forward on a highly detailed set of documents to provide design clarity for the tender and to the appointed builder. The appointed builder could provide cost certainty to reduce risk to the client while still taking ownership of the construction delivery.

The documentation process

The client's ambition to be open for the biennale in 2018 set a compressed timeframe for the tender documentation. Due to the time taken for design development and authority approvals, and factoring in the tender period, contract negotiations and a targeted 18-month construction program, there was only 8 weeks available for tender documentation.

In order to achieve the client's high standards for quality and design, it was agreed that the base building documentation would be completed to 90 per cent to ensure a realistic tender price that aligned with the design and quality ambitions for Dangrove. Although the rigour of research and testing during the design development stage had a high level of resolution, refinement was still required. Documentation proceeded with the implicit understanding that detailing needed to be considered but simple in order to ensure the design intent would survive potential substitutions and changes during the D&C delivery process.

With the significant challenge ahead, a large Tzannes team was assembled to allow for the concurrent documentation of packages. The team and roles were as follows.

Project directors: Alec Tzannes (co-design director, client focus) and Chi Melhem (co-design and delivery director, contractor focus).

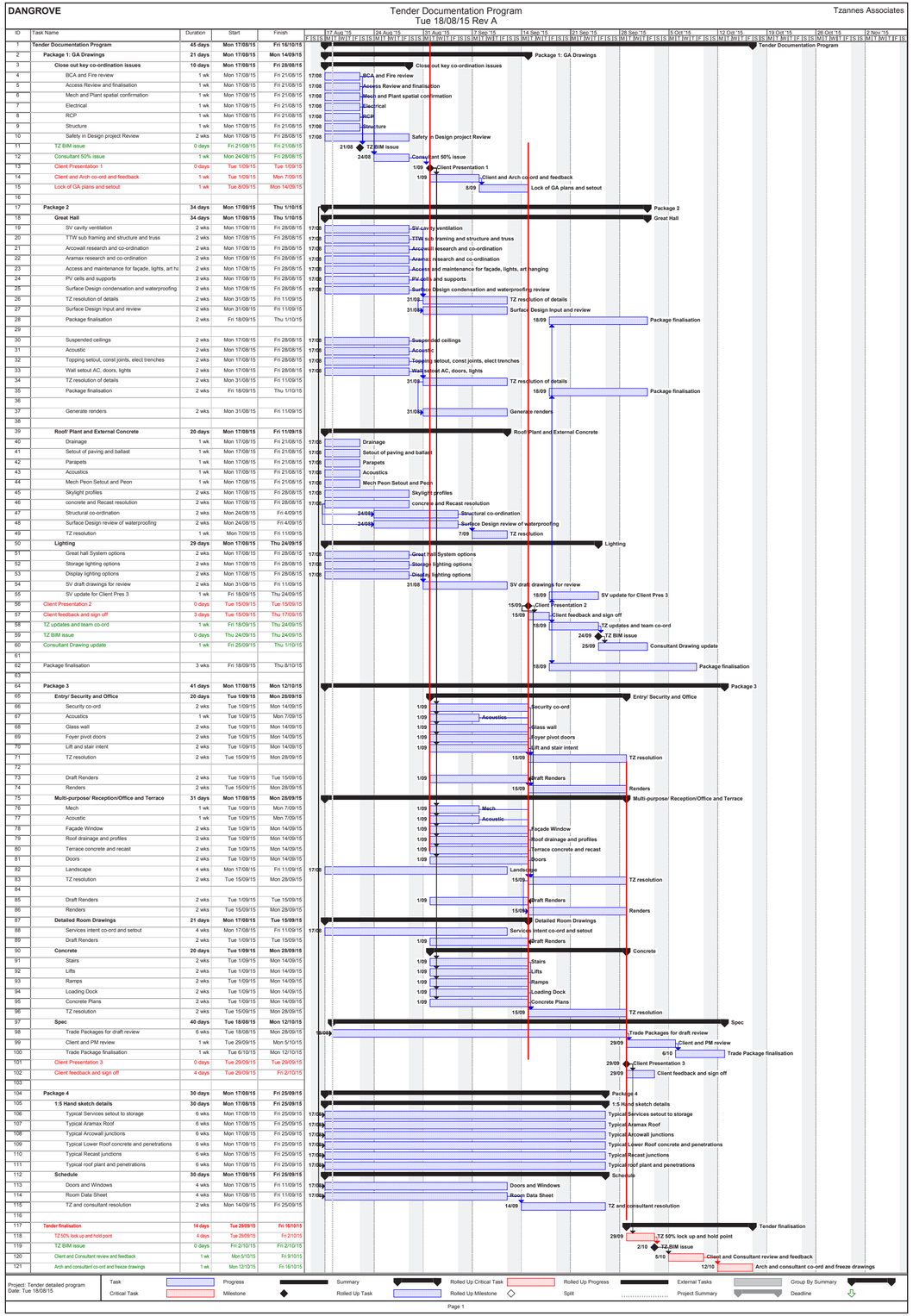
Sustainable design and design review: Jonathan Evans (director).

Brief and concept development: George Korban (associate director); project architects: Derek Chin, William Blake.

Design team: Neil Haybittel, Luke Novotny, Nicole Larkin, Kate Nason, Sarah Reid, Lily Tandeani, Tony Lam, Elanor Hyland-Falle, Georgia Spence, Nicholas Cheung, Juliana Conceicao, Wenxi Ren.

In consultation with the team, Tzannes created a documentation program to manage the key milestones and co-ordination meetings with the wider consultant team. The Tzannes team met at the start of each week to collectively discuss and review the status of the work. Documentation packages were reviewed by the directors at the end of each week and marked up ready for the team catch-up the following Monday. Design workshops with directors were held as required through the week to allow for quick answers on design and documentation decisions. Although packages were divided up, the Monday meetings allowed for the team to be across the overall project design and technical requirements

Draft documentation program.



in order to understand any overlapping requirements. Sign-off of milestone packages by the client and Aver were integrated in the documentation program to ensure the work proceeded efficiently.

With a project as bespoke as Dangrove, there was an energy and enthusiasm which was hard to describe. It propelled the team forward in ways not often experienced on a typical project. The ownership of the project by all team members and consultants allowed for not only an efficient and collaborative documentation process, but one that was unified and impassioned, knowing the reward of Dangrove once complete would be fulfilling for all involved.

The tender process and selecting the builder

Aver proposed a range of builders for review based on their track record and capacity to deliver a project such as Dangrove. Pre-selection interviews were held with the client, Aver and Tzannes before the tender list was finalised.

Before issuing the tender, Aver and Tzannes held a thorough briefing process with each tenderer. The purpose of this was to clearly set out Judith's vision, outline the core requirements of the design and, importantly, the reasons for the design decisions made to date. The modifications to the D&C contract were reiterated to affirm the importance of the design intent and the increased rigour around assessing changes proposed by the builder during the construction process.

The tender process provided opportunity to assess how the selected builders engaged with the design proposal and how they would work with the team on design refinements or alternative propositions.

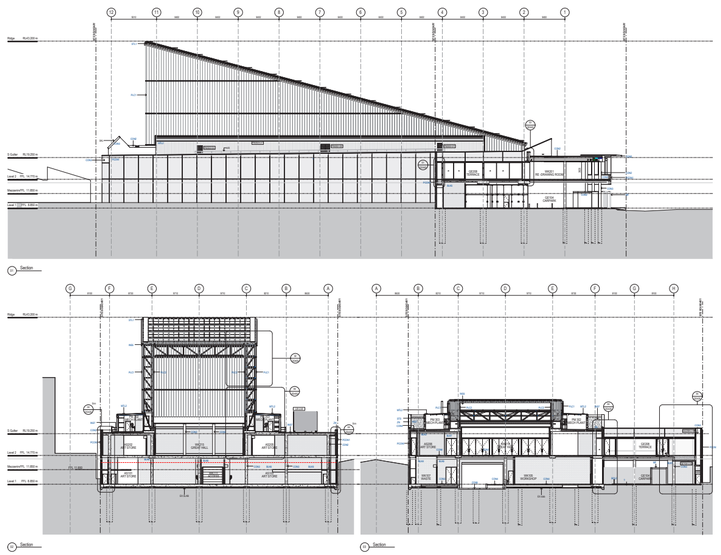
Following a highly competitive process, Infinity was selected as the contractor. They not only provided a competitive tender, but importantly demonstrated a clear respect for the design and an alignment to Judith Neilson's expectations. Through their interrogation of the design, they proposed innovative construction solutions and demonstrated a collaborative approach to workshopping refinements. Their proven record of delivering well-crafted buildings and their successful working history with Tzannes added a level of confidence that they were the right builder to deliver Dangrove.

Working with the builder

With the strict design framework established by the PPR, Infinity held weekly design review meetings with Aver, the client representative and Tzannes. Due to the responsibilities taken on by Infinity under the D&C contract, every single part of the design was questioned, interrogated, debated, reviewed, workshopped, proofed and settled by agreement. It was a thorough and exhaustive process, often involving extensive and robust debate.

This page: Set out of grids for Dangrove details.

Opposite: Sketch of hob detail.



These debates either led to changes as a result of improved construction processes or alternative product selections, refinement of details or confirmation the proposed design was the best option.

The Infinity team, led by Alan Yazbek, brought immense value and expertise to the delivery and trade craft of Dangrove. Infinity interrogated the design with rigour and a respectful collaborative approach to the sign-off of all decisions. This reassured the client, Aver and Tzannes that the delivery of Dangrove was going to be in good hands.

Design outcomes

Through the open and collaborative process from design through construction, the delivery of Dangrove remained consistent with its original design intent. The continual refinement of the building elements only enhanced the spatial and functional performance of the building.

The Tzannes team through the construction stage reduced down to project directors, Alec Tzannes and Chi Melhem, and the project architect (construction) William Blake. Some of the key design outcomes are discussed below.

General arrangement

MATERIALITY

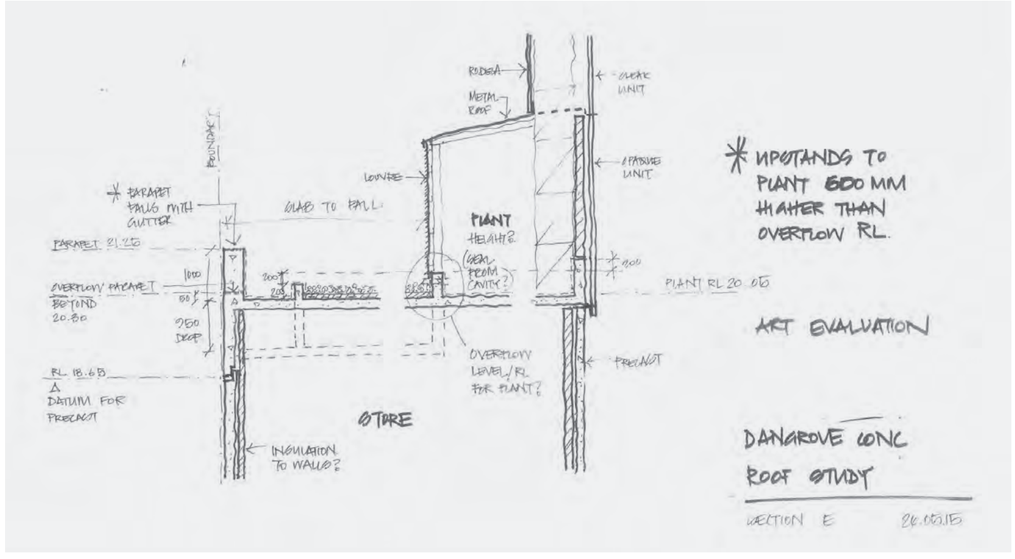
The architecture of Dangrove is an expression of its structure and function. Where possible, materials selected were robust and without surface finish. The building is mostly a singular palette of off-form and precast concrete for the walls, floors and exposed columns. Steel was used for the Great Hall structure, framed openings and as joinery items. Glass and a polycarbonate panel system completed the enclosure materials.

To celebrate the clarity in the materials, the assembly of elements were expressed throughout the building. This meant a high degree of care was required in the execution of the detailing to ensure the composition of the elements were simple yet crafted.

SERVICES

All services were designed to be exposed to allow for ease of access and maintenance. This required extensive co-ordination during documentation and construction to ensure all services were set out.

Design principles were established to create an ordered and logical services reticulation set-out.



- All wet services were required to be reticulated outside of storage areas to reduce risk of damage.
- All services were also required to be above the datum of the forklift backrest when in the up position.
- All services were allocated a designated datum for each discipline to manage reticulation and reduce issues of clash.

The exposed services are an expression of how the building operates and contributes to the distinctive industrial character of Dangrove.

ROOF

The roof design provided multiple fail-safe layers to ensure a robust waterproof strategy.

Natural overflow

The external leading edge of the roof was set out to be at least 50 mm lower than any internal edge. This meant that in the extreme event of all outlets becoming blocked (as often occurs in a hailstorm) the water overflow was to the outside of the enclosed space.

Downpipes and pipework

Reliance on pipework to reticulate water was minimised. Any pipework that couldn't be avoided was reticulated outside of storage areas. Rainwater outlets were eliminated to avoid puncturing the concrete roof. These principles meant the concrete roof would need to act as a large gutter system.

The concrete gutter

The entire concrete roof acts as a large detention area and gutter. Water from the expansive Great Hall roof is caught by the northern skylight scoop. The shape of the scoop is designed to catch the velocity of water coming down from the Great Hall roof and redirect it onto the lower concrete roof. The concrete roof falls at 1:100 towards the rear southern gutter and drains to the rear of the building outside of the storage areas. Large downpipes are taken down an isolated rear maintenance cavity and connected to the water retention tank in the plant room. In the event the downpipes fail, overflow of water is achieved through the lowered gutter edge.

This strategy was debated at length with the hydraulic engineer to ensure extreme weather events could be accommodated while eliminating unsightly pipes reticulating above and around the roof.

Membranes

The selection of the membrane system needed to accommodate the following roof requirements.

- Waterproofing of the structure.
- Insulation layer on top of the roof (rather than below) to reduce the risks of condensation inside the storage rooms.
- Protection of the membrane from damage due to maintenance access.

These considerations meant a double membrane system was required. Extensive co-ordination with industry suppliers and experts during design development were reviewed again with Infinity during the construction period. Infinity agreed the sheet membrane as a system was the best choice to accommodate the elasticity, expansion and movement of the roof. The build-up of the system however was extensively reviewed and the final design moved the second layer of trafficable membrane to the top of the insulation which allowed for greater control and inspection of the control joints.

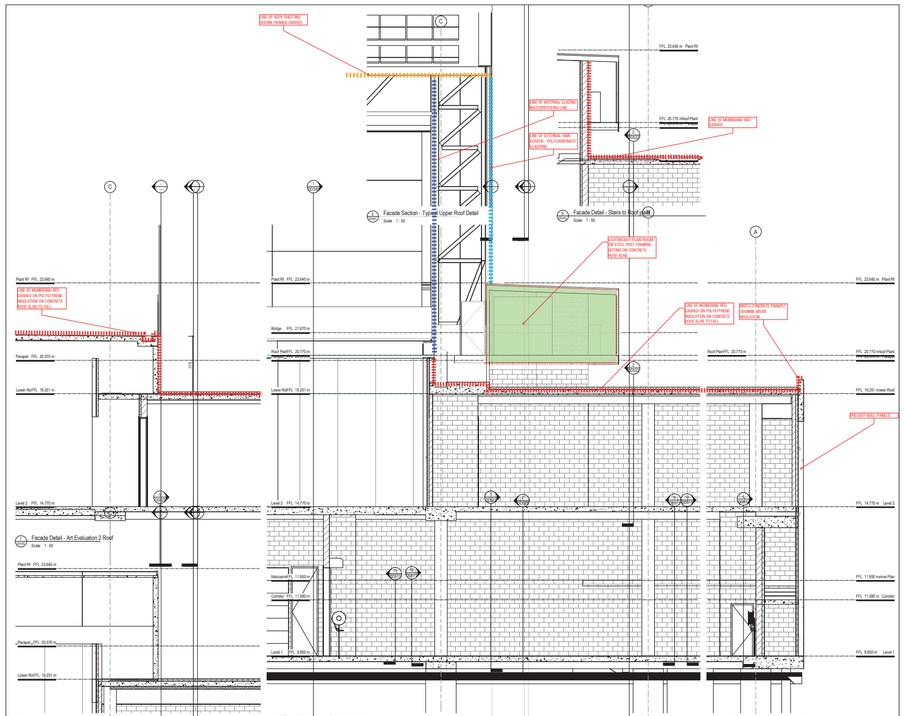
The Great Hall roof

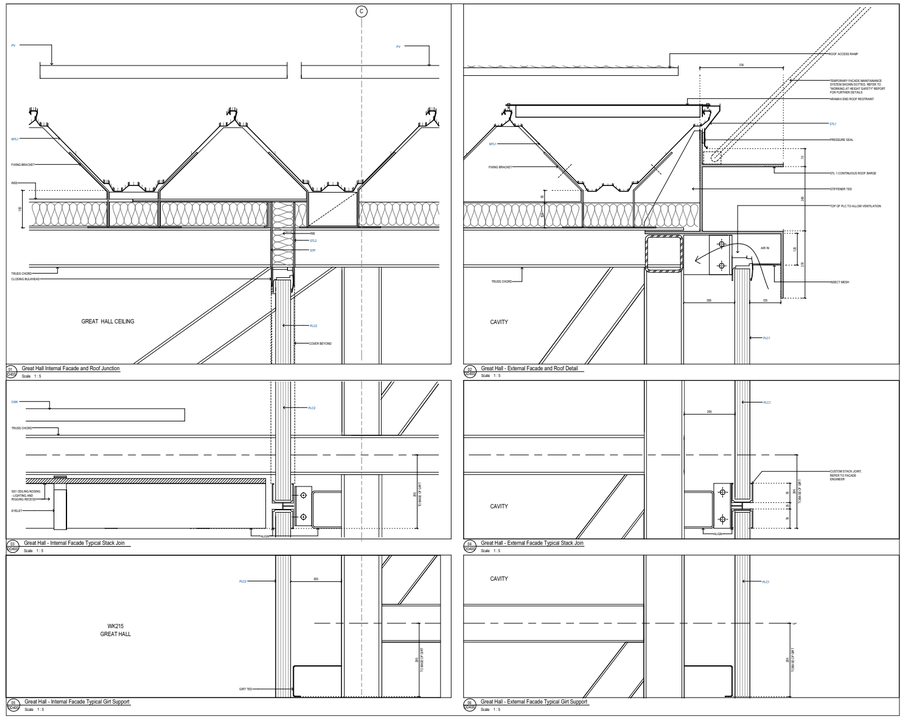
The roof over the Great Hall was originally specified as Aramax due to its structural profile to span the roof trusses. It could also be extruded as one sheet for the length of the Great Hall with assurances that the site did not restrict this assembly process.

During construction, Infinity questioned the practicalities of this system. Infinity demonstrated that there was not enough space on site to load and extrude the 90-metre sheets. In addition to this, the bespoke and unwarranted fixing system required to support the photovoltaic (PV) cells required a significant number of penetrations which would not be adequately accessed or maintained. Finally, the insulation system with Aramax was independent of the roof and required additional substructure to support it.

The alternate Kingspan roof system proposed by Infinity provided an integral double layer system with sandwiched insulation. This proved to be a better roofing system with warranties provided for the support brackets to mount the PV panels.

Polycarbonate and podium concept development, above.
Preliminary details of the Aramax roof, below.





FACADE

The facade and fire corridor provided an important opportunity to protect the storage rooms from water ingress. It also fulfilled an added functional criterion of acting as an insulation air pocket to increase thermal mass to the storage areas.

On the ground floor, insulation was added to the storage room walls to further increase the thermal performance created from the fire corridors. As the caulking of some of the precast panels could not be inspected on the boundary, an internal hob and gutter was designed to catch any water ingress and drain it to the rear cavity.

The upper level proved to be more of a challenge. The boundary wall to the storage rooms also formed the external wall. A double precast wall panel was designed with sandwiched insulation to achieve the thermal performance required for the storerooms. The risk of failure at the precast joints was a topic of great debate. Through numerous workshops, Tzannes proposed adding a sandwiched drainage cell to the double wall precast system to create a cavity for any water ingress. A prototype was made by Infinity to test its performance. The design proved to be a successful detail.

Great Hall

TRUSSES AND DESIGN SET-OUT

The design and resolution of the Great Hall integrates the architectural spatial design with the steel trusses to enhance the expression of the structural performance of the building. The setout of the trusses was used to reinforce key datums and detailing principles within the space.

Minimum truss sizes were established by the structural engineer to address structural requirements. The trusses were then adjusted to create the stepped ceiling profile, ensuring that the top and bottom of each truss bay aligned.

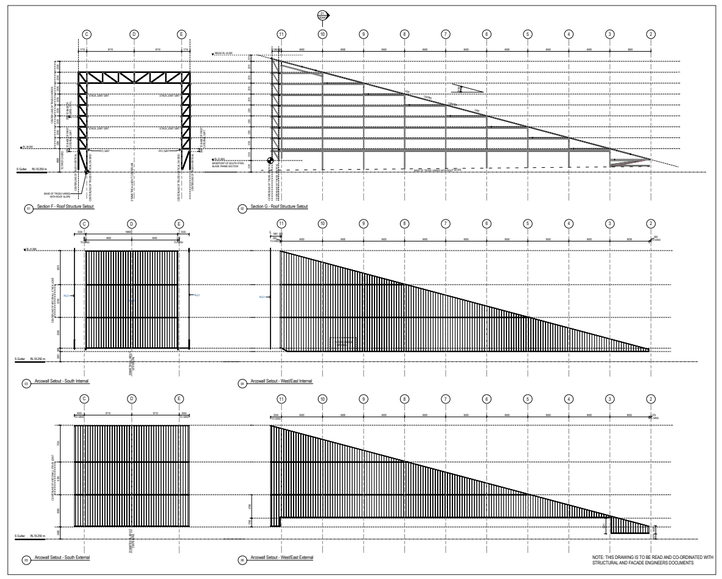
The spacing of the trusses then set the structural grid lines from which control joints were established and precast panel sizes were set for the walls and floors.

The spacing of girts required to laterally brace the trusses were adjusted to suit the maximum supports required for the polycarbonate wall.

The result is a fully co-ordinated alignment of grids and panel joints from the structure, to the stepped ceiling, to the polycarbonate panels, to the walls and floor junctions.

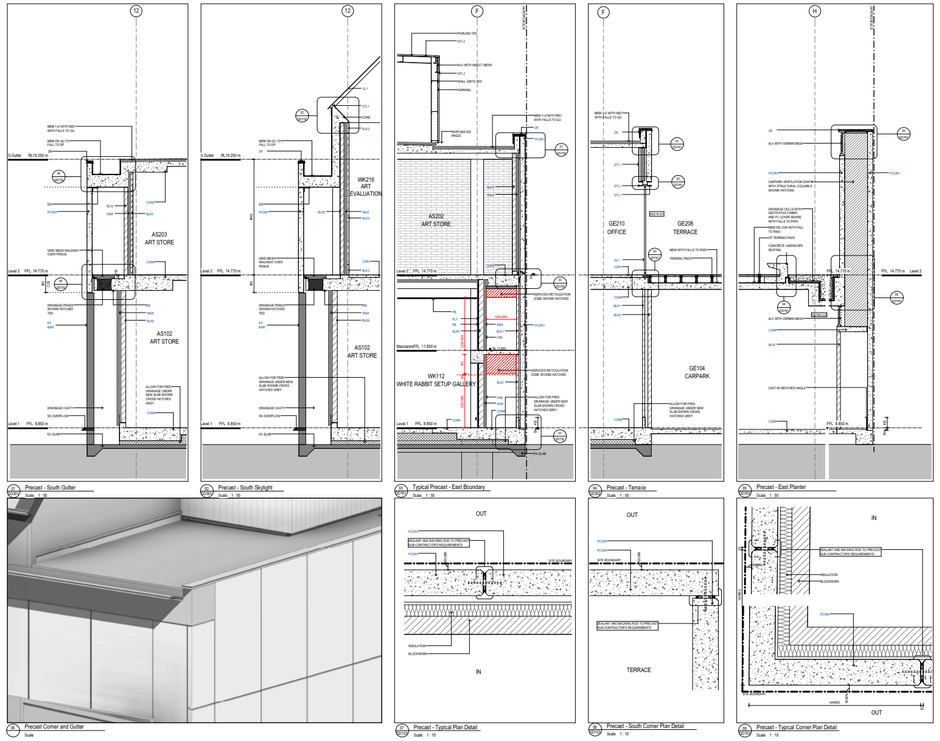
CEILING

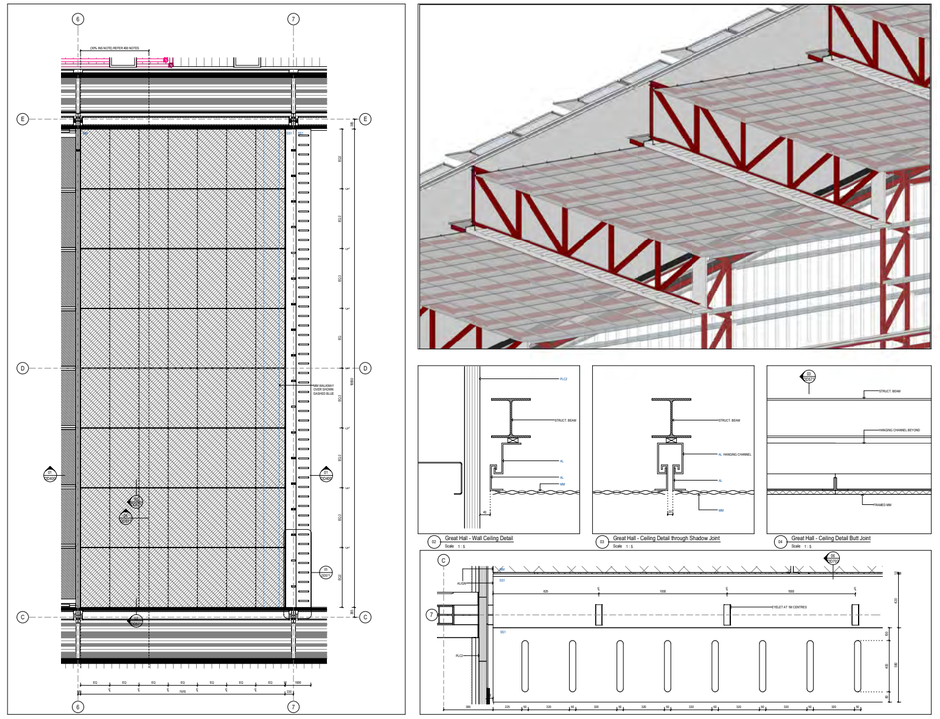
The ceiling at Dangrove appears as a simple stepped plane. Functionally, this simplicity disguises the operational complexity of permanent and temporary lighting, art rigging, acoustic attenuation and maintenance access.



This page: Polycarbonate wall setouts.

Opposite: Roof and wall details, above. Roof and ceiling details, below.





The ceiling mesh was selected to enhance the dynamic experience of the space when viewed from different directions and to maintain the industrial character reflected by the the exposed structure.

When viewed from the south, the mesh appears solid, creating stepped zones which rise within the Great Hall. When viewed in the opposite direction, the mesh appears more transparent and the trusses are exposed as the ceiling structure steps down to create a more singular volume of space.

To achieve this visual and spatial effect, various mesh types were tested during design development. The aperture of the mesh ranged from a fine grain weave to the larger expended metal eventually chosen. Due to the scale and height of the Great Hall, all samples were viewed from 10 and 20 metres in distance, which coincided with dimensions that could be established in the Tzannes studio. This enabled an appreciation of the weave options when installed. Quite robust discussions were held on this design issue internally at Tzannes, with other directors weighing in on the selection options. In the end, the larger mesh was chosen by the majority of the Dangrove team and confirmed as the appropriate choice by the directors. Although less aesthetic up close, the larger mesh was more appropriate when viewed at the distance it would be applied.

The ceiling panels were detailed as large removable elements – much like an office ceiling tile but bigger – to allow for access and maintenance of rigging, insulation and lighting connections.

The nosing beam which terminated each ceiling bay was one of the most debated elements. Structurally labelled as the LS1, it took eight months of explorations and prototypes with Infinity to resolve aesthetic, functionality and fixing of this element. The LS1 was to house the permanent recessed lighting track and, originally, the rigging points for the artwork. The alignment and hanging points for the LS1 were eventually moved forward of the truss to allow for an alternate fixing method and to simplify rigging details. To reduce the weight, the material of the nosing changed from stainless steel to highly polished aluminium. It was cut down into transportable sections and dimensioned to align with the ceiling grid.

ART HANGING

Due to the unknown nature of the artwork, hanging art from the trusses needed to be flexible and adaptable. With the large spans of the Great Hall, key hanging principles and weight distribution were established by the structural engineer and recorded in a manual to be followed by staff.

By moving the LS1 forward of the truss, eyelets were fixed directly into the truss cord where rigging could then be attached and triangulated when necessary. With the size and expanse of the ceiling space, they are not perceptible.

ART LIGHTING

The lighting to the Great Hall was somewhat of an unknown due to its unique spatial qualities. Principles were established with the Steensen Varming team. There were three categories of lighting.

- Permanent lighting to illuminate the space.
- Wall washing to light the precast walls.
- Specialist art lighting that could be curated for events and performances.

The permanent lighting was relatively straightforward. The recessed light track in the LS1 beam allowed for permanent lights to be installed. With the flexibility of the DALI system, additional lights could be easily added as required.

The wall washers were more challenging as the angle of the ceiling, the varying heights and the distinct datum of the wall panels required onsite testing. This meant that the position of the lights could not be determined until the walls of the Great Hall were built. Using cranes, the lights were positioned to establish an optimal location for each bay. Steensen Varming tested how the lights could be trimmed to sharply define the top of the wall and wash down to the floor. These positions were then located on the construction drawings, resulting in a V formation for the lights as the ceiling stepped up.

Additional rigging was provided by the ceiling grid to allow for theatre lights to be added where required for each event. The supersized grid of ceiling tiles enabled optimum functionality and reflected the geometrical set out of other elements.

As built polycarbonate detailing.

POLYCARBONATE FACADE

The design of the upper walls of the Great Hall underwent many iterations. At the core of the design, the wall needed to achieve the following.

- Luminance into the Great Hall.
- UV reduction.
- Lightweight construction.
- A double wall system that would allow the maintenance, repair or replacement to any layer of the facade without compromise to the water protection or function of the Great Hall.

Originally the Great Hall was designed with an outer layer of polycarbonate (to address the UV requirement) and an inner layer of a glass U-channel called Linit (to achieve an aesthetic quality and low maintenance facade to the Great Hall interior). The Linit system added significant weight and increased structural requirements in addition to material and installation costs. For these reasons, it was replaced with polycarbonate.

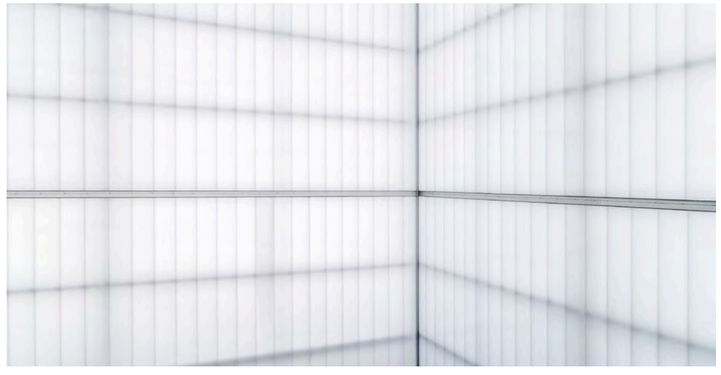
The challenge with this material choice was how it would perform in the event of a fire. Extensive research was undertaken with the fire engineer and, through modelling, it was found that the melting point of the polycarbonate was a positive for smoke extraction to the space. Tzannes and the fire engineer met with Fire and Rescue NSW to explain the research in order to achieve sign-off on this design proposal.

To address the 100-year life design objective, extensive research was undertaken on polycarbonate options. The selections were narrowed down to Arcowall and Rodeca. Both systems could achieve full length panels for the tallest section of the Great Hall even though sections were limited to 6 metres for transport and ease of maintenance. Both products had superior waterproof panel junctions. Both products achieved the wind loads and water tightness required and had test results for reduced yellowing over time. The deciding factor was the warranty. Unlike Rodeca, Arcowall was willing to provide a project specific warranty to extend the warranty period of the polycarbonate. For this reason, Arcowall was specified for the tender.

Discussion around the supplier was reopened by Infinity. Prototypes were made from both suppliers complete with multiple panels, sills and joiners. What became apparent with the full-size physical samples was that the Rodeca panel joint detail allowed for panels to be replaced individually without the need to slide a whole row of panels out. With a 90-metre-long facade, this was a significant advantage. Although both prototypes achieved the watertightness requirement, the waterproofing detail of the Rodeca sill was also preferred.

The last remaining difference between the two products was the warranty issue. Through extensive discussions with Rodeca, Tzannes was able to demonstrate the application of the polycarbonate was not a typical industrial situation. The maintenance by the client and the protection of the internal skin was also a key factor in prolonging the lifespan of the product. This resulted in Rodeca offering an extended warranty period to match Arcowall for yellowing and replacement.

On reviewing the selections again with the updated technical information, a final colour test was also undertaken with Judith who was happy to proceed with Rodeca.



PRECAST WALLS

In the initial stages of design development, precast panels were proposed for all walls in Dangrove. Internal walls were replaced with honed blockwork for the tender after the quantity surveyor advised this would be a necessary cost saving to meet the budget.

Infinity reviewed the use of blockwork against the original precast option and expressed a concern over the brittle nature of the honed face blockwork and the waste generated from disposing of chipped blocks upon delivery. A prototype wall was built to understand the practicalities of limiting waste, the logistics of delivery, labour and manual handling of the honed blockwork. A cost review of the blockwork proved to be a significant cost over the precast panels, taking into account damage risk and the height of construction.

The front-of-house walls returned to precast panels – a decision welcomed by Tzannes as the design intent of an integrated floor and wall finish to the Great Hall was achieved along with improved durability and longevity.

The wall panels were set out based on the truss grid. Openings into the storage rooms were centred on the panel set-out to ensure only one floating panel occurred over the doors.

The concrete mix used for the panels was a Brightonlite Cement which resulted in a lighter colour and avoided the need for additional pigment additives. Several techniques were investigated through prototypes to test how best to expose the aggregate and polish the slabs. Mixing the aggregate with the concrete resulted in the exposed aggregate sinking to the bed face when the panels were vibrated. The other method was to manually hand broadcast the aggregate onto the concrete just before setting. This technique delivered a positive outcome once polished. The density of the aggregate was tested across a range of samples. The preferred density was selected from the samples which allowed for the contractor to calculate the amount of aggregate per cubic metre of concrete to ensure the same ratio was broadcast for all panels.

With the appearance and control sample signed off, the precast panels were poured over a period of three months between spring and summer. Sydney experienced an unusually hot summer with temperatures reaching 36–40 degrees at the batching plant. A noticeable and unacceptable colour variation started to occur with panels arriving onsite in the summer months. On review with Infinity and the contractor, it was determined that the extreme temperature difference in the summer months was causing the concrete to dry much quicker than the original approved samples poured in spring. Although a slight variation in colour was acceptable to express the material qualities of concrete, and to limit extreme differences, the decision was to pour the Great Hall panels only in a temperature range of 25–35 degrees.

POLISHED FLOORS

Through design development, precast concrete floors were ruled out due to required joint tolerances between panels resulting in gaps that would need to be filled. These joints also had the potential to cause an uneven floor which would be detrimental when moving artwork around the Great Hall.

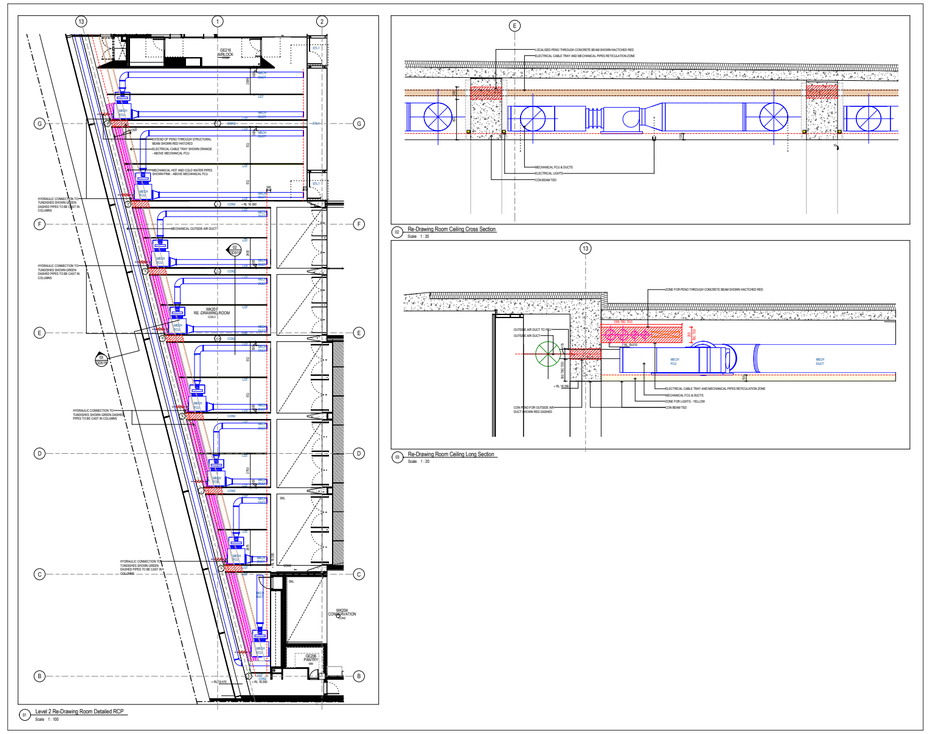
Infinity supported the decision for in-situ concrete when the floor was reviewed during construction. The in-situ polished slab was reinforced due to accomodate structural loads and unbonded from the structural slab below. To accommodate movement and minimise cracking, the floor was divided in slabs at a ratio of 3:1 and maximum 4 square metres. The panel divisions were aligned with the wall panels and set out in a brick pattern. The main structural grid and construction joints required along the truss lines were accommodated by an accessible cable channel to house the electrical and data requirements for events.

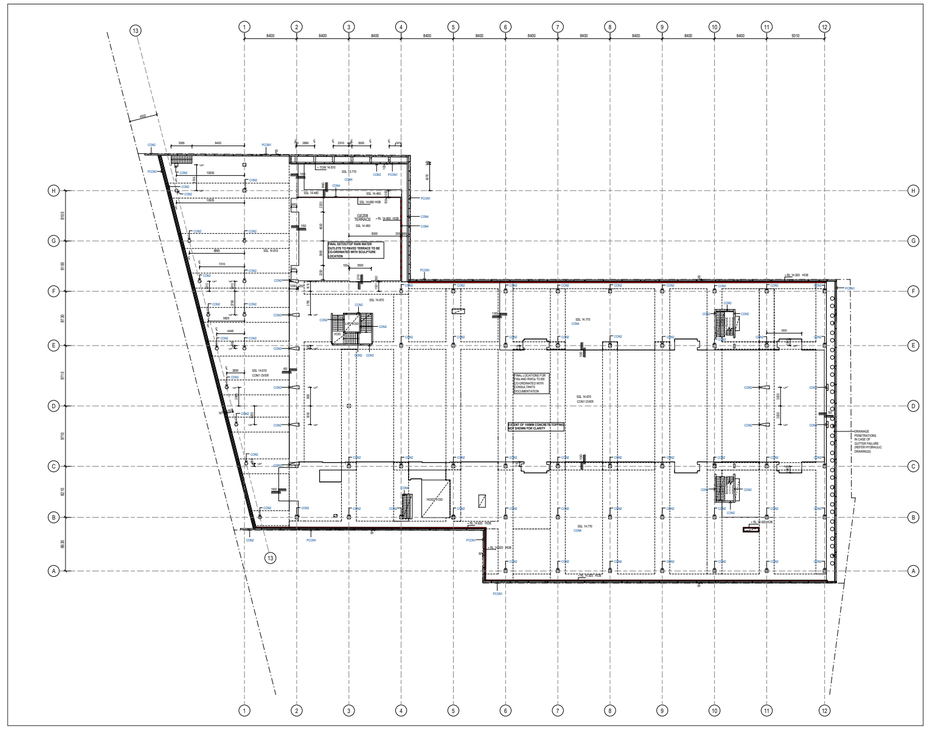
The panel joints were achieved through a proprietary Latham product across the width of the Great Hall. The vertical joints between wall panels were achieved through an aluminium angle. The angles and channels were fixed in one direction to ensure that each panel was disconnected from the next to allow for adequate movement.

For the floor, the same technique of broadcasting the aggregate on the precast wall panels was used, and the ratio of aggregate was also the same.

Once the floors were vibrated and polished, the Latham channels deformed slightly, resulting in an uneven line. In addition to this, within 12 months of occupation, settling of the structure and foundation resulted in cracking of the concrete along key structural lines. An extensive rectification process was undertaken to cement fill the cracks and polish the floor, resulting in only minor visible deformation at joints. Although the movement appears to have settled, the floor to Dangrove has not quite achieved the high standards for the rest of the building.

Opposite: Concrete soffit and services setout, above.
Concrete floor and wall panel setout, below









Opposite: Revised lightweight bridge concept.

This page: Interior joinery front of house desk in steel and bronze concept.









NORTHERN SKYLIGHT

The construction of the skylight was a significant technical challenge. The angle of the scoop made it difficult to pour and vibrate the concrete without too much slump. Originally designed as a splayed internal soffit, the proposal changed to a curved one during design development to improve the luminance of light over the Great Hall doors.

The curved interior lining required expert formwork to ensure a smooth and even finish. Infinity brought in an expert form worker who had just completed a similar complex ceiling. He recommended two layers of curved plywood placed in opposing directions to ensure the form of the scoops could withstand the weight of the concrete.

The result is an expertly crafted skylight which brings a dynamic luminance of light throughout the day into the Great Hall threshold.

BRIDGE

The original structural design of the bridge was a truss with a glass floor. Although deleted as one of the cost savings, Judith decided to reinstate the bridge during construction. With the opportunity of more time to reflect on the function of the bridge and how it sat in the context of the Great Hall, the structural design of the bridge was changed to a lighter more elegant structure and a solid floor installed as a cost consideration.

A concept sketch of a finer tensile structure was proposed and, within a week, the bridge was sized and assessed to be structurally sound.

Details for the brackets and connections were modelled by Tzannes and co-ordinated with TTW to ensure that all the exposed connections were finely detailed.

Stainless steel plate was selected over glass to reduce costs and structural loading. The plates were glass bead blasted to achieve slip resistance. Varying the glass bead blasting allowed for the word ‘Dangrove’ to be stencilled onto the floor. Extensive prototypes were made to test the slip resistance, scuffing and cleaning to ensure functionality.

Although originally designed as a viewing platform, the location of the bridge within the Great Hall created an opportunity for performance, and for art to be hung from it. This caused mild panic with the structural team as the bridge structure and spans were already at their limits. Due to the unknown weight of the art, TTW designed fixing points that required a weight distribution and a set of rules for the weight management in use.

The bridge has become a sculptural item in itself within the Great Hall. Functionally, it provides an elevated platform to view the art within the Great Hall. It has also been the backdrop and the apparatus for many performances at Dangrove.

Interiors

The interiors of Dangrove are a seamless extension to the principles of the base building. Blackened steel was chosen for its industrial prefinished qualities. Joinery and infill elements were detailed using different techniques with blackened steel. Tables and shelves were an exploration in folded plates, the radius of curves sized to accommodate how a hand folds over these edges. Walls were panels, sliding doors and cupboards became planes which sat like inserted objects in the larger expanse of the space.

The selection of the blackened steel and detailing with the architectural metal fabricator was a long and involved process. Due to the variable of the flamed surface from the rolling of the steel, control samples were chosen to allow the contractor to choose the appropriate panels to fabricate. Prototypes of edges and folds were made and tested with the client.

The blackened steel requires oiling every 6 to 12 months which was not made clear by suppliers during the selection process. On the positive side, it is easy to oil. The material character and neutral colour serve as a backdrop to complement the concrete and allow the vibrancy of art and performance to be the focus of the experience.

Conclusion

Dangrove first and foremost is informed by a clear vision set by a client whose passion for design excellence set the tone and culture for the project. The delivery of the building is an example of a robust continual process of design underpinned by a technical appreciation of how buildings perform and are built. The rigour through each stage of the project and the continual review of outcomes against the original design criteria ensured industry best practice was continually tested. This seamless integration of craft and function was achieved through a highly collaborative process which engaged many disciplines and industry experts. The outcome delivers on the client’s vision for Dangrove as a global benchmark for art storage, performance and curation.

Biography

Chi Melhem was employed at Tzannes from 2003 to 2021 and promoted to director in 2016. Chi co-led the design management, documentation and delivery phases of this project with Alec Tzannes.



03

Project Management

AVER

Background to Aver involvement

Aver's involvement with Dangrove commenced when the project was with council for assessment for development consent. Through the recommendation of Total Co-ordination, the builders of Judith Neilson's recently built private residence, Indigo Slam, she had entered into an Early Contractor Involvement (ECI) arrangement with Probuild.

At the time, Dangrove was one of four projects being undertaken by Judith Neilson, and as the largest of these projects, it came with commensurate financial and delivery risk. She immediately acknowledged that project decisions on Dangrove could not be considered in isolation from her broader property portfolio.

At the point Aver became involved, the resources and energies of the design team had been largely focused on responding to, and ultimately satisfying, council's Design Excellence criteria.

The consulting team required time to rigorously analyse the detailed functional requirements for the building and cross-check these with the storage profile of the collection in terms of volume and typology. Additionally, a cost estimate required a structured review, once development consent had been achieved.

Noting the above, Aver recommended, with agreement from the architect, that the ECI arrangement with Probuild not be continued in order to progress the design and ensure functional and design issues were at a higher level of resolution.

The development of the design and the cost plan to a higher level of detail proved to be critical to the commercial arrangement that could be entered into with a builder.

It is fair to say that with elements such as the Great Hall, the design concept had developed in a direction and to an extent that was broader than the original storage facility brief. This, and other design features proposed by Tzannes, reflected Judith's overarching ambitions for the facility – however, in doing this, it had also inspired and excited her in a way that was not originally envisaged.

A key project management challenge became to maintain these unexpected elements, while ensuring that the core storage function of the facility was delivered at a 'best practice' standard.

At a practical level, there was a strong desire from Judith to see the vision for Dangrove realised as soon as practically achievable. Her valuable and unique collection was spread across a number of storage facilities, most not ideal in terms of climate control and layout. Consequently, they could not be preserved nor enjoyed in the manner, and to the standards, she required.



The flow of an acquisition into and out of Dangrove, with red being the intake and orange the discharge.

Management of design development tender stage

Aver became heavily invested in the management of the design development and documentation process. With the input of Judith, White Rabbit staff – in particular, collection manager Jim Strickland – Aver, Tzannes and the broader consultant team began to progressively review and validate each of the functional areas of the building.

The methodology adopted was to follow a piece of art from its arrival at Dangrove, through the steps of receiving, logging, unloading, unpacking, interim storage, placement in a space for potential evaluation or display, permanent storage – and then the reverse of this process tracking works as they left the building.

This process was exhaustive, and included ensuring that fire protection, security, storage layouts, heights, corridor/aisle widths and door openings were all co-ordinated with the operational requirements of Judith's team.

This process was not limited to what presently formed part of the collection – instead, a deliberately broad horizon was projected on what the art may be in the future in terms of scale and mass. Judith was actively procuring artworks, some of which were at a scale and complexity that broke the mould of standard collections in the world.

Existing local art storage buildings, such as the Art Gallery of NSW storage facility at Lilyfield, were also evaluated to identify current best practice, and rejected as a model for this proposal by Judith. The overall imperative was to maximise the storage capacity of the building within the available spaces, while maintaining flexibility in all areas to enable changes in the profile of the collection to be accommodated as it evolved.

By far the greatest allocation of design time and resources were devoted to the realisation of the Great Hall concept, including the design detailing and construction methodology for the roof and the double-skin wall. The overarching principle guiding the detailed design process was to achieve fundamental and mandatory building requirements of longevity, watertightness and maintainability while delivering the aesthetic which had been put forward in the Design Excellence process.

As typical with any complex project during the design phase, project cost was a constant and evolving consideration with iterations, analysis and design modifications made to ensure the project did not exceed the client's budget. At times this process resulted in design and project team tension, but the team was committed to the budget and worked cohesively to achieve the outcome, noting the old adage 'the market is the ultimate QS'.

The tension of Design Excellence against budget happens on most projects, and open discussion is required to ensure the best possible design is delivered for the available budget. At Dangrove, this meant that the Great Hall bridge and other elements were set aside as options within the tender so the real market price could be determined, and the client could make an informed decision on inclusion of items nominally above budget.

Delivery methodology

In determining the appropriate delivery methodology for construction of the project, the factors that Aver needed to consider were as follows:

- The context of the Dangrove project within Judith Neilson's overall property portfolio, including three other projects either in construction or shortly to commence construction, and the cumulative risk profile that this presented.
- The level of activity in the property and construction market was at a historically high level with no reliable indications that this was to ease during the course of the project. The balancing of price certainty with value-for-money was absolutely critical, including avoiding the circumstance in which the scope and cost had advanced to a point where, by the time market pricing was received, it would be too late to make decisions without a major impact on the project.
- The advantage of being able to introduce subcontractor input into the design process – which both provided another set of 'eyes' on the design, as well as de-risking the delivery. This can also provide opportunities to further enhance the design outcomes in ways that may not be considered in a conventional design-build contract.
- The criticality of achieving the fundamental building objectives of longevity (100-year life), watertightness, climate control and maintainability.
- The importance of achieving the Design Excellence requirements for the project, along with delivering the standard of design detailing that has become a hallmark of Tzannes projects over many years.

- The preferences of the design team in terms of their own experience on construction delivery methods. This varied across the team and included fully documented lump sum, construction management, managing contractor, Design and Construct (D&C), and early contractor involvement (ECI) arrangements.

Like the cost plan process, the debate on project delivery method was spirited and passionate, but always respectful and with a sense of humour that is sometimes required to get through key project tensions.

Tzannes had experienced some less than satisfactory D&C projects and were considering a hybrid form of construction management to preserve the design integrity. Other consultants brought forward their experiences (both bad and good) into the debate. After considering all factors and various views and opinions, Aver's recommendation to the client was for a modified D&C arrangement to deliver Dangrove.

Ultimately, Judith accepted Aver's recommendation for a D&C delivery method, noting her exposure to broader property development considerations, cost and time risk and keen desire to see that the vision for Dangrove was realised as soon as was practically possible.

In hindsight and reviewing the cost and time struggles on her other projects, Aver is satisfied that this decision was the right one for the client to ensure her time and cost risks were mitigated, and the unique collection was safely stored as quickly as possible.

In the current market of defect-ridden projects, D&C is attributed as a root cause of quality failure through erosion of the design integrity and supervision of the final product. It is Aver's view that D&C can be a highly successful delivery model as long as the designers, project team and builders are aligned in their end goals of delivering the best product they can, as close as they can to budget and program. Everyone has a part to play and if the collaborative spirit and approach is lost during the D&C process, sub-optimal results can occur.

Dangrove was one of the most successful D&C projects in Aver's history.

Key and distinctive components of Dangrove D&C process were as follows:

- A defined period of time would firstly be allocated for the design team to progress their design documentation to an advanced level (nominally 80 per cent), including specification of all fixtures, finishes and other products and materials to be used in the project. To their credit, the design team responded to this challenge and produced a level of documentation for the tender that was both highly resolved and comprehensive, but also transparent and able to be understood relatively easily.
- As the output of this process was expected to be a highly comprehensive level of documentation, this would be supported by an unpriced bill of quantities (BoQ), providing tenderers with the greatest opportunity to quickly comprehend and appropriately cost the project in the time available for the tender.
- A robust written contract document would be developed (the PPR – Principal's Project Requirements), setting out the process by which the remainder of the detailed design work was to be undertaken, including hold points, prototypes, approval of samples and so forth. Importantly, this also included mechanisms by which the design intent could be clarified by the original design team, should it not be clear in the contract documents.
- An overarching principle of the PPR was to be that changes to the specification would only be made at the discretion of the principal's team – there was to be no 'carte blanche' modification of the project by the D&C contractor. Rather, the D&C process was envisaged as enabling the contractor to deliver the final part of the design in concert with their tender letting – and hence have the benefit of subcontractor input into the detailed design – while empowering the client's design team to fully focus on ensuring that the design intent was achieved as intended.
- In particular, the various front-of-house areas (including reception, offices, kitchen and amenities) were preserved as 'provisional sums' within the contract, so that the detailed design of these by Tzannes and subcontractor pricing could be afforded the maximum amount of time.
- Communications between the design team, the client and contractor were encouraged and conducted in an open and collaborative manner with the intent of delivering the design with integrity and at the cost set out in the contract.

Extract from Design and Construct contract indicating modification to standard conditions to provide greater certainty to achieving design intent.

2.4.9. Review Process for Design Changes

The design intent, as described by the PPR, has been carefully considered by the Principal. The Principal does not wish to consider any changes to the PPR unless the Contractor firmly believes a change will benefit the Principal's interests.

If the Contractor seeks to make a change to the design intent, the following process must be followed:

- Reasons for the proposed changes
- Reasons why the changes are equal or superior to the design within the PPR
- Statement of the extent of revisions to the Contract documents
- Statement of the extent of revisions to the Programme
- Statement of cost implications
- Statement of consequent alterations to other parts of the works if relevant

The Superintendent shall arrange for review of the proposed design change by the required Principal's Consultants. When the changes are deemed satisfactory by the Architect and required Consultants, written acceptance will be provided to the Superintendent before it will be noted by the Superintendent as 'approved'. Unless the design change is 'approved', it cannot be used in the Works.

The purpose of any review of design changes is to enable the Superintendent and the Principal's team of relevant consultants, to review if the changes will result (in their opinion), in a revised design that is equal to or superior to the original design.

The Contractor must allow for sufficient time in the programme for design changes to be reviewed, acknowledging that the steps outlined above may require more than one iterative process. Delays to the programme resulting from this will be at the risk of the Contractor.

For any design change, a response time of 10 working days is to be allowed.

2.4.10. List of Review Hold Points

The following table sets out the key points at which the Contractor is required to present design documentation and samples for review and approval by the Principal. Where logical, these are to be incorporated within the relevant Design Review Workshop (DRW). The Contractor is to incorporate the DRWs for the hold points below into the Contract Program. Further detail on these items is provided within the relevant specification documents for each discipline.

In reviewing drawings, samples or other documents, the Principal does not relieve the Contractor of the Contractor's responsibility for dimensions, quantities, calculations or performance. Nor does a review imply that all relevant information is necessarily shown. The purpose of the reviews is limited to enabling the Principal to assess whether the detailed design meets the design intent.

The tender process was highly controlled as follows:

Only contractors represented by equity directors were considered and reviewed. Beyond contractual obligations, an owner of a business is more concerned with the reputation of that business, and is more empowered to take into account broader considerations when making decisions. Consequentially, design integrity was more likely to be achieved.

The development of the tender list itself required careful deliberation and comprised an expression of interest (EOI) process to canvass respondents who had the requisite experience in delivering high-quality gallery-style projects, along with the necessary organisational capability to undertake a project of Dangrove's scale. The EOI submissions were reviewed by Aver, Tzannes and Judith Neilson, and the tender list arrived at by consensus.

The mandatory tender briefing was conducted at a facility close to the Dangrove site, and included the impressive scale models that had been produced as part of the Design Excellence process with council. The briefing was seen as another opportunity for the team – and particularly Tzannes – to reinforce to the tenderers the principles of the Dangrove project, and the manner in which it was to be delivered. This was to be no ordinary project, and no ordinary D&C contract. Tenderers were told to expect, and allow for, a high level of scrutiny and oversight throughout the D&C process.

The level of interest and queries throughout the tender process was intensive, and ultimately resulted in the shortlisting and collective interview of two tenderers.

Infinity Constructions Group (ICG) was selected as the preferred tenderer, noting:

- They had the greatest level of experience working with Tzannes, and hence the most understanding of the execution of the typical Tzannes detailing, particularly as it pertained to architectural metalwork and high-end concrete.
- The ICG tender price, while not the lowest, was consistent with the quantity surveyor's pre-tender estimate, and was determined to be a fair and reasonable price for the project – providing a level of assurance that the project would be delivered with the level of quality required.
- The ICG tender had suitably accounted for the various residual risks that they were required to undertake by the D&C arrangement, thereby providing the client with the certainty over program, cost and scope – a fundamental reason for selecting the D&C delivery model.

Construction delivery

Prior to ICG being engaged, a separate early works demolition and remediation package was awarded to DECC to reduce project timeframes and provide a clean and clear de-risked site to the D&C contractor.

With Sydney City Council DA approval secured, ICG contracted, and the delivery processes clearly defined and understood, the project could proceed to delivery phase.

An intensive, structured (and, at times, cumbersome) design development review process was implemented involving Judith Neilson's design team, Aver, ICG and their appointed architect, Antoniades Architects, and other ICG subcontractors and consultants. Many meetings and many issues were discussed, recorded and rediscussed until resolution.

ICG, led by their director Alan Yazbek, immediately brought to the project a number of pragmatic and considered design refinements, including the adoption of a precast wall model throughout the building (in lieu of blockwork, previously assessed as necessary to meet cost objectives instead of the Tzannes preferred and as built precast technology), advice on materials selection, and detailing for waterproofing and maintainability.

Alan Yazbek found a natural counterpart in Tzannes' Chi Melhem, and there was not a design detail on the project that wasn't examined, critiqued, debated and analysed (several times over) before a solution was agreed that achieved longevity and buildability requirements – while maintaining the distinctive Tzannes' architectural standards.

With a number of unique and bespoke design details and materials, ICG team and subcontractor input was critical to assist final detailing and product selection and approval by Judith.

The challenge in delivering these details and finishes in a busy subcontractor market was emphasised over the course of the project, with a large proportion (approximately one-third) of the project team's time spent on resolving, pricing and finalising the provisional sum (front of house) areas, even though they constituted only 5 per cent of the contract sum. While still considered the best mechanism to deliver these critical areas to the level of finish required, it also reinforced the merits of quarantining the remaining 95 per cent of the contract sum and scope from this process – in a time, resourcing and cost sense.

Conclusion

The defect and commissioning process was extensive. In the end, the project, due to its highly technical and bespoke nature, was delivered three months later than expected for final handover. Examples of the issues we faced included:

- The blackened steel could only be done by one contractor, who proved slow and elusive.
- The balancing of the mechanical system to ensure the artwork was kept at optimal temperature and humidity proved complex and time-consuming.
- The sequence of the works meant that the entry and access finishes needed the majority of the other works to be complete so as not to damage the entry finishes and security.

A staged handover was implemented so that the artwork could be delivered on time. We were able to facilitate early access to some areas so that impact to the client's operation was minimised. The project was delivered within budget.

Key project statistics

Item	
Overall project timeframe – from concept to completion	3 years, 10 months
Construction timeframe	27 months
Number of project meetings attended by Aver	398
Number of consultant firms involved	37
Number of subcontractor firms involved	67
Average spend per month during construction	$1.95m
Largest spend per month during construction	$4.08m
Number of Lost Time Injuries (LTIs)	Nil

Practice profile

Aver is an independent, privately owned development and project management consultancy providing strategic property expertise, advice and delivery across a wide range of project sectors, including infrastructure, urban renewal, commercial, residential and retail, in Sydney and Melbourne.

While our project portfolio is varied, we have found that our work on projects with significant complexities (either technical or stakeholder) or bespoke architecture including finishes has resonated with our clients and the people with whom we work.

Key people

David Riddell: director and founder

Nick Johnston: associate, senior project manager

Alex Lisney and Michael Carbone: assistant project managers

04

Planning

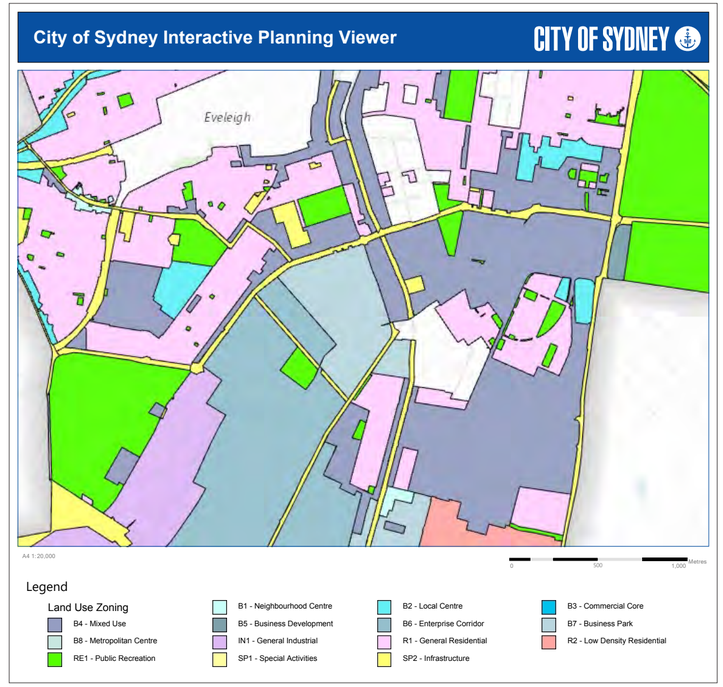
BBC Consulting Planners

A fish is not a bird: How Dangrove survived the idiosyncrasies of the NSW Planning System.

Permissibility

When the framework for any planning jurisdiction is based on rigid land use zoning involving the identification of defined land uses – some permissible (with or without consent) and others prohibited depending on which zone applies to the site in question – it is inevitable that there will be definitional omissions.

Such is the planning framework in the Australian state of New South Wales, within which the Greater Sydney Region occupies around 12,360 square kilometres, eleven times the size of Hong Kong. Within the Greater Sydney Region there are 35 separate local government areas (LGAs), each administered by a City, Municipal or Shire Council and each with its own regulatory town planning instrument known as a Local Environmental Plan (LEP). In NSW, there are 128 LGAs; the standardised LEP for each one contains



City of Sydney zoning of land use of the area around Dangrove.

a dictionary of defined land uses, a table of land use zones, a set of controls on building height and floor space ratio (the latter being the ratio between gross floor area and site area), a schedule of local heritage items and various 'local provisions' relating to such matters as acid sulphate soils, earthworks and flood planning.

There are 35 standard zones, standard mapping protocols and a prescribed set of standard LEP clauses. However, each LEP can contain subtle but potentially significant differences: for example, the lists of permissible uses in standard zones need not be identical, and the 'local provisions' while dealing with the same type of issues can be quite different from one LEP to another. One such LEP is Sydney LEP 2012, which applies to the City of Sydney LGA within which Dangrove is located.

Every LEP contains a standard dictionary of land use terms; the same land use definitions appear in every LEP. There are 290 defined terms, proving that the NSW Parliamentary Counsel who pored over the standard dictionary to ensure it was legally and technically sound before being given legal effect was striving to be all-inclusive. So much so that terms you might think do not need to be defined in a planning instrument are defined nevertheless. Take 'fish' for example: who would think that in a standard dictionary of terms relevant to land use planning in every one of the 200 or so LEPs in force in NSW there needs to be a definition of a 'fish'?

The reader will know what a fish is (and isn't), so why define it? In particular, the reader might reasonably ask why a 'fish' is defined as follows:

> 'fish has the same meaning as in the Fisheries Management Act 1994
>
> Note.
>
> The term is defined as follows:
>
> **Definition of 'fish'**
>
> 1. Fish means marine, estuarine or freshwater fish or other aquatic animal life at any stage of their life history (whether alive or dead).
> 2. Fish includes –
>   a. oysters and other aquatic molluscs, and
>   b. crustaceans, and
>   c. echinoderms, and
>   d. beachworms and other aquatic polychaetes.
> 3. Fish also includes any part of a fish.
> 4. However, fish does not include whales, mammals, reptiles, birds, amphibians or other things excluded from the definition by the regulations under the Fisheries Management Act 1994.'

While the reader will be pleased to know that a fish is not a bird, the need to define it is the desire of the law-maker to make land use planning as prescriptive as possible – presumably, to ensure order and certainty and eliminate doubt. Surely then, if land use planning terminology is so comprehensive and thorough as to warrant inclusion of a definition of fish, every conceivable land use must make an appearance in the standard dictionary? Incorrect. Student housing and co-living, for example, are not defined. Furthermore, buildings of a commonly well-understood type, such as an art gallery, are often bundled into an uncommon term such as 'information and education facility (not to be confused with an educational establishment)', defined to mean 'a building or place used for providing information or education to visitors and the exhibition or display of items and includes an art gallery, museum, library, visitor information centre and the like'.

So what about a private art storage facility? Well, good luck finding that in the standard dictionary. It is an innominate use, one for which there is no definition. That can potentially be fatal from a land use planning perspective because the defined terms in the standard dictionary populate the land use tables in all LEPs in each of the three mandated categories for each zone: the first category being those defined land uses which are permissible without consent, the second containing those land uses permissible with consent, and the third comprising those land uses which are prohibited. If a particular zone lists as permissible with consent only those defined land uses which are considered by the author of the LEP to be the ones which achieve the stated objectives of that zone and prohibits all other land uses, then all innominate land uses are automatically prohibited not because of any inherent fault or inconsistency with the stated objectives of the zone but rather – or simply – because they are innominate.



The former industrial building on the Dangrove site.

Dangrove achieved its permissibility because the strategic planners at Sydney City Council had the good foresight to make the zone in which it is located an 'open zone'. Here, a finite list of defined land uses is prohibited, thereby rendering all other uses, whether defined or innominate, permissible with consent. During the period that the development application for Dangrove was under assessment, Sydney City Council adopted a raft of new controls for the locality in which Dangrove is located, as part of which the subject site was rezoned from B5 Business Development to B7 Business Park. As both are 'open zones', Dangrove's innominate characterisation retained the status of development permissible with consent, thereby enabling the development application process to proceed.

Site selection

For any proposed development, ensuring permissibility is essential, but so is cautious and judicious site selection. Trying to fit a square project peg into a round planning hole is the demise of many a well-intended development scheme. Locationally, the site was well-suited for Dangrove, being part of the City of Sydney's Southern Employment Lands and in the East Alexandria Locality, the desired future character of which is as a 'thriving, evolving industrial neighbourhood with taller commercial buildings towards the Green Square Town Centre'. (Green Square is a 278-hectare area of former industrial land, Sydney's oldest, which extends across parts of the suburbs of Beaconsfield, Zetland, Rosebery, Alexandria and Waterloo. It is undergoing a $13 billion urban renewal transformation, including a new town centre, which will result in 30,500 new dwellings and a population of around 61,000 people by 2030).

What then of the adjoining uses? Did they pose an obstacle to Dangrove's prospects of development success? Opposite and to the north of the site, on the northern side of Mandible Street, is a concrete batching plant capable of operating 24 hours a day and a multi-tenanted warehouse/light industrial/office complex. To the east, when Dangrove was in the DA stage, was a NSW Fire Brigade training complex, in part since redeveloped into the imposing NSW Rail Operations Centre. To the west is a two-storey electrical supplies warehouse with associated offices, well-recessed from the street. At the rear is a 4-metre-wide stormwater channel which is uncovered for a length of around 160 metres between Mandible Street and the site's south-western corner, but until then runs beneath the rear of the neighbouring building to the south, a furniture showroom fronting Bourke Street. In short, the site selected for Dangrove had no sensitive neighbours (or so it was thought).

Also contributing to the suitability of the site was the then existing building, a structurally robust, large-volume, brick warehouse sleeved at the front by a wedge-shaped office component elevated above ground-level parking. The land was almost entirely covered by the existing buildings, with the only parts not occupied by structure being a narrow strip at the rear of the warehouse, an open car park located on the north-eastern part of the site (at the rear of the elevated office building) and a narrow strip along the northern frontage adjacent to Mandible Street. This was an essential aspect of the suitability of the site for the proposed development. The footprint of the existing warehouse building matched the spatial requirements of the design brief. Equally essential, however, was the height limit set by the LEP for the site: 35 metres. This ensured that the high volume storage space that the design brief demanded could be delivered within the statutory building height constraint applying to the site. As for the floor space ratio limit, the LEP prescribes a maximum of 2:1 (or 3.5:1 if community infrastructure is provided by the development) which, on a site area of 5533 square metres, equates to 11,066 square metres of permissible gross floor area.

The architect's design brief comprised 1200 images from the client's contemporary art collection. The collection, in total, was around 10,000 pieces (including one installation around 17.5 metres high and 10 metres wide), and was expanding at a rate of about 300 new works each year. The warehousing need arising from the world's largest private collection of contemporary Chinese art outside of China was for approximately 8200 square metres of gross floor area, excluding car parking and loading and unloading space, plant rooms and void. This quantum of gross floor area could readily be accommodated with the 2:1 FSR (floor space ratio) limit. For interest and comparison, the total building area, which is what the builder had to construct, was actually over 11,000 square metres, including plant rooms.

Contamination

As part of the assessment, and thus preparation process for all DAs in NSW, consideration must be given to whether the land is contaminated and, if it is, whether it is suitable in its contaminated state – or will be after remediation – for the purpose for which the development is proposed. If the land does require remediation, the consent authority has to be satisfied that the land will be remediated before the land is used for that purpose.

The site, which had been used for warehouse and/or light manufacturing purposes for decades, and on a small part of which were two underground storage tanks, was the subject of a preliminary (Stage 1) environmental site assessment which identified the potential for contamination in the soil, in the groundwater and in the existing structures. A more detailed (Stage 2) contamination investigation was then carried out as part of which eight boreholes were sunk, four groundwater wells were installed, and soil and groundwater samples were collected and analysed. Detected contaminants in minor quantities included heavy metals, TPH, BTW, PAHs, OCP, PCBs, VOC and asbestos in both soil and groundwater. None of these contaminants posed an ecologically significant threat and were capable, where required, of being remediated or removed.

Flooding

Dangrove lies in the Alexandria Canal Stormwater Catchment area. In larger storm events, run-off that exceeds the capacity of the local drainage system forms overland flow paths in the vicinity of the site, including on Mandible Street and along the stormwater channel at the rear, which forms part of the Sheas Creek catchment. In the 1 per cent Annual Exceedance Probability event, the amount of run-off exceeds the capacity of the trunk drainage network leading to the open stormwater channel system and, obstructed by existing buildings upstream of the site, the overland flow is diverted southwards along Botany Road and then westwards down Mandible Street, past the front of the site. In other words, in peak storm events there is an east to west flow of flood water in front of and at the rear of the site with respective peak flood heights of RL8.7m AHD and RL8.3m AHD, thereby requiring the finished ground floor levels in the new building to be constructed at RL8.85m AHD.

Development application

In addition to the essential architectural, landscape and stormwater management drawings, the Dangrove development application (DA) was accompanied by technical reports on planning, contamination, flooding, geotechnical conditions, traffic and parking, acoustics and energy efficiency, as well as management plans for acid sulphate soils, construction and waste minimisation. It was lodged on 14 November 2014.

Clockwise from top left: Satellite image of Dangrove site; flooding depth diagram of Dangrove and surroundings; flooding depth diagram; flood level model peak at Mandible Street.

The DA was for a combination of partial demolition of, and alterations and additions to, the existing building but mainly for the erection of a new building. The partial demolition of the existing building included:

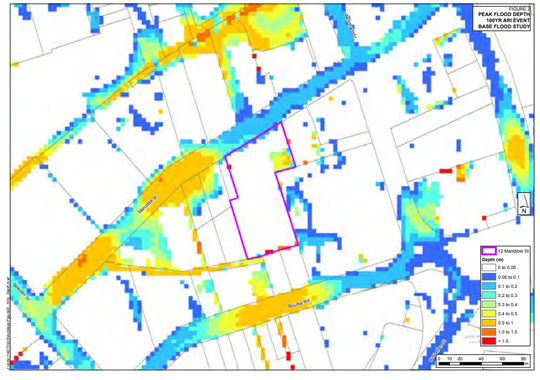
- Demolition of the front commercial offices.
- Removal of the existing roof of the rear warehouse.
- Demolition of the top sections of external side and rear walls of the existing warehouse to a height of approximately 5.8 metres.

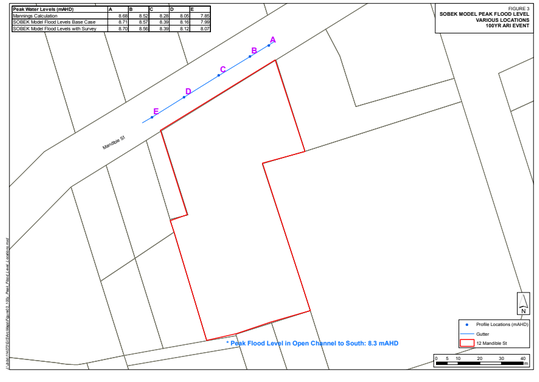
The footprint of the existing warehouse was retained, but that of the replacement new front building was increased marginally (relative to the previously existing office component) with a first floor terrace provided over what was then an at-grade parking area.

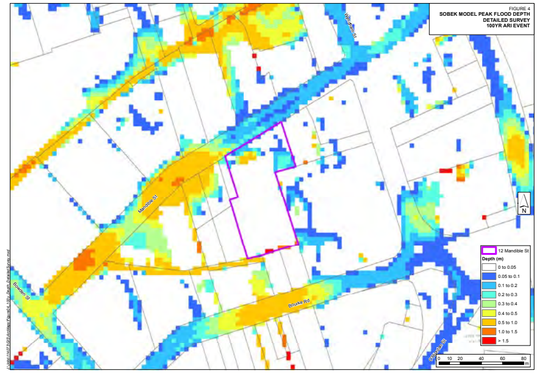
The alterations and additions and new building works included:

- Raising the side and rear walls of the warehouse by 6 metres.
- At ground level: on the front part of the site – a new undercover car park, entry via lift and stairs to a first floor reception area and stair access to the caretaker's residence; and on the rear part of the site – a loading dock, security office, staff amenities, bicycle parking, goods lift, workshops, sorting/packing rooms, plant rooms, stores and photography room.
- At first floor level: on the front part of the site – reception, canteen, amenities, caretaker's flat; and on the rear part of the site – a central, linear, art stock management and evaluation space, with art stores either side, meeting room, office and a outdoor terrace.









- At the lower roof level: mechanical plant and access bridge over the void below.
- A new raked roof form over the art stock management and elevation space of the building rising from north to south, with a maximum height at its southern end of 30 metres.

Having demonstrated the project's permissibility, suitability of the site for redevelopment as a private art storage facility, compliance with the development standards in the LEP relating to building height and floor space ratio, and having addressed the constraints of site contamination and flooding the remaining key issues for the DA to overcome related to the council's requirements for:

- Achieving Design Excellence.
- Provision to be made for a publicly accessible pedestrian access way across the rear of the site.

Key issues in the assessment of the DA

DESIGN EXCELLENCE

On 24 November 2014, 10 days after the DA was lodged, the council's planning assessment team requested that the DA be withdrawn within the next 14 days because no competitive design process was conducted in its preparation. Furthermore, the council advised that if the DA was not withdrawn, it would be refused. To the reader this may seem surprising: the DA was for an operationally benign and uncontroversial permissible purpose, which was compliant with the height and FSR controls in the LEP, on land zoned for business purposes with no sensitive neighbours, with little or no environmental impact and with a positive streetscape outcome. This demonstrates world's best practice in art storage and management, and designed by an architect with a track-record of Design Excellence.

The basis of the council's withdrawal request for the DA lay in Clause 6.21 of Sydney LEP 2012, the objective of which is to deliver the highest standard of architectural, urban and landscape design. (Sydney City Council was the first council in NSW to include a Design Excellence clause in its LEP.) Clause 6.21 provides that development consent must not be granted to 'development to which the clause applies unless in the opinion of the [council], the proposed development exhibits Design Excellence'. It identifies sixteen matters that the council must have regard to when considering whether a proposed development exhibits Design Excellence. These matters are as follows:

a. Whether a high standard of architectural design, materials and detailing appropriate to the building type location will be achieved.
b. Whether the form and external appearance of the proposed development will improve the quality and amenity of the public domain.
c. Whether the proposed development detrimentally impacts on view corridors.
d. How the proposed development addresses the following matters –

  – The suitability of the land for development.
  – The existing and proposed uses and use mix.
  – Any heritage issues and streetscape constraints.
  – The location of any tower proposed, having regard to the need to achieve an acceptable relationship with other towers (existing or proposed) on the same site or on neighbouring sites in terms of separation, setbacks, amenity and urban form.
  – The bulk, massing and modulation of buildings.
  – Street frontage heights.
  – Environmental impacts, such as sustainable design, overshadowing and solar access, visual and acoustic privacy, noise, wind and reflectivity.
  – The achievement of the principles of ecologically sustainable development.
  – Pedestrian, cycle, vehicular and service access and circulation requirements, including the permeability of any pedestrian network.
  – The impact on, and any proposed improvements to, the public domain.
  – The impact on any special character area.
  – Achieving appropriate interfaces at ground level between the building and the public.
  – Excellence and integration of landscape design.

Development to which Clause 6.21 applies relevantly includes any building with a height greater than 25 metres and any development in respect of which a development control plan is required. Development for which a development control plan is required relevantly includes land with a site area of more than 5000 square metres. As Dangrove had a maximum height of 35 metres and as the site area was 5533 square metres, the DA attracted consideration under Clause 6.21 on two counts.

Clause 6.21 (5) provides that consent cannot be granted to development falling into the categories noted above unless a competitive design process has been held in relation to the proposed development. A 'competitive design process' is defined to mean an architectural design competition, or the preparation of design alternatives on a competitive basis, carried out in accordance with the City of Sydney Competitive Design Policy.

Although, Clause 6.21 (b) also relevantly provides that a competitive design process is not required if the council is satisfied that such a process is unreasonable or unnecessary in the circumstances of the case, the council's planning team did not accept that Dangrove warranted an exemption.

The applicant's design and planning teams appreciated from the outset that the proposed development was one to which a competitive design process might potentially apply and, in this regard, the reasons initially submitted, but not accepted by the council's planning assessment team as to why a competitive design process was not necessary in the circumstances of this DA, included:

- Tzannes Associates had a demonstrated history of conceiving and achieving Design Excellence.
- The proposal was for a highly specialised, single-purpose use (i.e. private art storage), the bespoke design for which demanded a special understanding, particularly of technical and industrial requirements, between applicant and architect.
- The applicant had demonstrated a history of achieving excellence in design outcomes for the built environment elsewhere in the Sydney LGA.
- The narrow focus of the architectural brief on specific functional requirements supporting the operation of the White Rabbit Gallery and housing one of the world's finest art collections of contemporary Chinese art did not suit a competitive design process.
- The immediate locality comprised utilitarian industrial and commercial buildings, being a local context in which the proposal would have superior architectural and aesthetic characteristics, demonstrating abundant design quality for its setting.
- The provisions of Part 5A of State Environmental Planning Policy (Exempt and Complying Development Codes) 2008 applied to the site which would have allowed the erection of an industrial building up to the applicable height and floor space controls in the LEP (but with contextually irrational setbacks) as 'Complying Development' being a type of development which does not even require a DA to be lodged, accessed and determined by a consent authority, but which instead can be the subject of a certificate issued by a private certifier.
- It would be unreasonable to burden unnecessarily the process of delivering an architecturally bespoke private art storage facility when a bulkier industrial building with less design merit could be built on the site as 'Complying Development'.
- The proposal did not exceed either the applicable FSR or height controls in the LEP, and did not rely on a bonus height or FSR incentive in the LEP. (If an applicant undertakes a competitive design process and a DA is a result of such a process, the applicant for that DA can be granted either a 10 per cent increase in the maximum building height, or a 10 per cent increase in the maximum floor area of the proposed development, but not both.)

The design team at Tzannes Associates believed that Design Excellence could be achieved by an alternative method to a competitive design process – for example, via a design review process or via a conscientious design review panel. However, the council's distinct preference, indeed insistence, was still for a design competition notwithstanding the

arguments put forward above. No comparably scaled project for a new building had been exempted from the design competition process required by Clause 6.21 in Sydney LEP 2012. With this in mind, and in response to the council planning team's request that the DA be withdrawn, the design team instead:

- Undertook to build two physical models, one sectional model at 1:100 and another at 1:200 scale, the latter including neighbouring and other buildings in the surrounding locality. The working drawings for the modelmaker took a month to prepare and the models were fabricated using recycled Huon pine. Reflecting their exquisite exhibition quality, they remain on display in Dangrove today.
- Prepared five photomontages using what was, at the time, innovative cloud point technology which enabled the architects to survey the works of art in the collection and place them in the virtual interior spaces.
- Invited members of the council's planning assessment team to view these models at the factory where they were stored.
- Presented the design, the models and the photomontages to the council team, emphasising why the design would be unlikely to change in a competitive design process, because it could not be made more efficient or more consistent with, or responsive to, the brief.
- Submitted further documentation assessing the proposal against all of the sixteen matters in Clauses 6.21, being the matters for consideration by the council in determining whether a proposal exhibits Design Excellence.

Ultimately, following the process above, the council planning assessment team was satisfied that a competitive design process was unreasonable and unnecessary in the circumstances of the case *and* that the proposed development exhibited Design Excellence.

Rear setback from the stormwater channel

The 4-metre-wide stormwater channel at the rear of the site is ambitiously identified on the Green Square Public Open Space map in Sydney DCP 2012 as being a future water channel open space link intended to comprise a total width of around 25 metres, requiring dedication of land by owners on either side of the channel as redevelopment occurs. A landscaped setback of 10 metres is required for any new building from the edge of the stormwater channel.

As the proposal relied on the rear wall of the existing building on the site being retained, the provision of such a setback was impractical. Furthermore, if such a setback were to be provided, the resultant building would not satisfy the design brief in terms of either floor area required or the spatial configuration of the interior.

The Dangrove DA was primarily assessed by the council's planning team, but also with scrutiny by the council's urban designer, building approvals unit, environmental health team, public domain unit, transport and access team, tree management officer, landscape management officer, land surveyor, waste management team and cultural officer.

Notification

The DA was advertised for public comment for a period of 28 days, attracting two submissions, one of which, surprisingly, raised concern with the use of the new building for the storage of artworks, including a caretaker's flat, on the basis that it might be incompatible with the operations of the concrete batching plant on the opposite side of Mandible Street. The second submission objected to an alleged loss of privacy and an increase in overshadowing of nearby residential properties in Mandible Street arising from the height of the art storage space.

Determination

In NSW, an approval of a DA can be issued in the form of a 'Deferred Commencement' consent being one where, before the consent becomes operational, certain conditions must be satisfied. Dangrove was the subject of this type of consent. It was granted, under delegation of the council, on 27 May 2015. The deferred commencement conditions required:

- A Remediation Action Plan (RAP) to be prepared in order that the site would be made suitable for the development which included a residential component in the form of a caretaker's flat.

Rendering of Mandible Street facade, one of the five photomontages lodged as part of the application for development consent. Visualisation by Tzannes.

- Additional acoustic data on noise from mechanical plant operation to be provided.

The required information to satisfy the deferred commencement conditions was duly prepared and the consent became operational on 16 September 2015. The operational consent was subject to 82 conditions which included:

- A condition aimed at ensuring that the design quality excellence of the development be retained, requiring:
  - The design architect to have direct involvement in the design documentation, contract documentation and construction stages of the project.
  - The design architect to have full access to the site and to be authorised by the applicant to respond directly to the consent authority where information or clarification is required in the resolution of design issues throughout the life of the project.
  - Evidence of the design architect's commission to be provided to the council prior to release of the Construction Certificate.
  - The design architect of the project not to be changed, without prior notice and approval of the council's Director Planning Development and Transport.
- A condition requiring the caretaker's flat to remain incidental and subordinate to the art storage facility and not be set out or used independently of the art storage facility use.
- Payment of a monetary contribution of just over half a million dollars for affordable housing calculated on the basis of $58.04 for each square metre of the 8992.2 square metres of floor space.









Three of the five photomontages prepared, using cloud point technology, as part of the application to council by the design team. The proposed design for the entry, top, was later substantially changed.



The retained brick wall in accordance with the development consent. Due to the structural inadequacy of the wall, a subsequent variation application to the development consent requesting demolition was approved.

Modifications
In NSW, the detail of a development consent can be modified, provided the scope of the modification is not so great as to render the development as no longer substantially the same as the development originally approved. The Dangrove consent was modified three times:

- On 20 November 2015, to permit minor design modifications.
- On 6 June 2016, to permit the replacement of existing street trees and reconfiguration of the vehicular access way to the site.
- On 11 April 2017, to permit further design modifications including the demolition of the retained rear wall of the original structure to permit erection of a new wall.

In relation to the last mentioned of the above modifications, the rear wall which had, to date, been planned for retention, had subsequently been assessed by the project structural engineer to be unstable and unsafe. Although there was an initial position adopted by the council's planning assessment team that the demolition of the original rear wall had provided a new opportunity for a 10-metre setback to be provided from the top of the stormwater channel at the rear of the site (to facilitate, at some time in the future, a 'livable green link'), the design and planning teams' rationale for not doing so was ultimately accepted and the modification was approved as proposed.

Conclusion
Dangrove, in its function and form, is a highly specialised building which tested design and development assessment norms. It did this through a rigorous process of continually demonstrating design excellence, from initial concept presentation to the consent authority through to design and contract documentation and construction. It is a wonderful example of what can be achieved when a visionary client, trusted architect and forward-looking consent authority combine to promote innovation, avoid the adequate but mediocre, and facilitate a standard of development outcome commensurate with the significance and quality of the artworks it contains.

Practice profile
BBC Consulting Planners is a Sydney-based town planning consultancy established in 1993.

Key people
Bob Chambers: founding director
Philip Bull: associate director

05

Quantity Surveying

Bylett Associates

The key role of the quantity surveyor is to provide cost advice to the client and design team to assist with developing the project within the client's budget. We achieve this by reviewing the design documentation, including discussions with the design team on the scope and intent of the works, and providing cost budgets based on the design at various stages throughout the development of the project. Usually, our involvement commences at the inception of the project and continues through all phases to the completion of the construction works.

Architects will invariably start a project with an idea of the design resolution and/or client and community response they wish to achieve. It is our task to provide the client and design team with cost advice to assist them with guiding the project to meet its goals. Our training requires us to understand the principles of structural design, services such as hydraulics, electrical and mechanical and, at least, some grasp of architectural design, along with the ability to capture all these components and place an appropriate value on the sum of all the parts.

Quantity surveyors are usually selected either by the client, project manager or the architect, as they have a certain vision for the project and understand its design requirements, and so are best able to approach a quantity surveyor with the most appropriate experience for that particular project. We have previously worked with the Art Gallery of NSW for many years on new gallery buildings and spaces at the Domain site along with their off-site purpose-built gallery store, so we understood the design complexities of both.

It was apparent at the outset that Dangrove was going to be a hybrid of both the need for storage and for exhibiting the artworks; each has its own unique design requirements. The scale of the building, along with the soaring Great Hall, the climate-controlled and secure storage areas, the external envelope, the extensive use of off-form concrete and architectural steelwork, presented a number of challenges to the design team and us. It is very unusual for art storage facilities to accommodate visitors for performances or exhibitions – we needed to understand the level of presentation required in a building that blended the functional aspects of back of house with the more visual impact of front of house. It was important when doing the cost planning to maintain the integrity of the design. The budget was generous, but a firm one that had to be met. The process was design led, with budget management fully integrated.

How refreshing to have a project where the design resolution had a greater significance than the likely cost of the building. However, it was still necessary to provide cost advice on the concept designs so that we could establish a cost framework for the client and design team. To commence the cost reviews, we obtain all the documentation that has been developed and listen carefully to the client and design team and then ask lots of questions in order to understand the design when most of the reference material is only gradually being documented. In other words, we try to get inside the architect's mind. In the case of Dangrove, we would ask about anything from the visual appearance of the parking area to the finish of the concrete floor. We also consider how the building will be constructed, which will be the builder's challenge, and capture those costs into our cost advice.

The initial cost estimate is critical as it is the first time the design has a monetary value applied to it. We include in the estimate all the information that has been prepared, along with our anticipation of the cost of the work that has not yet been documented. This often requires providing a written scope of the work as we find this a more digestible format for the design team to review, and comment whether there any differences with their own requirements. For us, this is the most interesting phase of the project as we have to 'tune into' the vision and translate it into something more physical, which is the cost of the

Bylett Associates

Project: Dangrove Art Storage
Building: Dangrove Art Storage

Details: Dangrove Art Storage - Hold Point 1 Estimate

Description	Quantity	Unit	Rate	Subtotal	Total
DANGROVE ART STORAGE FACILITY					
DEMOLITION WORKS				712,250	712,250
SUBSTRUCTURE				2,370,939	2,370,939
COLUMNS				1,041,447	1,041,447
SLABS & SUSPENDED FLOORS				2,642,814	2,642,814
STAIRS				192,958	192,958
ROOF				5,283,192	5,283,192
EXTERNAL WALLS & WINDOWS				2,932,077	2,932,077
EXTERNAL DOORS				85,120	85,120
INTERNAL WALLS & SCREENS				2,964,231	2,964,231
INTERNAL DOORS				671,039	671,039
WALL FINISHES				846,176	846,176
FLOOR FINISHES				995,908	995,908
CEILING FINISHES				575,937	575,937
FITMENTS				320,978	320,978
HYDRAULIC SERVICES				1,034,261	1,034,261
MECHANICAL SERVICES				6,817,275	6,817,275
ELECTRICAL SERVICES				8,992,587	8,992,587
FIRE SERVICES				773,363	773,363
LIFT SERVICES				574,000	574,000
EXTERNAL WORKS				263,793	263,793
EXTERNAL SERVICES				225,000	225,000
TOTAL TRADE WORKS				**40,315,345**	**40,315,345**
BUILDER'S PRELIMINARIES @ 12%				4,837,841	4,837,841
SUB-TOTAL				**45,153,187**	**45,153,187**
BUILDER'S MARGIN @ 5%				2,257,659	2,257,659
SUB-TOTAL				**47,410,846**	**47,410,846**
DESIGN CONTINGENCY @ 10%				4,741,085	4,741,085
SUB-TOTAL				**52,151,931**	**52,151,931**
CONSTRUCTION CONTINGENCY @ 5%				2,607,597	2,607,597
TOTAL CONSTRUCTION COST				**54,759,527**	**54,759,527**

Bylett Associates

Project: Dangrove Art Storage
Building: Dangrove Art Storage

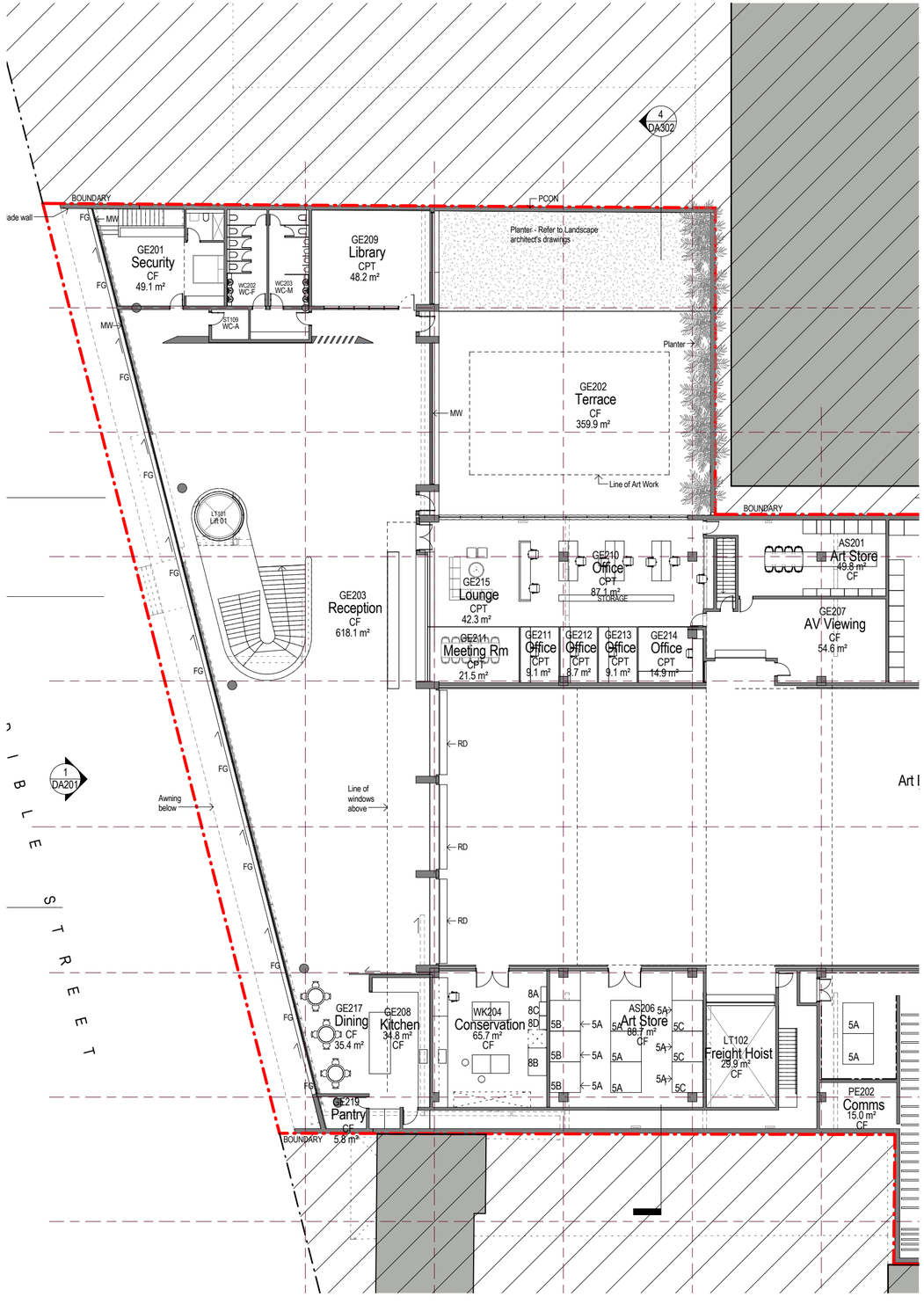
Details: Dangrove Art Storage - Hold Point 1 Estimate

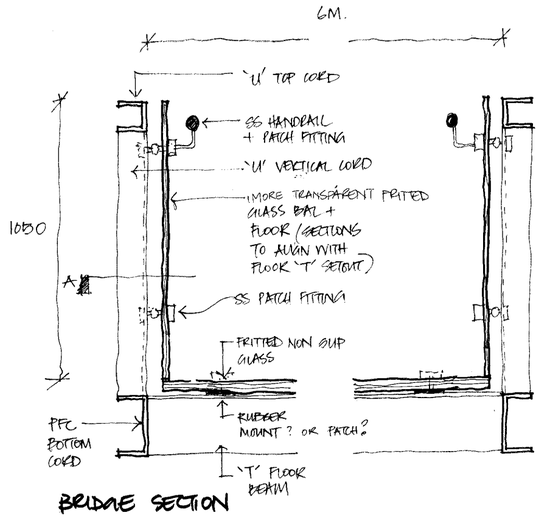
Description	Quantity	Unit	Rate	Total
1 DEMOLITION WORKS				
DEMOLITION WORKS				
Existing Warehouse				
Structure				
Demolish metal sheet roof and purlins, gutters etc	4,550	m2	25.00	113,750
Demolish structural steel beams to portal frame	487	m	100.00	48,700
Demolish structural steel columns including cutting bolts at slab	126	m	100.00	12,600
Full demolition of brick external walls	1,288	m2	35.00	45,080
Demolish walls, doors, ceiling and finishes to toilet area	1	item	10,000.00	10,000
Demolish two storey structure including walls, doors, ceilings and finishes including stairs and joinery	1	item	15,000.00	15,000
Existing Offices				
Structure				
Demolish office comprising concrete slab and columns, glazed and solid external walls, internal walls, doors and finishes	875	m2	100.00	87,460
Hydraulic Services				
Disconnect and remove redundant services to warehouse	4,074	m2	15.00	61,108
Disconnect and remove redundant services to office	967	m2	15.00	14,504
Mechanical Services				
Disconnect and remove redundant services to warehouse	4,074	m2	5.00	20,369
Disconnect and remove redundant services to office	967	m2	5.00	4,835
Electrical Services				
Disconnect and remove redundant services to warehouse	4,074	m2	25.00	101,847
Disconnect and remove redundant services to office	967	m2	25.00	24,174
Wet Fire Services				
Disconnect and remove redundant services to warehouse	4,074	m2	15.00	61,108
Disconnect and remove redundant services to office	967	m2	15.00	14,504
External Works				
Demolish bitumen paving including concrete kerbs and hardstanding; 50mm	1,206	m2	15.00	18,090
Remove bitumen from site	181	t	200.00	36,200
Remove metal fencing and landscaping	62	m	50.00	3,121
Allow to pump out fuel tank and fill with sand	1	item	15,000.00	15,000
Remove fully grown tree's at the front	4	no	1,200.00	4,800

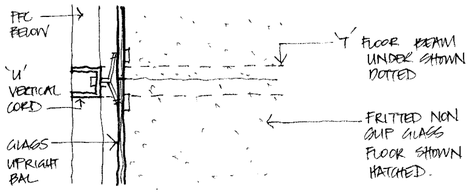
To Collection: 712,250

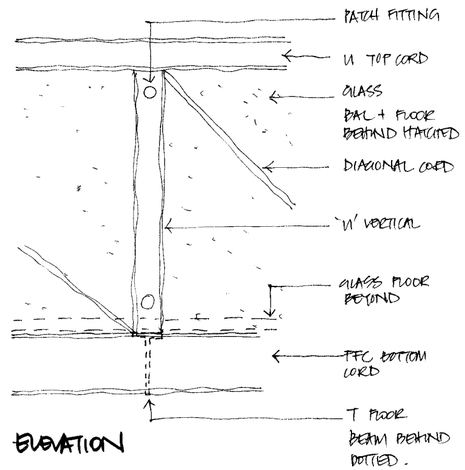
These pages: Extracts from the Hold Point 1 Budget Estimate document Bylett prepared in 2015 for Aver. This page shows an estimate of the total cost for Dangrove; the page opposite shows an estimate of the complete cost of demolition.

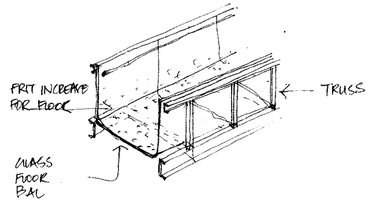
To meet the budget, various design elements were changed. The page opposite shows the original concept for the entry to Dangrove, including a sweeping circular stairway. A photomontage of this can be found on page 90. On this page, in its original concept, the bridge had a glass floor; at one stage, the bridge was deleted altogether from the plans, but was eventually reinstated wtih a precast concrete floor.







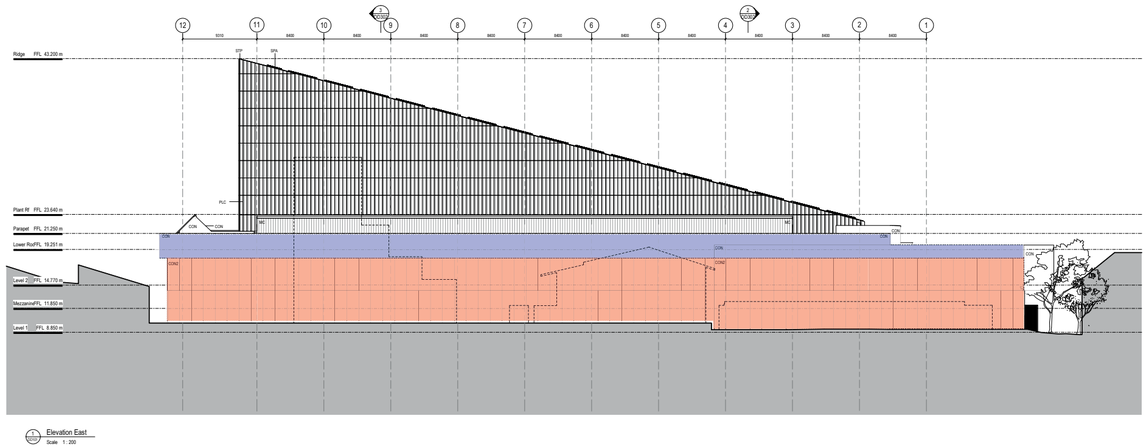


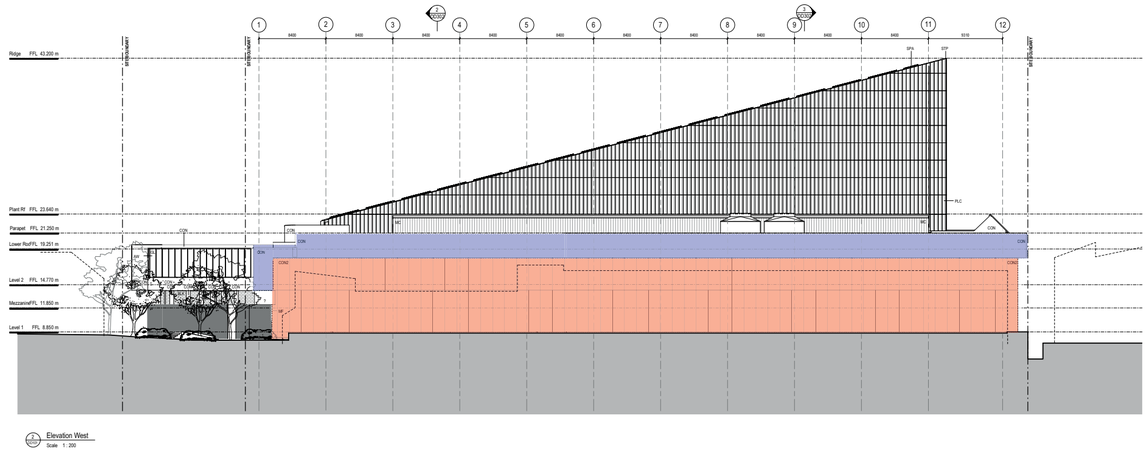


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works. At times, we almost border on being creative in attempting the leap from intangible to tangible.

It is at this stage that the hard decisions have to be made if the cost estimate does not fit within the budget. Adjustments need to be made to the design and/or budget. For the Dangrove project, there were many instances in which the design had to be changed for functional and cost reasons. An example was the initial design for the main visitor entry to the reception on the first floor, which was to be a separate ground floor building with a circular lift and stair. This, however, had functional and cost issues. The resolution was to incorporate the visitor and staff entry into the main ground floor building with a conventional lift, which improved the security and access aspects, and reduced costs in the lift design. By capturing and costing all the information provided by the design team,

The original design for Dangrove included precast concrete walls. For cost reasons, these were replaced with concrete block. The selected builder, however, preferred to work with precast, and so this was reinstated.

both the client and the architect are able to relate the design to the cost and can then make informed decisions on any changes required.

Other examples of changes that were made partly due to cost were the bridge and the use of precast concrete. In the case of the bridge, which was originally designed with a glass floor, a provisional sum of $500,000 was included in the tender document. When adjustments were made, the bridge was deleted from the plans, but eventually reinstated at the request of the client with a precast concrete floor. The original design for Dangrove included precast concrete walls. We suggested that block walls should be included in the tender, as an alternative cost option, in lieu of the precast concrete walls in order to obtain a cost comparison between the two materials. The design went out to tender with concrete block walls, but the selected builder preferred to work with precast concrete walls, suggesting block walls would be more likely to sustain damage than precast concrete walls. The precast concrete walls were reinstated for practical reasons which had the potential for a better maintenance outcome.

At each cost check, adjustments can be made to the scope of work to keep the project in line with the client's budget. Once we have established a dialogue with the design team, it becomes an intuitive process in which we translate the design team's ideas into costs. This often requires us to conceptualise the two-dimensional design information in a way that we can understand the three-dimensional resolution of the building. For some of our projects the design has been developed using software that generates a three-dimensional view of the building in a process known as Building Information Modelling (BIM), which means that we are less dependent on our own visualisation of the building. In the case of Dangrove, BIM was used later in the process.

Subsequent to the initial cost review, the process continues with further cost updates as the design progresses through to the preparation of the tender documentation when we prepare the pre-tender estimate. The purpose of the pre-tender estimate is to provide one last check on the cost of the work before tenders are sought from the builders and also to use as a benchmark against the tenders when they are received. For the Dangrove project our initial estimate was within 1 per cent of the accepted tender received from the builder tendering for the project.

A constant theme raised on many of our projects is whether the final building offered value for money for the client. While this may be answered by comparing the cost of the building to the financial return generated by it, this doesn't capture the emotional, cultural and community benefit of some buildings. A public library can be built as a regular sized box with standard floor heights, facades and finishes and meet the functional demands. But today, public libraries are often built with distinctive facades, with an emphasis on their visual impact, along with well-finished interiors and facilities; councils understand that they offer an enhanced experience for the community. For Dangrove, the question can only be answered by the client. If the building meets and exceeds all their expectations, then that is the only criterion to be met.

For us, this was an extraordinary project that blended so many different design requirements and provided us with a challenge to savour and enjoy. The site visit after completion was the highlight of our involvement in the project; it confirmed many of the design aspects we had to visualise from the design documents – we often liken the reading of design documents to working in virtual reality – and then took it to another level as the true vision of the design team was realised. There have been many interesting projects that we have been involved with, but Dangrove is unique and will certainly stay in our memory for a long time.

Practice profile

Bylett Associates was established in Sydney in 2005. It provides cost advice to a large range of clients, often in the heritage and cultural sector and frequently for councils. It specialises in non-standard projects – these have included the refurbishment of Audley Boatshed, Ngununggula at Retford Park and the Western Sydney Animal Rehoming Centre at Blacktown.

Key people

Chris Bylett

06

Architectural modelmaking

Brian Nagle Architectural Models

Introduction to the two models

There were two architectural models commissioned in the design process of Dangrove – the site and context model at a scale of 1:200, and the internal/external section model at 1:100. Both are in timber and with a minimum use of acrylic glazing elements.

The site model, measuring 1.8 metres square, shows Dangrove and its precinct, with neighbouring properties, roads, landscape and trees within a 150 metre radius of the site boundary.

The section model cuts through the main gallery on a longitudinal axis, showing internal working forms, volumes, glazed walls, entry points, bridge links and circulation spaces. The model measures 900 mm in length and 450 mm in height. The Great Hall dominates the section with its triangular raked ceiling at approximately 30 metres to its highest point at the southern light wall. In the finished building, the light cast through this frosted glass wall illuminates the Great Hall.

The function of the models

Initially, the models were used by the architects to develop and resolve the design. They were later crucial to argue the case that the architecture had achieved Design Excellence as required by the planning legislation of the Council of the City of Sydney.

The 1:200 model represents the environment in which the scheme fits, and shows how the scheme affects that environment. The larger scale, 1:100 model, enables viewing of the building's function and form. Essentially, one model is about urban impact and the other is about interior and exterior architectural language, functionality and spatial design.

The models have also been extensively used to communicate design ideas to specialist designers and the client. Since completion of Dangrove, the models have been on display at the entry to the building, and serve as an explanation of the building to visitors.

An architectural model can surprise, delight and inspire those involved in a building's evolution. It is a tangible interpretation of what was previously an abstraction in drawing form. This recognition reinforces that crafts still have a place in our economy. Architectural modelmaking is one of the last surviving crafts in which the product is generally handmade, is unique and, for the maker, provides a livelihood.

On viewing an architectural model, one should consider the design presented is a stage in an ongoing process. It is rarely the end point, but a mark in time. It may convey an ideal in the mind of the architect – an example being Tatlin's Tower, which only exists in model form. The model's value becomes archival, as in the many stages of design documented in Utzon's Sydney Opera House models.

To a degree, this is the case with the Dangrove models. Some variations have occurred, but in the main, the model design is relatively consistent with the finished building.

Use of timber as the medium

Architects generally prefer either timber or monochromatic models, as they present a neutral surface, without reference to colour or texture. A monochromatic model enables the designer to view the building sculpturally; form dominates, and light and shade reveal the scheme's essential relationships.

Perhaps for this reason, Tzannes selected timber as the most appropriate material for the Dangrove models. Also, timber has a softness of finish, a play of grain and lustre. With age, timber mellows to a warm finish, whereas plastics, for example, can discolour and are

Overleaf: A detail of the 1:200 site model, showing Dangrove within its surrounding precinct.



sterile in comparison. Of course, plastics, to give credit, are a more immediate material, suitable for quick, colourful and versatile models, and widely used in machine-made applications. A model can be gauged by its requirements – sometimes fine details are warranted, or form and mass are important, and materials will be chosen accordingly.

The materials that would best serve Dangrove's requirements was Huon pine. It is a straight-grained, straw-coloured softwood from Tasmania, traditionally favoured in boat building and furniture making. Its qualities are excellent for finely crafted work; in thin dimensions it remains rigid and strong, sharp and clean edged, and displays an exciting, wavy, close grain. Occasional small knots give it added life. With age, it turns golden brown. When cut, the fragrance of the timber has an invigorating aromatic scent and its surface shines with a smooth waxy lustre. Huon pine is a pleasure to use, and has a biophilic effect on the senses. As well as acting as an insect repellent, the natural oil within it causes the timber to be water-resistant, adding to its durability.

However, this timber is not without its problems. It has been reported from the timber industry that due to over-logging, the Huon pine is now a protected tree in Tasmania and strict controls are placed on its felling – as a result, it is becoming increasingly difficult to procure. It is a rare timber, although it is not deemed endangered; there are large reserves of Huon pine trees within conservation zones and national parks in south-west Tasmania. Bylaws allow only milling of trees that, through age or storm, have fallen. Certainly enough can be sourced for modelmaking, where thin boards, 6 to 10 mm, can easily be milled for fabricating. Thicker sections can be purchased as mill waste or stock up to 100 mm, but in short runs.

Complementary to the use of Huon pine is sheet plywood. A Finnish birch ply is useful for broad surfaces such as landscape zones, roads and model sides. This ply, generally used for model aircraft, is lightweight and durable, and is available from 1 mm thickness. It has a smooth surface and is similar in colour to the pine. It is easily cut with a craft knife or saw, and the fact that it's so thin allows it to be contoured to the levels of terrain or curved around an arc.



A detail of the 1:200 site model, showing Dangrove within its surrounding precinct.

The 1:100 model, partly made, in Brian Nagle's studio.



To give a consistent tone to the models, trees have Huon pine shaving as foliage upon a wire armature. In both models, clear and frosted perspex or acrylic is used for glazing elements. In the site model, this crisp, glassy material offers Dangrove a focus within its surroundings, while in the section model, acrylic glazing creates a balance between contrasting materials. As light is a specification to the design, both opaque and translucent materials work to this effect.

Using traditional and digital methods

Within my practice, the construction approach is mainly traditional. To ensure confidence and a reassuring collaboration, a person-to-person liaison, physical meetings, site visits and direct communication are essential. These were the parameters taught in this craft in the 1970s and 1980s. Teachers were master craftsmen, from architecture and art backgrounds, who had a strong belief in thinking out problems and working closely with designers. This always resulted in a mutual respect between the disciplines.

Today's remote communication, online meetings and virtual site visits are not without problem, and cannot replace the real thing. It is advisable to request drawings on paper, attend a personal briefing from the architect and a site visit before costing or making any product.

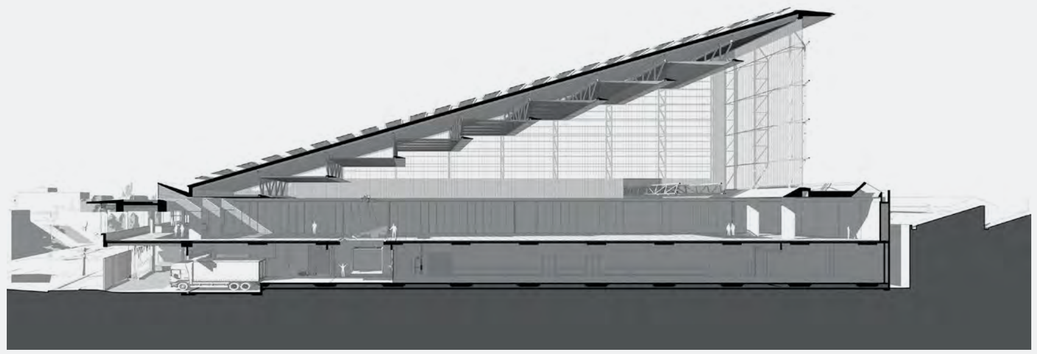
Though relying heavily on hard copy scale drawings for direct measurement and templates, computer programs such as SketchUp do have a place. They can serve to double-check the drawings. The multi-view walk-through does surpass the conventional perspective, and the computer-generated imagery is valuable when referencing colour and materials. Working digitally can save time (and therefore money) and be more accurate. Revisions can be delivered quickly and queries can be notated in screen shots.

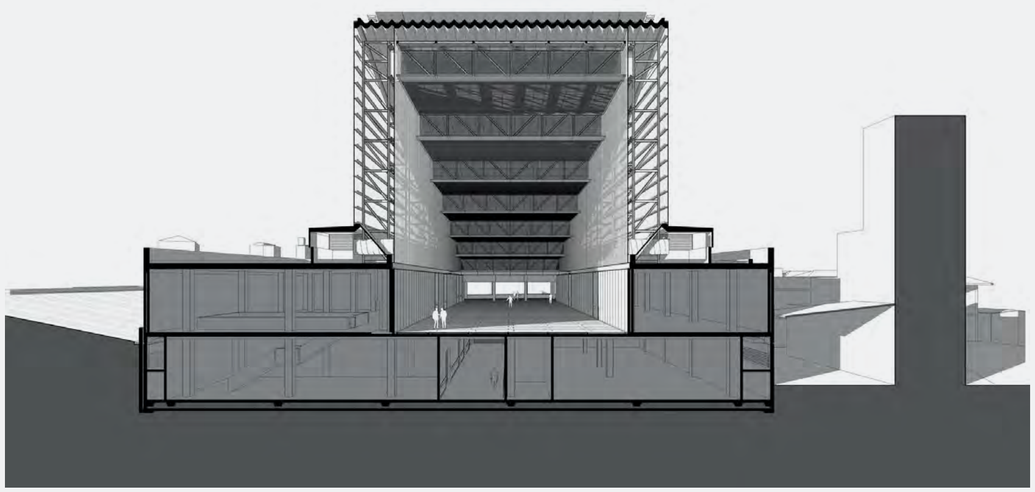
Working on Dangrove models

With the assistance of Neil Haybittel of Tzannes, the design for Dangrove became increasingly clarified through his work on the 3-D spatial imaging. This enabled a ready and invaluable checking system the co-ordinate the 2-D drawings and the physical modelling. 3-D images were done specifically for this task, taking Neil considerable time to produce. Other drawings and sketches by both Neil Haybittel and Alec Tzannes were also invaluable in driving the model's production, and as further assistance to the model making. The aim was for the models to be integral to the development of the design rather than an after-product.

The model construction commences with the base plane. This is to define its limits and establish the ground lines that will lead to upper levels. The site models started with three hollow core timber doors – in this case, being the right size and weight, as such, formed a rigid base and a flat, regular structure to work upon. Modelmakers look for a head start – doors weren't originally my idea, but I've used them many times as a base, as they're flat and cheap and ready to go.

Once the profiles of the various upper levels are calculated and cut to their tolerances, glazing and cladding can be considered. These elements are not glued just yet. Floors





Opposite: To make the models, Brian Nagle worked with a wealth of material supplied by Tzannes, including sketches, plans and, as shown, 3-D images.



A selection of tools in Brian Nagle's studio.

and walls must float free to access further details, such as painting if that is required. The building is continually assembled and disassembled for the fitting and measuring of components. All aspects of the building are worked in unison. Many hands can be employed on the various levels if scale and time permits. In the case of the Dangrove models, a team of four worked on them for two months. The modelmaker knows the building literally inside out, knowing its rationale, and is able to make informed conclusions based on the geometric code that drawings and instructions provide. Consistently following this process and managing time, the product is completed – a beautiful result.

The question arises of what constitutes a 'beautiful result'. Is it purely in the eye of the beholder or does it have intrinsic quality? Arguably, both.

Personally, it is the play of materials – the ability to take a material, understand it and shift it into another form. In the apparently effortless appearance of the modelled forms, and aided by the modelmaker's style, a model can be outstanding. Viewing a model should convey both its complexity and its implied simplicity, revealing a harmony of ideas and materials. As in many fields, simplicity is the desired effect.

The tools and materials

Models can be defined as prototypes. They are specialised and one-off. Each element is fashioned to a specific dimension to fit into an intricate puzzle to form an orderly outcome. Resourceful creativity is the key to a fine outcome, as time is often the factor that determines how these elements are produced. Modern cutting programs and hand manufacture can work side by side. In general, for one-off elements, the hand is more economical than the machine, taking in cost factors such as plant and maintenance, and time factors such as programming. For this model, mostly hand manufacture was appropriate for the character required, along with quality and cost considerations.

Models are made on a commission basis. A fixed cost gauges how time, method and materials are to work logically to achieve results.

A trust in time-honoured methods will usually be the course when working to deadlines. And tools are the reliable ally.

Hand tools are instruments of beauty. They are functional forms, little changed over the centuries, and thus forming a connection with masters of the past. Knives, squares, rules, geometric guides, dividers, clamps and the humble pencil, used at a work bench scarred by every cut that is made.

Power tools do play a major role in production. Cutting timber into precise dimensions requires fine hollow-ground or tungsten-tipped circular blades in a solid bench saw (such as a Wadkin). This saw is the main power tool. Other tools include disc sander, band saw, air-compressed spray gun, battery and pedestal drills, and so on. Then there is a range of adhesives, paints, solvents and hardware items to stock. The usual cluttered shelves of possibilities, all ready for some necessary application.

The fabricated timber elements of the Dangrove models are adhered with PVA or epoxy glues. The acrylic glazing uses a chloroform solvent to fuse edges together. (If painting or tinting is required, it is hand-painted with artists' sable brushes or sprayed with acrylic lacquer.) Minor accessories are usually added with superglue and accelerant; perspex covers or acrylic lamination use ultra-blue polymer to achieve an invisible joint. This chemistry is by way of suggesting the need to be aware of recent materials and methods and their hazards.

The role of architectural models

The model is a display tool, and it tells a story. Guided by the architect's brief and the maker's creativity (the art of the miniature), the function of the building is demonstrated at its best. Selective aspects must come together in a singular form, such as commercial and residential, circulation and access, security and privacy, leisure and green space, heritage and environmental impact. It needs to be an immediate visualisation.

A sectional model is favourable to many of these requirements. A particular example of this immediacy is the Pliny Villa model in the Ashmolean Museum, Oxford. It employs cut-away walls and roof sections, vivid colouration, human activity demonstrating usage, has a large scale (1:48) and, having been built in the 1940s, displays the charm of a bygone era. It attracts the eye at once, as do many other well-detailed models displayed worldwide, including here, with the models of Dangrove.

New technologies

The new technologies have changed the model industry. Arguably, the computer-generated model (3-D printed or laser cut) can be sterile in appearance, and the handmade has a softer, more artistic feel. It can be said that the imperfect of the handmade adds to the







Brian Nagle, with one of the models, which is now on display at Dangrove.

item's beauty. 3-D printing has yet to rival the appeal of hand manufacture, especially when colour is required. In its traditional form, this industry has not become redundant by the computer age, but simply changed in some approaches.

The preference for finely crafted architectural models shows the capability of the human hand, which is reassuring in a world that is losing manual skills. This is a point not lost, I suspect, on the client of Dangrove.

To give credit to the new technologies, the modelmaking fraternity is increasingly employing digital methods as the process of choice. There is anecdotal evidence that work can be produced more economically and accurately, and be widely acceptable to the architects and clients. Digital transmissions, paperless designs and 3-D printing find modelmakers more likely in front of a screen than at a workbench with hand tools. A colleague, working independently, reports that 25–30 per cent of time is now spent on a computer, and saving 60–70 per cent of time making components.

Larger workshops have principals on computers full time, and general hands either operating printers, lasers or assembling components on work in progress. Note that a pair of hands is still required to assemble the components cut from the digital source.

An in-house modelmaker within a well-established firm informs that foam cut (hot wire) study models have been the mainstay within their design development. However, with the rapidly developing advances in 3-D, resin and colour filament printing, interest is shifting in that direction.

The convenience of the desktop process is promoted as limiting waste, dust, toxins and noise. Clearly, now and in the future, this will be attractive in many practices. Toxins, the aforementioned hazards, are a major concern to all craftpersons.

Students also are moving away from balsa and card into the printing methods and it will be this generation who will gauge whether handmade models survive into the future.

It is possible that both traditional and technological craft will work together as they do now. The choice will be a matter of taste and preference of both client and maker.

The place of Dangrove in my practice

I have worked on major projects, such as the Sydney Opera House, Australian Bicentennial, Sydney Olympics, State and private projects, including sculptors' maquettes. This has allowed my practice to have a connection with some of Australia's most highly regarded architects and artists.

Working overseas in the UK, Japan, Greece, Indonesia and New Zealand has given me an even wider experience. My respect for architectural discipline and its philosophy of order has given me a critical eye for quality.

As a craftsperson working at scale, a personal disconnect is often felt in the completed building. Remarkably, for one always working with scale, the completed buildings' volumes are always surprising. Upon entry, the Great Hall at Dangrove was more impressive and more vast than expected, even though I was familiar with its measurements and details.

Of the many outstanding architectural designs my practice has engaged in, works by Tzannes must be included, and in particular, Dangrove. What makes this project meaningful to me is the respect for handcrafted quality. These models were a test of my professional ability and resources, and working on them brought out our best practice.

Within this project, there was a genuine appreciation for problem solving and the generation of ideas. Given this latitude, the project ran cooperatively.

Dangrove houses a unique art collection and it is gratifying to know that my contribution to the building's creation is there on display as a testament of this craft.

Practice profile

Brian Nagle has worked as a modelmaker since 1973, while an art and architecture student. During the 1980s he worked in the UK, Greece and Japan before returning to Sydney, where he is now based. His practice, Brian Nagle Architectural Models, trades as a limited liability company in the Inner West.

Key people

Brian Nagle

Opposite: Sectional model at 1:100 scale, top.
A detailed view of the sectional model, below.

07

Life Cycle Assessment

The Footprint Company

How we got involved with the project

The Footprint Company came to the Dangrove art storage project via prior work with Tzannes to support the quantification of ‘sustainability’ value for 71 Macquarie Street, an apartment building at Sydney’s Circular Quay. For this we used the embodied carbon/ecological footprint as an alternative approach to the City of Sydney 5 Green Star requirement.

The Green Star requirements were a point of challenge on the Macquarie Street project, with Alec Tzannes feeling that the sustainability values his team brought to the design were better demonstrated using an evidence-based system. The approach also engaged the developer, Mirvac, in a broad variety of construction methods, which contributed to the footprint reduction, which would have otherwise been ‘unrecognised’ under the Green Star system.

The articulation of a building’s contribution to the broader sustainability goal of ‘living well on one planet’ is simply expressed with the ecological footprint and planet method. It allows measures such as life span, reuse, dematerialisation and low footprint materials to be quantified and demonstrated in tangible terms. Many of us are familiar with the concept of our own ecological footprint (i.e. how many planets we would need if everyone lived like Australians). The concept of the ecological footprint has been adapted to buildings with the Global Footprint Network in order to connect local design actions to global scale outcome.

For Judith Neilson and Alec, the idea of supporting the social and environmental sustainability value of Dangrove, with evidence-based measures was aligned with the project vision. At the time (and still) there is no ‘rating’ system that is well suited to a facility of this nature. The social value of a 100-year life – so crucial to Judith’s legacy – is neatly measured in the whole building/whole life ecological footprint method.

Some of the challenges and solutions

An early key sustainability performance challenge arose with the ‘additional’ concrete (and therefore footprint) associated with the 100-year design life. The reference assessment adopted a conventional 25-year life span, which had a negative impact on the results. Working with the engineers to quantify the impacts opened up the innovative responses of retaining/reusing the existing structure. Seeking lower impact concrete (which at the time was leading – and an early mover in – the ‘greening concrete’ process). Using lightweight plastic Rodeca cladding resolved many challenges faced by this iconic design element, including both thermal performance and a radical reduction in material carbon and associated structural carbon impact, as well as delivering the ethereal and diffuse internal light quality which is a signature of the design.

To complement the progressive low energy systems and passive design elements, an extensive photovoltaic array was incorporated. The combination of these delivers 30 per cent of the 100-year carbon footprint reduction.

Taken together, the delivered footprint of Dangrove was just 25 per cent of that of an equivalent art storage facility benchmark of the time. Since its completion, the world of sustainable design and low carbon materials has progressed rapidly. Thus, it is without doubt, that if built today, the whole of life carbon and ecological footprint could be improved by another substantial margin. Advances in the availability of low/no carbon materials, improvements in equipment energy efficiency and the radical change in affordability for photovoltaics provides a fundamentally different environment for development.

In this chapter we present the life cycle assessment results, with technical disclosures provided at the end. The structure of this section is framed around International Standards and the core purpose is to communicate to the reader the quantified life cycle impact of the proposed design in terms of whole of life carbon and ecological footprint and compare the results to a normative reference case. The objective is to make evident the absolute environmental impact reduction over a conventional design approach.

The overall result of the as-built facility was to achieve a reduction of 75 per cent in ecological and carbon footprint as compared to a conventional design approach, over a 100-year life span. The absolute carbon avoided is approximately 69,000 TCO_2-e over a 100-year life (24,500 TCO_2-e operations and 44,700 TCO_2-e capital). Assuming the average annual household emission of CO_2-e is 18 T, this is the equivalent to offsetting the carbon emissions of 3800 households for a year.

Life cycle approach

International Standard ISO14044 provides the whole of life quantification framework on which the ecological and carbon footprint assessment of the project is based. For this project, the 'life-span' proposed was 100 years. The emissions impact of the aspects of the project included in the scope of assessment were: the embodied impact of the materials of construction; operating energy and water; the ecological value of the site and its land use; as well as the emissions produced by staff commuting to work.

The ecological footprint itself is an approach to calculate humanity's demand on nature (Earth's biocapacity) and communicates it tangibly, in terms of hectares per person (or planets). This gives an understanding of how much we have, how much we use, and who uses what.

Today, humanity uses the equivalent of 1.6 planets to provide the resources we use and absorb our waste. This means it now takes the Earth one year and eight months to regenerate what we use in a year. Moderate United Nations (UN) scenarios suggest that if current population and consumption trends continue, we will, by the 2030s, need the equivalent of two Earths to support us each year against a fixed supply of one.

Results are reported in terms of global hectares and global metres square per square metre per unit area of a project. These units represent the physical area of productive land theoretically required to extract the resources and absorb waste (emissions) to create, maintain and operate a building.

Results

The total materials impact of the design is approximately 23,320 tonnes of carbon dioxide equivalent (TCO_2-e) or 3.1 tonnes/m^2 NFA (net floor area). This total accounts for materials emission from production to finished in place on site at project practical completion (A1-A5 in terms of EN 15978). The ecological footprint is approximately 380 global hectares per annum, or 2.2 planet equivalent (on the basis of the population of the facility).

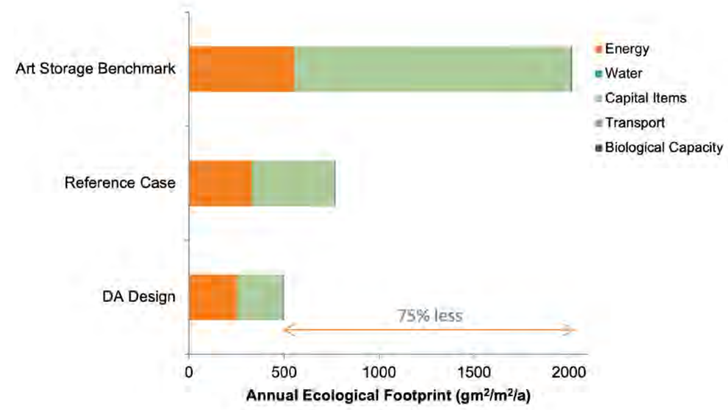
Dangrove results

		DA Design
Absolute Footprint	(GHa/a)	380
Annual Footprint	(gm2/m2/a)	499
Capital Carbon Footprint	(TCO_2-e)	23,320
Operating Carbon Footprint	(TCO_2-e/a)	773

Throughout the report, the 'DA design' should be read as 'Tendered Design' with recycled materials and installed photovoltaics (PV). The 'reference case' reflects the DA plans if they were built with standard materials. These are compared with the 'art storage benchmark', which takes standard ecological performance of storage facilities and operational energy requirements of art storage facilities.

Through extended material life, low carbon material substitutions, passive design and PV, the DA design has achieved an ecological footprint reduction of approximately 75 per cent compared to the reference case and a 35 per cent reduction compared to the art storage benchmark. Comparative performance is shown in the figure below.

Performance comparison with benchmark



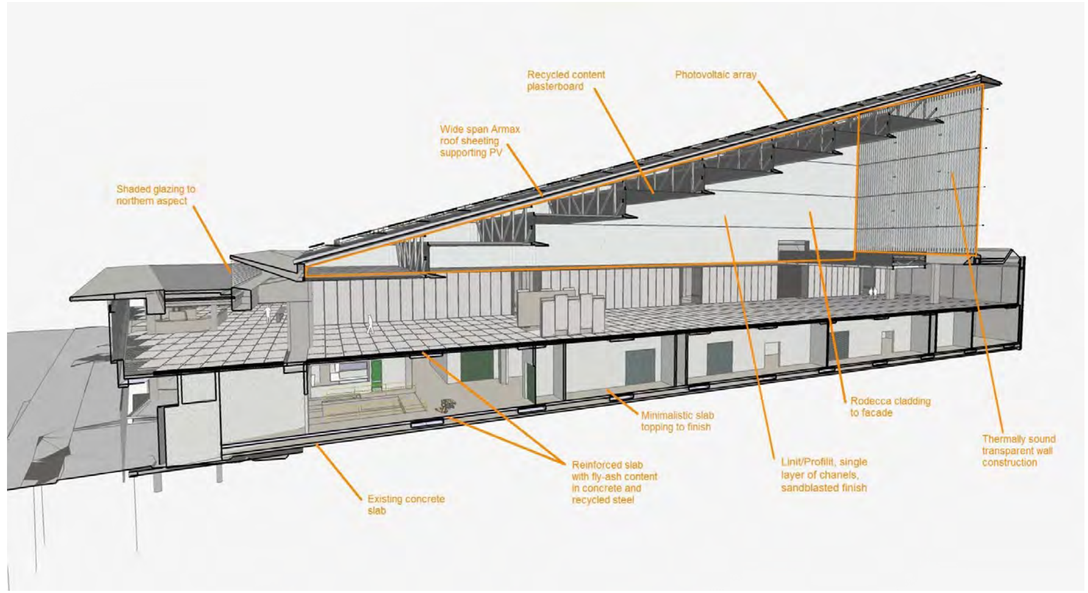
Main initiatives

The DA design (Tendered) achieved impact reductions through a combination of operational and capital design initiatives. See the figure overleaf for a visual summary.

The table below describes the main reduction initiatives.

Summary of main mitigation initiatives

Materials with 100-Year Lifetime 430 TCO_2-e /a saved 168 $gm^2/m^2/a$ EF reduction 59 per cent of EF reduction	Preference was given to structural materials that will survive 100 years compared to the standard twenty-five years. The client has safeguards in place to maintain the building and prohibit demolition by future owners. This allows the depreciating of the embodied impact of construction over an extended period, reducing the annual impact as well as preventing the impact of new materials and demolition.
Photovoltaics 244 TCO_2-e/a saved 82 $gm^2/ m^2/a$ EF reduction 29 per cent of EF reduction	Installation of an extensive photovoltaic system contributes to a net operating energy emissions reduction. The orientation of the large, north-facing roof was deliberate to optimise the scale of the system.
Reclaimed/Recycled Content Materials 348 TCO_2-e saved 22 $gm^2/m^2/a$ EF reduction 8 per cent of EF reduction	A major driver of the embodied carbon footprint arises from the reinforced concrete structure. The adoption of cement replacement fly ash – an innovation at the time – and the specification of recycled content reinforcement drove the mitigation solution. Now common practice – these two initiatives were breakthrough at the time.
Retained Structure 770 TCO_2-e saved 11 $gm^2/m^2/a$ EF reduction 4 per cent of EF reduction	Extensive retention and reuse of existing ground floor slabs was achieved. However, proposals for retention of retaining walls was not. Extending the life of these elements assists in the structural and thermal properties of the new facility without increasing the carbon and ecological impact of the project.
Low Operating Carbon Design 660 TCO_2-e/a saved 221 $gm^2/m^2/a$ EF reduction	The operational impact of energy services has a strong tie to the design and material properties of the building. The northern alignment, sealed building envelope and material density have produced modelling estimates noticeably below similar operational art storage facilities. Energy savings are in comparison to a similar facility in Sydney.

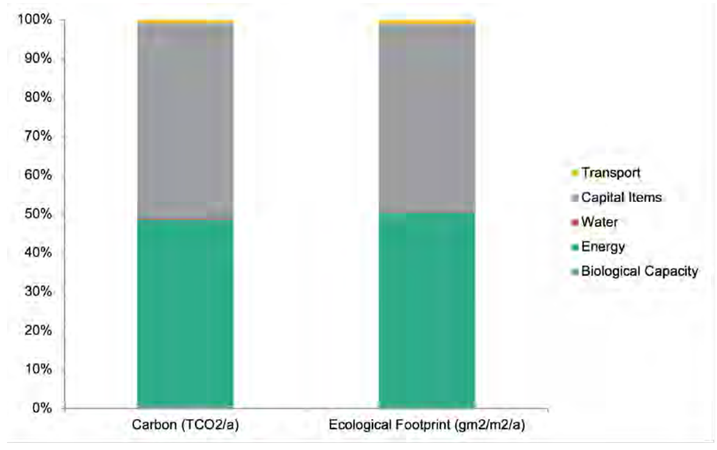


Summary of initiatives for the DA design

Key drivers of footprint

The figure below compares the relative impact of each element to both the carbon and ecological footprints. On an annual basis both footprints are driven by the operational energy use and the embodied energy within the capital items. Impacts caused by transport, water use and the bio-capacity are relatively small.

Design annual carbon and ecological footprint breakdowns



Note: Results shown are for the DA/Tendered Design. The capital elements for both the ecological footprint and carbon footprint results are annualised to one year of operation. To reflect initiatives of the project, structural elements are assumed to have a 100-year lifetime while facade, wall and interiors are assumed to have a standard 25-year life.

Sustainability impacts by element

Operational footprint

The operating energy is the second largest component of annualised carbon emissions (48 per cent) and largest component of the annualised ecological footprint (50 per cent). This is driven by the high energy requirements to maintain the building's temperature and humidity throughout the year. Compared to the art storage benchmark, the DA design performs 54 per cent better in the operational ecological footprint. The table below outlines the operational impact of the building over its 100-year life. The figure below shows the estimated reduction in ecological footprint from passive design elements and PV from the art storage benchmark and the Reference Case.

Operational impact results

Operational Element	Extended Life TCO_2-e absolute	
	Reference Case	**DA Design**
Energy	99,000	74,520
Transport	1400	1400
Biological Capacity	1080	1080
Water	290	290
Total TCO_2-e	**101,770**	**77,290**

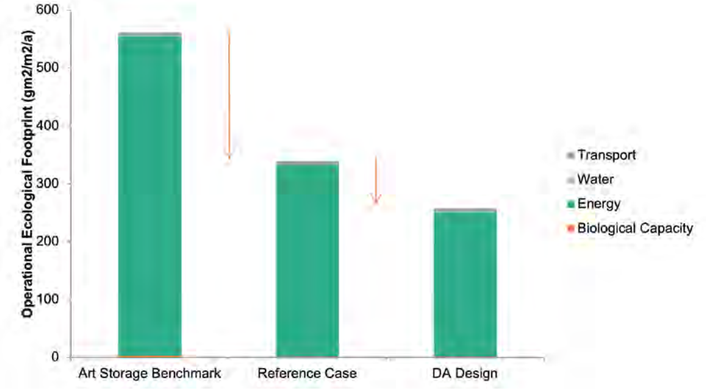
N.B. Results show the absolute carbon emissions over a period of 100 years.

ENERGY

In total, the DA design achieves an approximate 55 per cent reduction in terms of energy of the art storage benchmark. The operational impact of energy has been calculated from modelling undertaken by Steensen Varming and assumes an annual electricity consumption of 900 MWh. The operational impact of energy services has a strong tie to the design and material properties of the building. The northern alignment, sealed building envelope and material density have produced modelling estimates noticeably below similar operational art storage facilities (approximately 40 per cent less).

The addition of a photovoltaic system will further decrease this impact. The DA design assumes the photovoltaic system has a proposed annual output of 222,560 kWh, based on a feasibility study by Steensen Varming. This has achieved a further 25 per cent reduction from the reference case. Given this estimate, it would take approximately two years of operation to 'pay back' the embodied energy within the capital elements of the photovoltaic system.

Operational ecological footprint comparison



TRANSPORT

The impact of transporting staff and stock is relatively small annually due to the small amount of staff and few stock changes throughout the year.

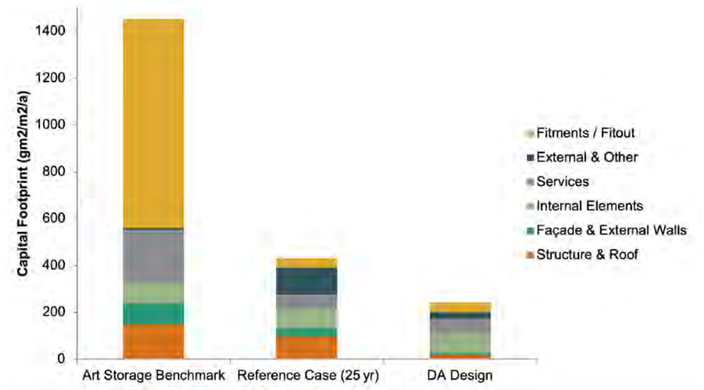
WATER

The carbon and ecological impact of water is relatively small compared to the rest of the facility. It should be noted that given Sydney's historic relationship with water scarcity, the provision of catchment tanks provides local benefits not measured within a global impact scope. Due to water's low operational footprint, the embodied carbon of the catchment tank is expected to be equal to the impact of 52 years of water consumption.

Capital footprint

Initial estimates suggest capital elements have an ecological impact of 241 gm^2/m^2 per annum, 83 per cent below the art storage benchmark. This equates to an embodied carbon footprint of 3.1 TCO_2-e/m^2 NLA, or 23,320 TCO_2-e absolute. The figure and table below show the impact of capital elements compared with the art storage benchmark and the reference case.

Capital ecological footprint comparison

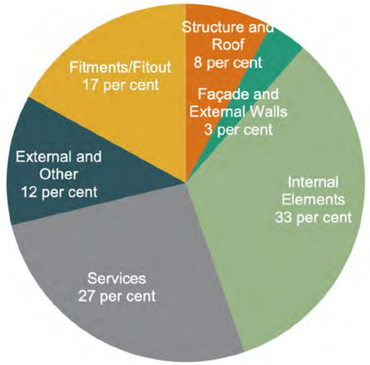


Capital impact results

Capital Element	Standard Life (25 years) TCO_2-e absolute		Extended Life TCO_2-e absolute
	Reference Case	DA Design	DA Design
Structure and Roof	21,630	20,484	5,121
Facade and External Walls	7,194	7,106	1,777
Internal Elements	41,819	41,424	41,424
Services	17,232	17,232	17,232
External and Other	29,796	29,796	7,449
Fitments/Fitout	5,226	5,226	5,226
Total TCO_2-e	**122,898**	**121,268**	**78,229**

Note: Results show the absolute carbon emissions of capital items over a 100-year period. The 'Standard Life' case assumes average element lifetimes (Structure and Roof, Facades, Services, External and Other are 25 years, Interiors and Fitments are 10 years) and includes replacements over this period. The 'Extended Life' case assumes design for longevity (Structure and Roof, Facades, External and Other are 100 years).

Breakdown of capital ecological footprint



INTERNAL ELEMENTS

Internal elements have a large comparative ecological footprint due to the internal walls which feature large quantities of reinforced concrete block walls and fire-rated block walls. Internal wall, floor and ceiling finishes have a relatively small impact due to low footprint material choices and minimalistic design.

SERVICES

Services in aggregate are 27 per cent of the capital ecological footprint of the facility, mainly from electrical services. Only the lift services trend above the art storage benchmark.

EXTERNAL AND OTHER

External and other elements are driven by the allowances for contingencies, preliminaries and design. This impact is estimated from cost allowances and therefore subject to actual performance while building. Efficient building practice will reduce this and the allowance will inevitably spread to other elements during construction.

FITMENTS/FITOUT

Fitments and fitout account for 17 per cent of the overall capital footprint. The majority of the facility is dedicated to storage areas which contain stand-alone steel racking. The steel construction and modular nature of these systems allows for material longevity and future repurposing. A relatively small area of the facility consists of a typical office fitout.

STRUCTURE AND ROOF

The majority of embodied carbon in structure and roof is from reinforced concrete slabs in the structure and roof. While this only represents 8 per cent of the annual capital ecological footprint, it represents 22 per cent of capital carbon emissions. The low footprint compared to the benchmark can be attributed to the 100-year lifetime design and low-carbon material substitutions.

The DA design used recycled steel content in structural elements along with high content fly ash concrete. This represents a 22 per cent reduction from the reference case ecological footprint.

The ground floor of the facility was constructed on an existing concrete slab. Extending the life of these elements assists in the structural and thermal properties of the new facility without increasing the carbon and ecological impact of the project. The value of this existing structure is to the order of 770 TCO_2-e or 11 gm^2/m^2/annum.

FACADE AND EXTERNAL WALLS

Facade and glazing elements are 3 per cent of the reference footprint. The majority of the facade embodied carbon is from cladding and steel-framed windows. The chosen cladding has fairly low carbon intensity which drives this reduction. Block and concrete walls contribute around 46 per cent of the facade's impact mainly due to large quantities required. Other glazed materials such as the folding glass wall and glass louvres contribute 27 per cent of the facade's impact due to high carbon intensity.

Conclusions

The outcome of the project team's design mitigation initiatives as lodged for development consent resulted in a 75 per cent reduction in the life cycle ecological and carbon impact of the facility – as compared to a conventional approach. Key initiatives contributing to the improvement were achieved for materials and operations including: large scale retention/reuse of existing structures; adoption of innovative recycled content materials; low carbon design strategies (dematerialisation); assiduous application of passive design principles and large scale embedded solar photovoltaic systems. The '100-year covenanting' of the facility was also a major driver of improvement and a leadership initiative from a social and environmental perspective.

Post completion postscript (2021)

1. As with many voluntary leadership approaches, it is always possible that design phase initiatives can be lost due to build-ability issues or value-engineering barriers. For Dangrove, the final as-built solution did not achieve the recycled content steel goals and the retention of the complete extent of the concrete structure planned, for a variety of construction level reasons.

   Notwithstanding these omissions, the as-built solution has achieved significant outcomes from both an operational carbon footprint associated with the operational energy efficiency (and on-site solar PV array off-set contribution) and capital carbon, with the extended structural design life.

   Together, these two elements will, over their target 100-year design life, contribute an approximate net reduction (avoidance) of 35–39,000 TCO_2-e in absolute terms. This is approximately equivalent to the embodied (materials) carbon footprint of 55–60 average suburban project homes.

2. The commitment of Tzannes and the Dangrove Board to delivering the targeted operational outcome must be recognised. Too frequently, the outgoing design and construction team fail to enable the incoming operational team with any measure of skills adequacy to maintain and continuously validate the operational performance of the capital sustainability investment. In the case of Dangrove, the operational transition and calibration of real-time performance, with the design modelling, was completed with exactness and continues with Board oversight of ongoing utility costs.

   The Board's leadership in maintaining rigorous oversite on results and ongoing commitment to the economic, social and environmental performance of Dangrove is a significant benchmark for this type of built asset.

3. Subsequent to the completion of Dangrove, the Architects Accreditation Council of Australia's draft review of the National Standards of Competency for Architects has included as a required competency an understanding of whole of life ecological and carbon impact principles for the registration of architects in Australia.

Technical disclosures

About ecological footprint
The ecological footprint calculates humanity's demand on nature and communicates it tangibly in terms of hectares per person (or planets) – giving an understanding of how much we have, how much we use, and who uses what.

Today humanity uses the equivalent of 1.5 planets to provide the resources we use and absorb our waste. This means it now takes the Earth one year and six months to regenerate what we use in a year. Moderate United Nations (UN) scenarios suggest that if current population and consumption trends continue, by the 2030s, we will need the equivalent of two Earths to support us each year against a fixed supply of one.

The ecological footprint is an objective methodology used to quantify and report impacts of economies, businesses, buildings and their individual products. It is based on International Footprint and Life Cycle Assessment Standards, and provides quantitative estimates of life cycle impact associated with land use, materials, transportation, energy and water use.

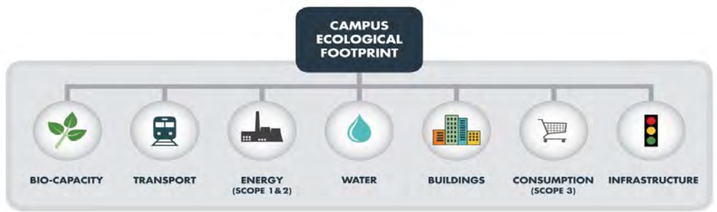
Ecological footprint results are reported in terms of global hectares or global metres square per square metre of functional area. These units represent the physical area of productive land theoretically required to support the capital formation and operational needs of a population, product, organisation or service. When expressed in terms of planet equivalents, it means that if all buildings, activity or fitouts were built and operated in the manner proposed, then it would equate to approximately the number of Earths of productive area as indicated in the report.

Standards
Assessments executed within this calculator are consistent with the requirements of the following standards;

- Ecological Footprint Standards, 2009.
- International Standards Organization ISO 14040-49 (current editions) Life Cycle Assessment.
- Greenhouse Gas Protocol – Product Life Cycle Accounting and Reporting Standard.
- Publicly Available Standard PAS 2050:2008.

Scope and coverage
The goal of the assessment is to estimate the anticipated ecological footprint associated with a project's capital formation, fitout and operation requirements from cradle to site with consideration of life cycle requirements.

The scope of property related assessments includes land bio-capacity, base building built-form, tenant fitout as well as operating consumption requirements including energy, water, transport, general consumables and, if desired, operational capital requirements or replacements over time. The figure below provides a summary of the impact aspects considered and also a sense of their overall importance to the total Ecological Footprint of a built asset.



Functional units
Ecological and carbon footprint estimates of the project are required by Tzannes to communicate in a meaningful manner the ecological and carbon footprints have been expressed in absolute and relative functional values. The table below describes the functional units selected and used.

Functional Units

Footprint Measure	Functional Unit Description	Comment
Carbon Footprint	Absolute tonnes of CO_2-e	TCO_2-e absolute
Carbon Footprint	Tonnes of CO_2-e per annum	TCO_2-e/annum
Ecological Footprint	Absolute global hectares per annum	gHa/annum
Ecological Footprint	Global sqm per sqm per annum	gm^2/m^2/annum

Data quality, sources and method

Initial cost and material quantity plans were used to construct a preliminary model in the Footprint Calculator. Where available, detailed material quantities or built-up rates for building elements were put into the calculator. Items not accounted for with this methodology were entered as a dollar term under an appropriate product category.

The table below provides a summary of the information used to prepare this assessment, its source and a statement of quality and accuracy.

Data Sources and Quality

Data	Source	Quality	Accuracy/ Per cent Complete
Drawings	Tzannes concept	Concept and as-built	90 per cent
Schedule of quantities and costs	Bylett and Associates, dated 30 October 2014	Concept level estimate at elemental level	85 per cent
Embodied carbon and ecological footprint rates	Footprint Company datasets – HIO and HLCA with various data sources	Good – Excellent	90-95 per cent
Economic carbon co-efficient	Balancing Act,Vol 1-4, 2005	Good – Excellent	90-95 per cent
Operating energy	Steensen Varming, 900MWh/a	Good – Excellent	
Operating water	NABERS Water Star Rating, 5 star assumption		
Transport	NSW Transport: Household Travel Survey Report: Sydney 2012/13	Good – Excellent	

Practice profile
The Footprint Company was created to make low-carbon design easier, faster and more accessible. TFC joined TSA Riley in 2022, and has played a key role in helping clients achieve measurable carbon reductions through industry-leading tools like The GreenBook™ and The Footprint Calculator™. Now, fully integrated into the TSA Riley brand, it continues delivering the same trusted expertise, services and tools – strengthened by our broader ESG capabilities and resources.

Key people
Dr Caroline Noller

08

Sustainability

Steensen Varming

Good design and sustainability

'If a building becomes architecture, then it is art. Clearly if a building is not functionally and technically in order, then it isn't architecture either, it's just a building.'
Arne Jacobsen

Our approach from the initial formation of architectural concepts was to integrate sustainable initiatives which supported both the function of the building as a place for the display and storage of art and the architectural vision for the building.

Our global sustainability team comes from a diverse variety of backgrounds and disciplines including architects and engineers. This allows us to cover and respond to the broad range of sustainability elements developed and designed for the project. These range from the thermal performance of the building fabric through to to waste management, materials, indoor air quality, plant efficiency and use of renewable energy.

While the terms 'ESD', 'sustainability', 'green design' and the like are commonly used today, they only emerged in Australia after the 2000 Sydney Olympic Games. Triggered by the development of new buildings and infrastructure to support the Games, this presented the opportunity to do things better. It could be argued that this was a contributing catalyst and the start for change in the building industry in Australia to look at design differently, in ways that result in outcomes which are better for people and the environment.

For us as a practice though, our long-term philosophy is that ESD or sustainability is not a tick-box approach with green ideas grafted onto a building, but is, rather, just the result of good design, considered thought and collaboration between like-minded people. Good design practices existed well before these new terms emerged and didn't require a separate ESD/sustainability discipline and consultant within the design team to achieve. An example of this is our design with Jørn Utzon for the Sydney Opera House, in which the Sydney Harbour was used as a thermal heat sink to efficiently heat and cool the Opera House, eliminating the need for cooling towers and the large amounts of fresh water that they ingest to reject heat from the building.

The sustainable issues for Dangrove

The approach to sustainable design for Dangrove was based on a wholistic view and an understanding of the key issues affecting the performance of the facility. Understanding both external (i.e. climate) and internal factors (functional needs) was essential to delivering a sustainable design outcome. Another vital step in design was to establish the key sustainability issues for the project, giving the design team direction and focus on issues that should be addressed.

The key sustainability issues we established for the building included:

- Energy conservation.
- Indoor environmental quality.
- Occupant amenity/human environment.
- Efficient water usage.
- Disposal of waste.
- Environmentally preferable materials selection.

We were fortunate enough to be involved at the project inception so all ideas developed with Tzannes and the design team could be assessed and adopted early in the design process. This meant we did not miss any opportunity to capture initiatives that would benefit the project.

Having the design team embrace sustainable design principles early on in the process was key to achieving an integrated approach, and ensured the combination of passive and low-energy active design strategies in a systematic and optimised manner. The systems were seen as complementary to, and integrated with, the architecture rather than competing with the architecture.

As with any building, human and life safety is a given, of course; however, the primary function of the building is to provide an environment suitable for the preservation and conservation of the art collection. From a hierarchical perspective, energy conservation then follows. It was this approach that led to the sustainable strategies that have been embedded within the design and the finished building.

Apart from the broader issues of sustainability, our time was primarily spent on optimising the building skin and internal construction to provide a thermally responsive building conducive to the needs of providing stable close control environments. The preservation of the art collection requires not only the provision of stable temperature and humidity set points, but also a minimal rate of change of these over time, against ever-changing external conditions the building will experience both in a 24-hour period and through each season from the height of summer through to cold winter days.

Interestingly, it is not so much the temperature and humidity set point in which art is stored, but the rate of change of these that the art experiences over time which is most damaging from a conservation perspective. The continual cycling of temperature and humidity leads to the structural degradation of various components of the artwork. Change in temperature, as we know, causes expansion and contraction of materials, and change in moisture content (humidity) causes materials such as timber and bark to swell and shrink.

It is, over time, the stress of continual expansion and contraction, and the associated damage caused, which is the greatest concern for conservators. Air quality and gaseous contaminants such as SOx, NOx (sulphur oxides and nitrogen oxides) and ozone also need to be considered.

While sustainability is an important attribute, the proposed sustainable design strategies were established by giving due consideration to collection conservation and other key operational requirements as well as supporting the architectural vision, thus ensuring the functional needs were not compromised.

Energy costs can contribute up to 30–50 per cent of overall operating costs for art gallery and storage facilities due to the 24/7 controlled environmental conditions which are required for the preservation of artefacts. In addition, there is a potential risk of increasing operating costs as utility costs continue to rise.

Time spent in developing and optimising passive responses of the building – including location of vapour barriers, applying appropriate levels of insulation and use of thermal mass in the building form – provides a firm foundation in which to provide stable environments with reduced reliance on energy needed for mechanical air conditioning systems to maintain.

This was a key element in ensuring the building remains operationally efficient without compromising the conservation needs of the collection.

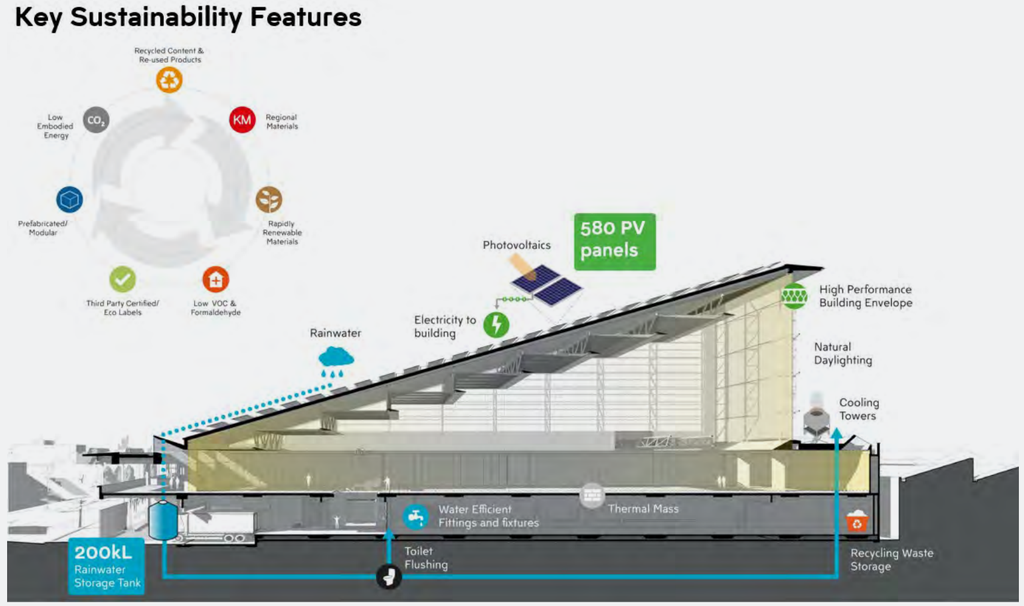
To achieve this, extensive assessment and computational analysis was undertaken during the design phase to test options and optimise the thermal performance of the building.

While this was very much a linear design process and involved simple assessments, such as testing the effects of various insulation R-values, extent and thickness of thermal mass (floors, walls and ceilings) and the like, there were some unique elements of the building which required more attention.

The main sustainability strategies

The key sustainable strategies adopted for the building included a double skin translucent polycarbonate facade with low thermal conductivity, thermal mass to the storage and Great Hall, extensive solar array, efficient space conditioning strategy for the Great Hall achieved through use of side blow jet diffusers to maintain conditions in the occupied level, prefinished materials to reduce maintenance and waste, and appropriate thermal zoning, ultrasonic humidification compared to traditional steam and consideration of reuse of the existing warehouse structure.

Our approach to achieving a low energy outcome was through adopting the energy hierarchy approach, whereby the reduction of energy use is the first priority, followed by meeting the remaining energy demand by the most efficient means applicable, before the inclusion of on-site generation and importing of green power.



Cross sectional diagram of initiatives.

The figure on page 123 shows a cross sectional diagram of the facility and the overarching passive design response.

The following provides an overview of key sustainability strategies employed.

- **Building massing and orientation:** The building features a large wedge-shaped roof with a slope pitching down towards the north. This approach assists with reducing direct solar heat gains from high intensity mid-season and summer sun. In addition, the slope maximises the optimum north-facing orientation for the roof-mounted solar photovoltaic array (which also provides further shading to the roof surface). Reducing solar heat gains is vital for minimising the energy associated with cooling.

  Spaces with similar environmental conditions were also grouped together, ensuring that tightly controlled areas are in the centre of the building where the conditions are more stable. Those requiring less stable conditions are located on the building's envelope. Spaces with less stable conditions include any non-conditioned back-of-house areas or transient spaces where strict environmental control is not needed, and hence acceptable for greater fluctuation of internal conditions.

- **Ventilated double skin translucent polycarbonate facade:** The facade system was designed to play several key roles in delivering a low energy solution. The system was arranged with UV control and translucent white polycarbonate sheeting to the exterior, 2-metre-wide internal void and translucent white polycarbonate for the interior skin.

  The ventilated cavity was used for the removal of heat from solar heat gains, thus minimising the conducted heat transfer through the internal skin and the Great Hall. Natural ventilation studies were also undertaken at the time to assess options to purge the captured heat from within the facade.

  The polycarbonate facade has low thermal conductivity W/m².K (U-value) of 0.74 and 0.76 (approximate R-value of 1.3 K.m²/W for each layer). The low thermal conductivity is attributed to the insulating properties of polycarbonate air gaps between the extruded structural reinforcement grids.

  Furthermore, the double skin polycarbonate facade provided low solar heat gains (approximately 0.2 SHGC), while diffusing natural daylight to the Great Hall.

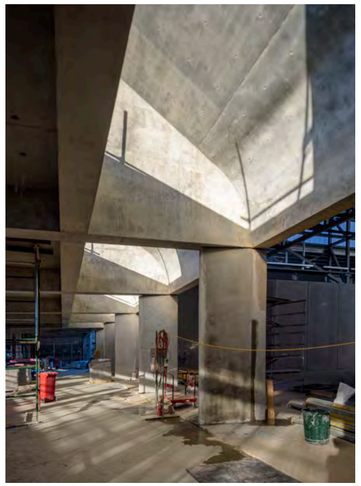
- **Daylighting and glare:** While the use of translucent panels provided many benefits, it also meant the potential for instances of glare as the facade could act as a luminous surface in the mornings and afternoon when the sun was in direct exposure to the eastern and western facades. Extensive glare and daylighting studies were undertaken during the design stages to evaluate which combination of translucent panels would offer the best result with regards to balancing daylight contribution and providing a level of glare control. This is important from both a collection conservation perspective as well as from a human experience perspective, for both staff working in the space and guests experiencing functions within it.

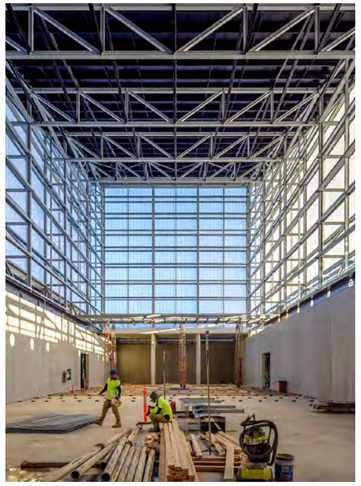
  Glare occurs when there is a large contrast in luminance (brightness) within the field of view. Glare studies were used to identify the level of contrast between facade options, and hence the more favourable solution. Daylighting studies were undertaken in parallel with the glare study to identify the facade solution offering meaningful natural daylight contribution.

- **Thermal mass:** The preservation of artwork relies heavily on maintaining constant temperature and humidity to close tolerances and avoiding high rates of change. To further support preservation by passive means, thermal mass – through exposed concrete floors, walls and ceilings – was introduced into the gallery and storage spaces. The thermal lag and hygroscopic properties of concrete walls provide heat and moisture absorption which assist with regulating temperature and relative humidity stability.

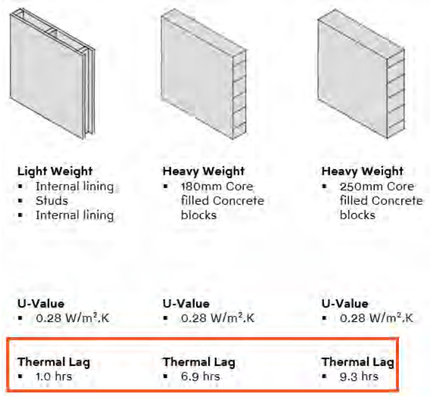
  Thermal mass is also a key design attribute in the event of plant failure. The thermal mass in the structure reduces the rate of change of temperature and humidity when compared to lighter weight structures, due to the storage capacity of the mass. This not only assists in the case of the plant failing, but also aids in reducing peak loads and HVAC energy for space conditioning, ventilation and humidification/dehumidification.

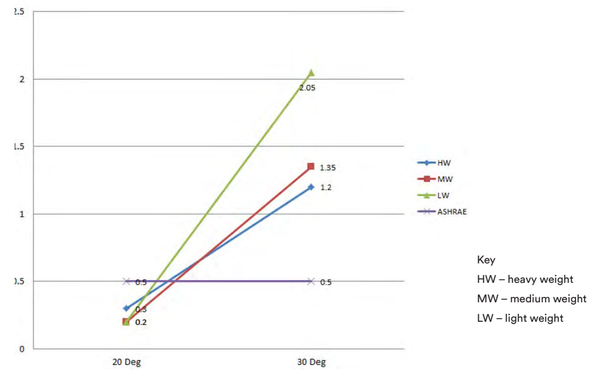
  To quantify the benefit of employing thermal mass in the building construction, detailed studies were undertaken to evaluate the performance of low, medium and heavy weight structure against Sydney's climate. From our analysis, it was established that the use of thermally heavy construction was best suited in providing the necessary thermal capacity to the structure in dampening the diurnal temperature fluctuations.





Top: Natural daylighting, without glare, was an important element of the design. Above: The Great Hall under construction, showing the double skin translucent polycarbonate facade.





Graph highlights the various rates of change of internal temperatures for different weight structures. The flatter the line the lower the rate of change, which is the desired outcome. The heavy weight structure performs better than the other building fabric options assessed.

- **Ultrasonic humidification:** Ultrasonic humidification is a very efficient approach when compared to more traditional energy intensive means, such as steam, when introducing moisture (humidity) to the air-conditioned air. Ultrasonic humidification works by introducing moisture vapour/mist into the supply air stream prior to entering the gallery and storage spaces. Only a small amount of electrical energy is needed to vibrate water at a very high frequency to a point in which water molecules are forced to separate, creating a mist which humidifies the air. This system was first used in Australia when we replaced the old humidification system at the National Gallery of Australia, which generated a 40 per cent annual saving in gas consumption and was the largest system in the Southern Hemisphere at the time.

- **Solar photovoltaics:** The large roof area and orientation offered an ideal location for a solar photovoltaic array. Feasibility studies were undertaken to estimate the annual electrical power generation and contribution of the PV system. It was estimated at the time that a 194 kWp solar array could be installed and could generate approximately 798 MWh, equating to approximately 60 per cent of the total energy required for the HVAC systems.

Other key design strategies recommended and adopted included:

- Rainwater harvesting to provide cooling tower make-up water and for onsite stormwater detention (OSD). It is estimated that the captured rainwater would provide around 80 per cent of the domestic water use.
- Environmentally preferable materials with low levels of volatile organic compounds (VOCs) and formaldehyde emissions.
- Provision of recycling waste storage space to facilitate collection of recyclable waste during the operational phase of the facility.
- Implementing seasonal adjustments of HVAC set-points to ensure internal temperature set-points are aligned closer to the averaged external ambient conditions.
- Zoning of HVAC and lighting services to avoid energy wastage. Artefacts requiring tight tolerances can be grouped into dedicated areas, so that remaining areas of the building can be controlled to wider tolerances.
- Efficient systems with high full and part load efficiency heating and cooling plant, controls, variable speed drives.
- Power factor correction to minimise electricity demand.

- Enhanced commissioning of building services, along with quarterly fine tuning to ensure that the systems perform at their optimum capacity. An independent commissioning agent was appointed to provide specialist guidance to the design team and the contractors.
- Efficient lighting controls and installation of LEDs, T5 or equivalent energy efficient lighting.
- Ongoing monitoring to establish annual energy targets and monitor the building's annual energy performance.
- Testing of the building air tightness to achieve low infiltration (air permeability). This was one of the key recommendations made during the design stage. Air infiltration has the highest impact on overall building energy consumption, which is critical for Dangrove as it is continuously air-conditioned. This process would involve pressure testing to assist in identifying leaks within the building envelope that will have a direct impact on the building's energy consumption and occupant comfort. These tests find and identify leaks that, when repaired, provide a higher level of energy efficiency and comfort.

Reflections on the key challenges
In balancing the needs of the building against the sustainability aspirations, the main challenges faced on the project included the following:

- Designing for a low energy use building that achieves stable temperature and particularly humidity for the preservation of artefacts.
- Providing optimal comfort and indoor air quality for staff and guests.
- Assessing performance of the polycarbonate facade in terms of daylight and glare and air tightness.
- Achieving a balance between the competing priorities influencing the building envelope design such as daylighting, glare control, thermal insulation, building air tightness and high thermal mass.

A key challenge encountered during the design phase was the translucent polycarbonate sheeting proposed for the eastern, southern and western facades of the Great Hall. Such expanses of lightweight translucent material presented numerous risks to our designs and potentially the end performance of the building.

More conservative concepts would have supported greater areas of insulated opaque elements in the facades, however this would have compromised the vision of this beautifully illuminated vaulted space that we see today.

It is a story worth sharing as it highlights the knowledge, collaboration and trust embraced by the design team to solve without compromising the core objectives of the building.

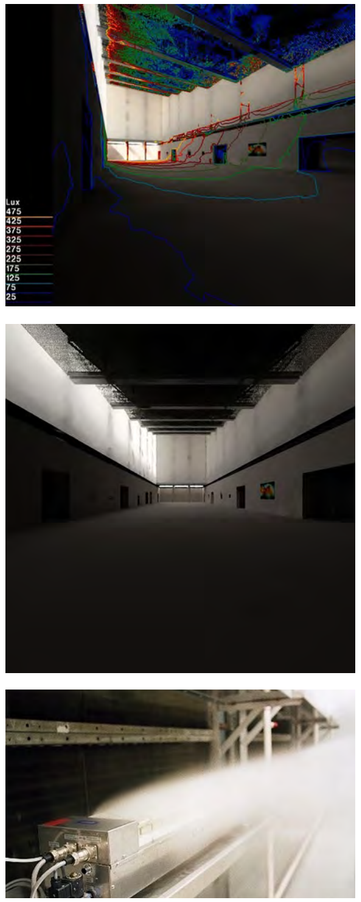
Tzannes lifted the roof with a calculated tilt angle to the north so as to optimise the mounting and alignment of the photovoltaic panels to achieve the greatest efficiency. An elegant solution, it provided a greater roof area to accommodate more panels. The panels could be installed parallel to the roof plane, removing the need for cumbersome and costly mounting supports typically seen as sawtooth arrays on flat-roofed buildings.

With the prominent roof plane tilted to the north, we now had large infill facades to close the gaps around the perimeter of the Great Hall. Tzannes had created vertical planes to glow and illuminate the volume of the Great Hall with diffuse daylight, and asked Steensen Varming to model the concept.

A great journey so far, but we now had the challenge of designing these facades to provide appropriate lighting levels, reduce the risk of glare and eliminate damaging UV exposure in the Great Hall, particularly when the rising and setting sun has direct exposure on the eastern and western facades. Heat gains and losses, radiant heat control and air tightness, rain protection and acoustics were other key issues which had to be assessed and managed. As the client intended this space to be used for the display of her collection sometimes, we also had to be cognisant of the environment needed for the protection of the artwork. It has a tighter tolerance than that for humans, which further compounded the challenge we had in finding the right outcome.

Our test as engineers was to think outside the box and solve these problems in an elegant and innovative way that respected and complemented the architecture and its vision.

Numerous options and design iterations were tested and modelled using a product called Arcowall, which is manufactured by an Italian company called dott.Gallina, or equivalent. Through consultation with Tzannes and the facade engineer, we were able to resolve the challenges through some innovative thinking and refinement of the initial architectural concept.



Top and centre: Examples of daylighting analysis results showing lux contours of daylight distribution for the sky conditions modelled. Above: Ultrasonic humidifier in operation. The water vapour is absorbed into the air stream thereby increasing the humidity to the desired set point.

The control of light and glare was tackled through modelling and testing various layers of the polycarbonate sheeting of differing properties before arriving at a suitable visible light transmittance (VLT) of the facade construction which provided the right lighting level and distribution within the space. However, compromises had to be made to achieve the right balance. A facade with a VLT that was too high would result in too much light entering the space, while a facade with a low VLT would result in the space being too dull and gloomy. When you consider the changing light levels and qualities of light experienced throughout a day, and a season overlayed with clear skies through to cloudy skies, you start to get the sense of the number of scenarios we had to consider, and the tough task it turned out to be.

To achieve the right balance, the compromise was that on bright sunny days we had to allow a higher level of brightness; if we were to reduce this light through having a lower facade VLT there was a risk of creating a dark and gloomy environment in the space during low ambient light conditions in winter or overcast periods.

A simple analogy to help explain this better is to think of sunglasses. We wear them in summer to reduce light and glare on bright days, but wouldn't wear them on overcast days. Our challenge was to have the right 'sunglasses' to provide the best balance between bright and overcast days.

From a thermal perspective, an Arcowall or similar product has multiple layers of cells creating air pockets which improved the insulation properties of the panel immensely.

This was further improved by creating a cavity formed through having two walls, one on each side of the structural support truss. This double skin facade not only improved the insulation quality of the overall facade construction but allowed any collected heat to be purged from the cavity through introduction of low level and high level vents.

An alternative product, Rodeca, was eventually used for a number of reasons – the jointing detail allowed for easier installation and removal; the client preferred the colour; and Rodeca improved the warranty to meet that of Arcowall.

The end result is a solution that maintains the architectural integrity of the space without too much compromise of the internal environment.

A review of the completed building and its systems has been undertaken to ensure strategies work as intended and offer the environmental outcomes envisaged for the project.

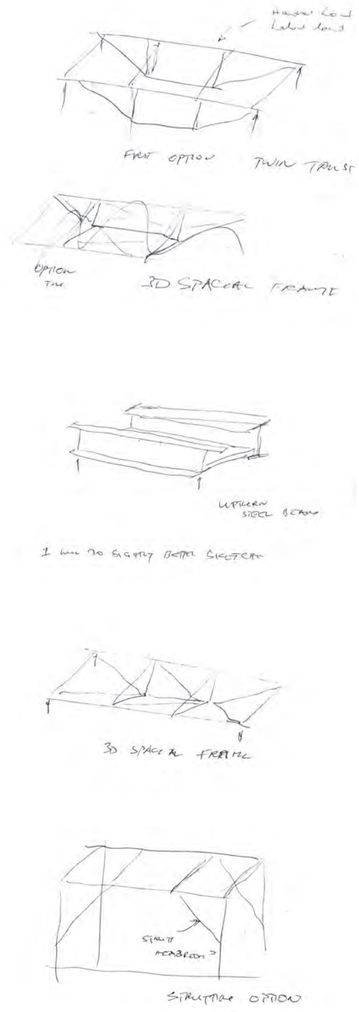
Practice profile
Steensen Varming, founded in Denmark in 1933, are practitioners in mechanical and electrical engineering, lighting and sustainable designs that enhance spatial design. The practice provides unrivalled expertise in cultural projects, in particular museums and galleries, and has long-term relationships with many institutions internationally. It provides advice to the Museums & Galleries of NSW in the preparation of their published guidance documentation, and is a member of the Museums Association, which represents the people and institutions consulting some of the most significant international museums and galleries. Steensen Varming has studios in Copenhagen, London, Sydney, Canberra, Hong Kong and New York.

Key people
Chris Arkins
Garry Luu
Diksha Vijapur

09

Structural Engineering

Taylor Thomson Whitting



Concept sketches by Richard Green, structural engineer.

On most projects, the structural engineer works closely with the architect, and especially so on a project such as Dangrove, where the structure is expressed as a major part of the architecture.

Taylor Thomson Whitting has worked with Tzannes since early 1980, and this project was able to build on the past relationship between the two firms. TTW has a reputation for working with architects, and together they have produced high quality architectural designs. Many of these projects have been recognised with engineering and architectural awards.

The properties of the site

Starting a new project, a structural engineer has to establish the properties of the site – generally, with a geotechnical study and through considering such elements as boundary conditions, existing buildings and wind conditions. The geotechnical study for the site revealed that rock existed at 8 metres below ground, overlaid by fill and marine sediments, which is fairly common in this part of Sydney. It also showed that there was no contamination in the fill. However, an acid sulphate study found that there was acid sulphate soil below the water table, which varies between 600 mm and 1700 mm, and a flood study indicated there was a high water table, which varied across the site.

A steel-framed shed with brick perimeter walls was on the site. We investigated whether part of the building could be reused but came to the conclusion it could not, due to the brief's spatial and technical requirements.

During the design process of the new building, minimal calculations were used to produce basic concepts. Rough sketches were made to give an indication of structural details, such as slab thicknesses and to work out a column grid. It was important to give as close an approximation of these elements as possible early; if truss or beam depths are underestimated, this may tend to push floor-to-floor heights up – and the height of a building is an issue for councils.

The exposed structure

The approach to the building was that it should be a sophisticated warehouse, simply but elegantly detailed. The structure was designed to have minimal column transfers; in the final design, there was only one. The member sizes and the general geometry of the structure had to be designed to meet the architectural concept. As all parts of the structure are exposed, it had to meet the architectural aesthetic. The details had to be considered to give a clean, simple, uncluttered structure. The solution had to be economical, and this was another reason to keep the building simple. The building used conventional construction techniques and conventional member sizes.

For the final design, the engineering design team used a 3-D model of the concrete and steel elements to analyse the building for wind and earthquakes. Slabs and columns were designed using standard concrete packages.

As there was found to be acid sulphate soil on the site, the existing slab was left in place. The existing slab effectively provided a capping to the existing soils.

A raft floor slab without piles was considered, but this would have meant major treatment of the existing fill, and there would have been problems with excessive and uneven settlements.

Because of the high water table, concrete-injected continuous flight auger piles were used to provide foundations to rock. As the material from the piles was brought to the

surface, it was neutralised and spread over the site. That was also the case with the material taken from the lift pits and service pit.

The service pit was the only excavation to go below the water table – in this case, by 2 metres. The pit was shored, and a series of spear points were used as a cut-off wall to allow the pit concrete base and walls to be constructed in the dry.

The vertical elements consist of concrete columns on an 8.4 metre grid in one direction and a grid of varying dimensions between 8.2 metres and 9.7 metres in the other. A variable grid was designed for the administration area. Initially, there was to be an area that had a grid similar to the White Rabbit Gallery column grid, so that exhibition concepts could be set up as part of the curatorial process. This didn't go ahead, as it meant a transfer structure and the loss of future flexibility for the building.

The floor structure

At tender stage, the floor structure was a prestressed banded slab system. Initially, it was proposed to use fill as support of the level 1 floor slab between the bands.

Once the builder came on board, the level 1 and 2 floors were converted to the banded slab with ultra-floor prestressed spanning between the prestressed bands. This was done in order to reduce the propping to the formwork required for level 2 and the fill under level 1 – propping is a major cost for buildings' wall-length floor-to-floor heights.

In the area of the car park and truck dock, the slab is 'on ground' over the retained earlier slab with a regular grid of joints. There is minor cracking around the columns, due to the differential settlement between the slab on the ground and the slab supported on the pile caps.

There are no building joints in the main concrete floor structures, but the slabs were poured in small sections working from the south to the north.

The large areas of the second floor slab have a polished concrete topping slab. In the administration area, there is insulation between the main slab and topping slab as the soffit is exposed to the outside area. The 100-mm-thick topping slabs in the Great Hall were all bonded to the base slab. For the bonded slab, care was taken to prevent curling, and this was successful except for one small area.

Curling arises due to the differential shrinkage between the top and bottom surfaces of the topping slab.

There was some cracking in the topping slab where the ratio of the dimensions of the slab was too great.

Generally, the dimensions of a topping slab should be less than a ratio of 1 to 3. Generally, the ratio of the dimensions of the panels was less than 3.

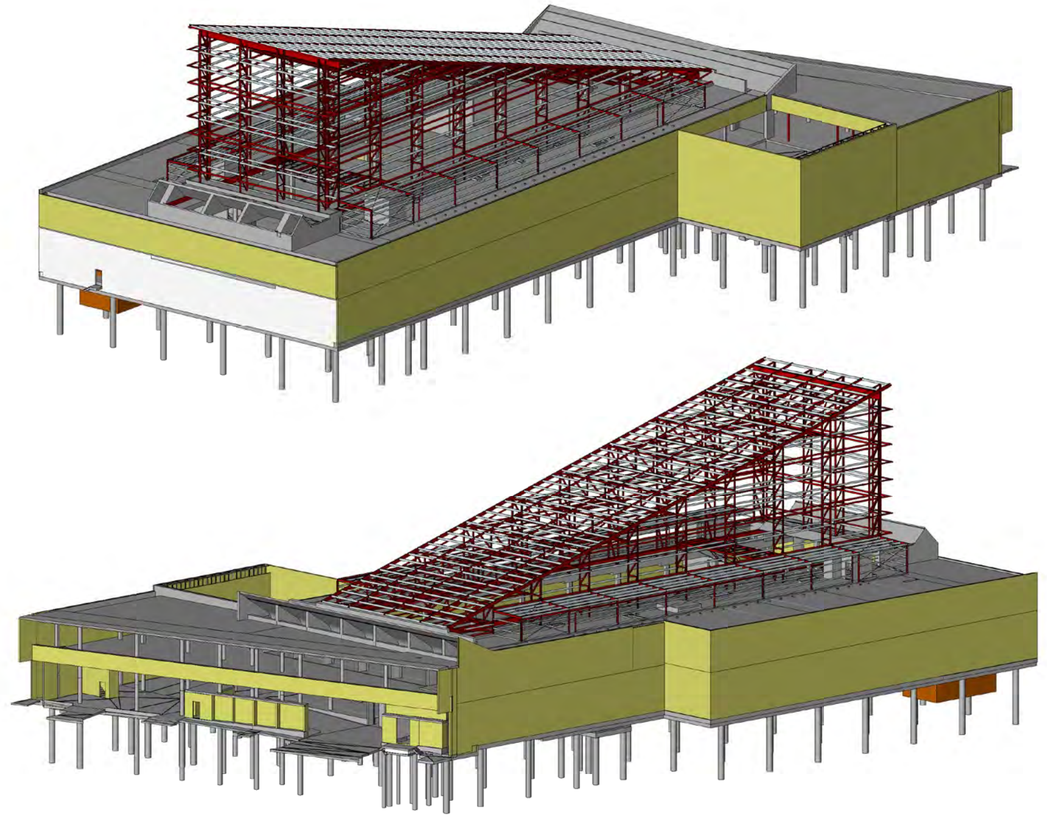
To try to prevent curling, the panels need to be small enough, the topping slab thick enough, and the concrete well cured. We did everything that was good practice to try to stop it. Curling is hard to avoid – we couldn't have done anything else, and are lucky we didn't get more curling.

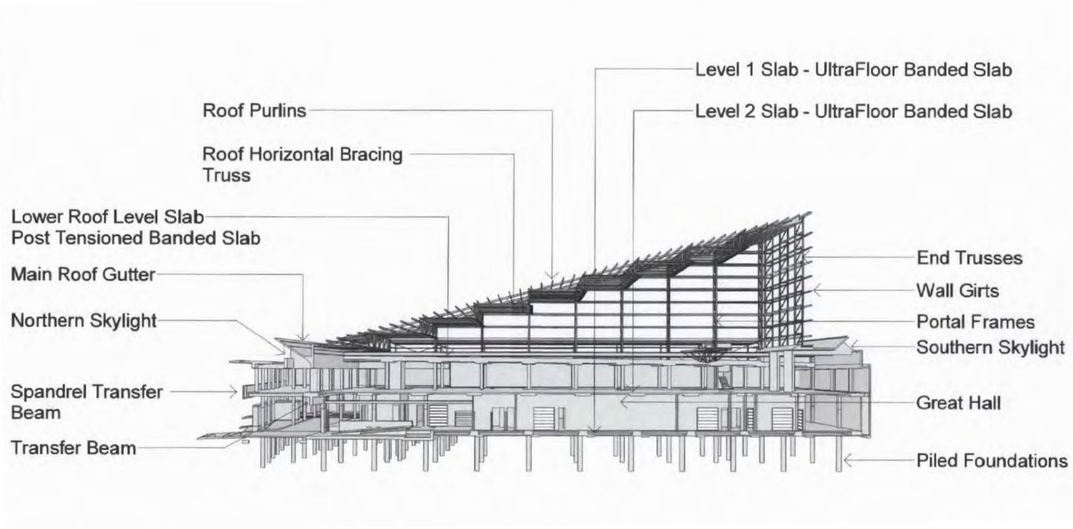
Floor loadings

Much thought went into the design of floor loadings to reduce the cost of the floors, columns and footings. The art storage area was designed for 12 kPa, while the Great Hall floor was designed for 6 kPa with an additional moveable load of 6 kPa that could be placed anywhere in a bay. We have designed many art galleries, and sometimes the brief has a very heavy floor loading – 20 kPa in the case of one gallery. Similar in principle to the design of Dangrove, instead of designing the whole floor for 20 kPa, we cut it back to 10 kPa, and had an area of load that moves around. What that means is that column and footing loads are less, and the floor slab could be designed for less. For Dangrove, we arrived at the figure of 12 kPa being a realistic floor loading in the storage areas, which is still reasonably high. It's the artwork, and the requirement to move the artworks about the floor, that determines the floor loading – to put it into perspective, a car park would have around a 2.5 kPa.

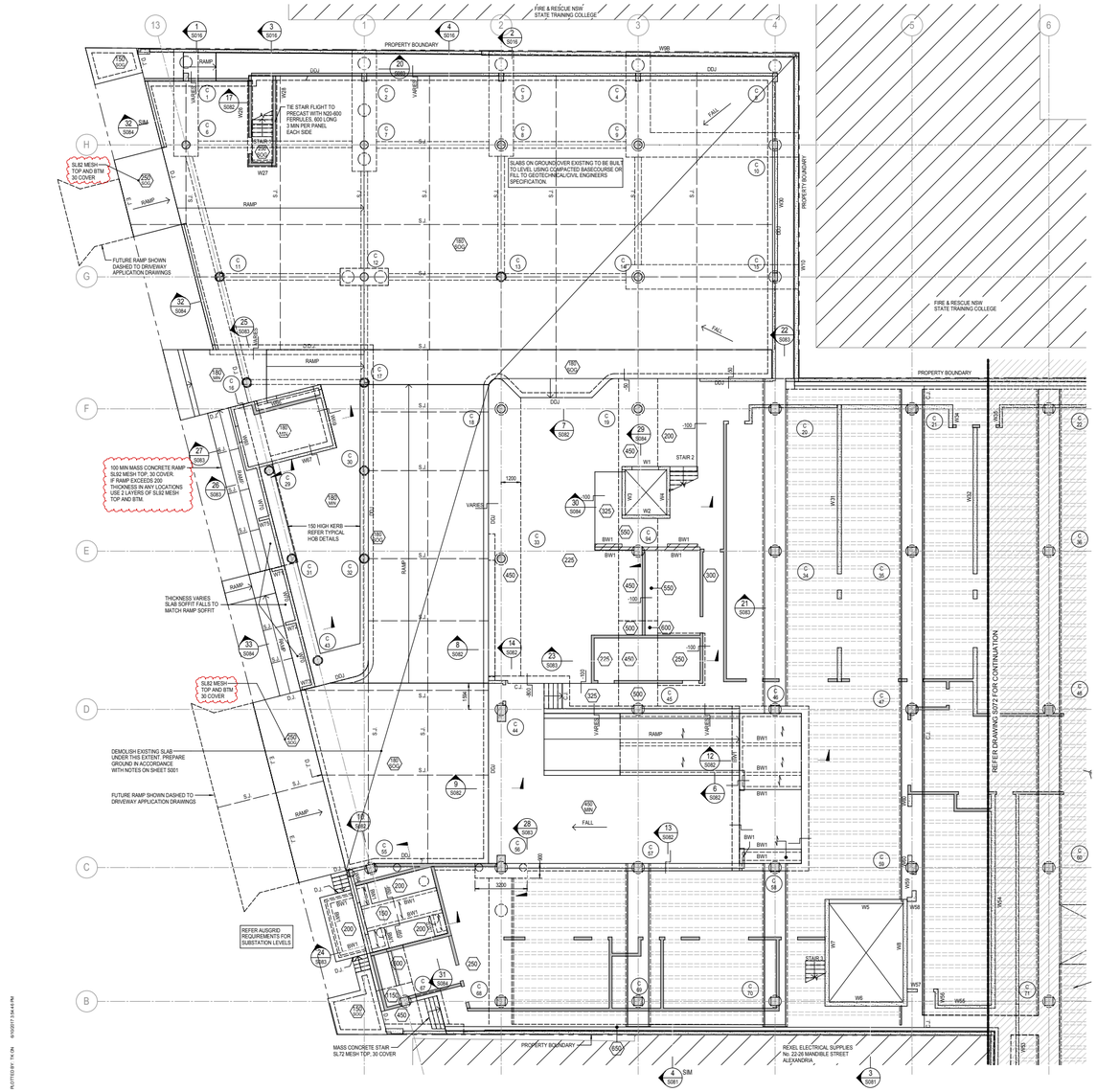
General rules were put in place for each store room in respect to loading. If the local loading is to be exceeded, the client must seek the engineer's advice.

An overall picture of the structure, with top showing the southern view and centre, the northern view. Green indicates concrete walls; grey is the concrete slab and red is structural steel. Below: A long section of the structure.

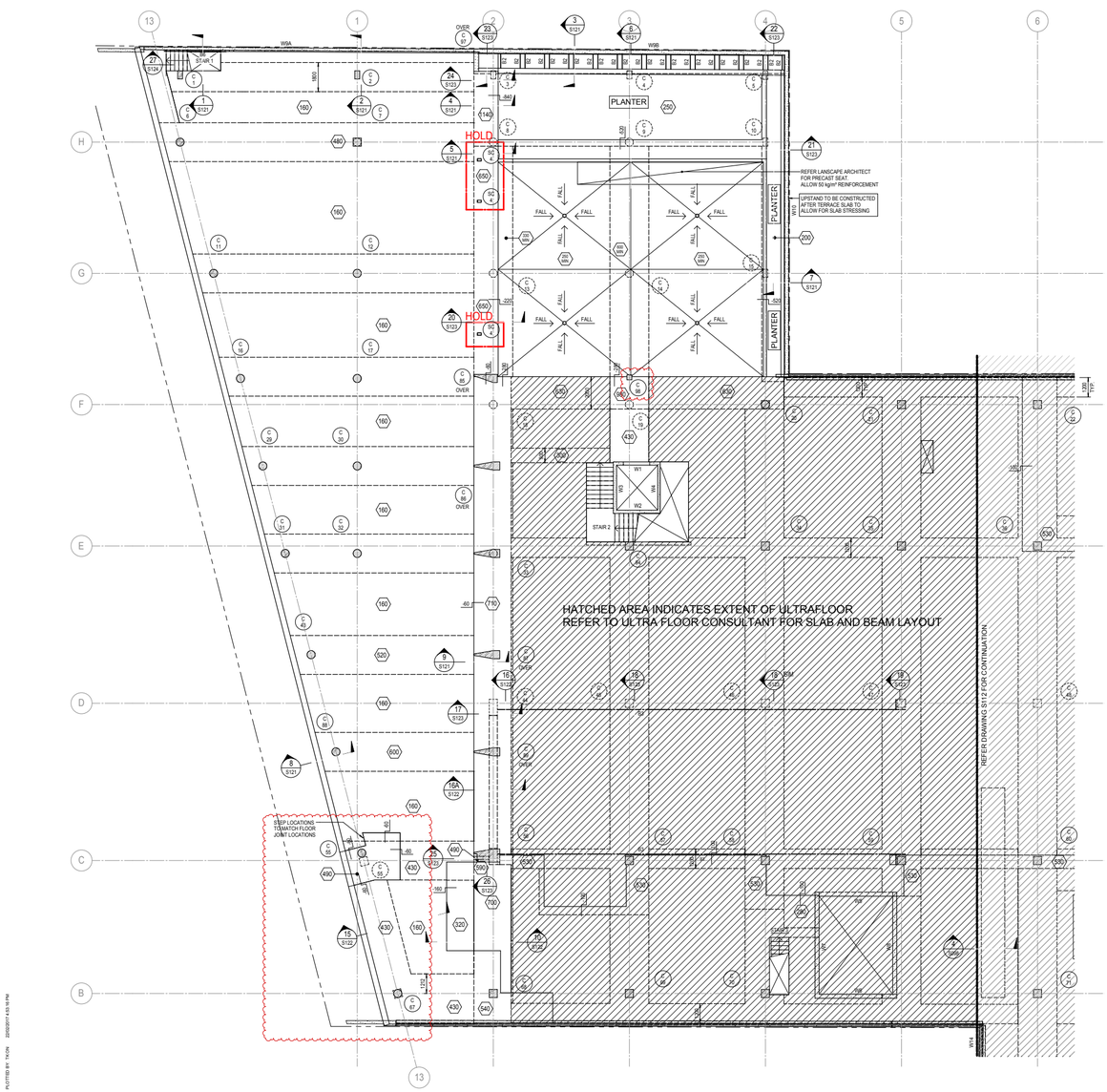




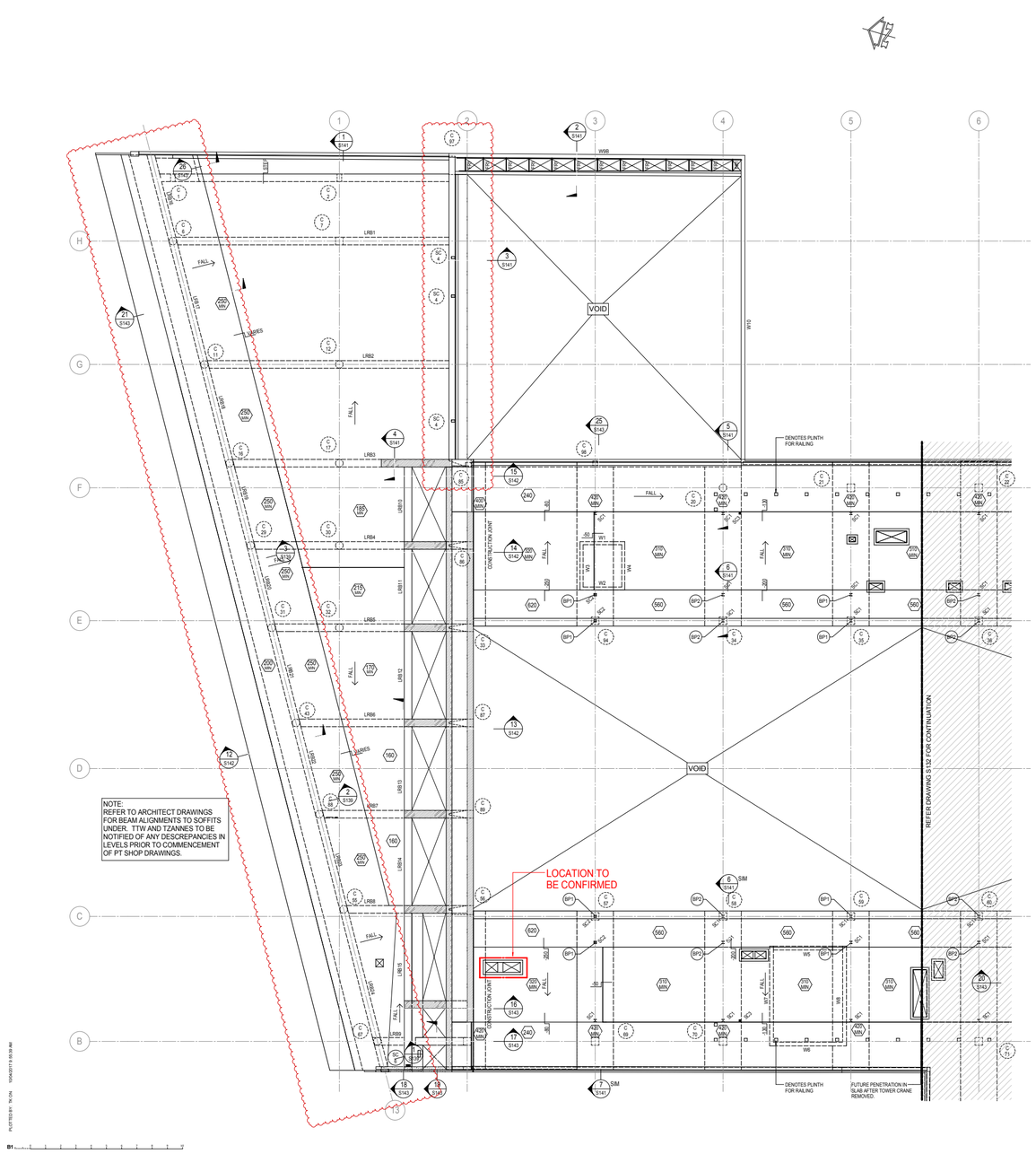
Ground floor (level 1) northern plan.

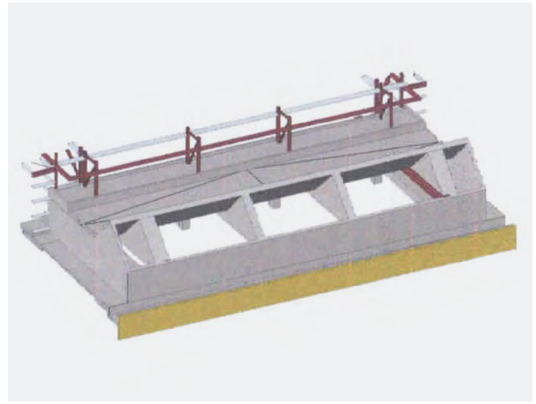


Level 2 northern plan.



Concrete slab outline on northern section of roof.





3-D view of southern skylight.

The wall system and skylights

Originally it was planned that non-load bearing walls would be of blockwork. However, the builder advised that precast panels were quicker to erect and cheaper – this was contrary to the original advice by the quantity surveyor who indicated that blockwork was more economical. Precast insulated panels were used for the perimeter walls above the first floor, and there are non-insulated panels in the service corridors. There are also non-structural precast panels on the Mandible Street facade, supported on the concrete beam with insulation between the structural beam and precast panel. All surfaces exposed to the outside temperature were insulated. Having concrete walls meant the building has thermal mass which helps limit variation in the temperature. Stair walls and lift walls are load-bearing panels. The stair and lift cores provide vertical support to the slabs and lateral support to the building.

The most challenging aspect of the concrete structure was around the skylights at either end of the Great Hall – this involved complex formwork, and there needed to be careful consideration of where the construction joints were placed to not be visible and the appearance needed to satisfy the architect.

The roof

The roof is in two parts – a lower concrete section and a major steel roof. For the concrete roof structure, a conventional prestressed banded slab rather than the ultra floor was used with increased prestressing to ensure the slab was waterproof. A double membrane was placed on the roof as additional security against water penetration.

The design of the concrete roof slab had to take into account the depth of the water raised around the plantrooms. The plantrooms were above the general roof level with minimal plinths.

Initially, at the Mandible Street facade, the lower level roof was supported by steel columns, but these were deleted for two reasons – bulk due to fire rating requirements and the desire to have a continuous horizontal window. The concrete columns were set back from the boundary and the roof cantilevers 3 metres.

Above the lower concrete roof, on which there are steel-framed plant rooms, is a sloping steel roof to the Great Hall, made up of a series of parallel truss portal frames, and soaring 30 metres above the second floor at the rear of the site. The portal frames were made of trusses, fabricated using universal beams. The insulated metal roof panel system is supported on purlins, which in turn were supported on beams spanning between the steel portal frames. The stress in the joints of the trusses was carefully analysed using SPACE GASS, a 3-D frame analysis computer program.

Climate control and maintenance are critical. The trusses are clad on both sides with Rodeca, a polycarbonate, to produce a cavity for ventilation, insulation and double waterproofing, ensuring each side can be replaced without exposing the interior to the weather. The double transparent glazed wall also allows the structure to be visible, and therefore an important component of the architecture. The set-out of the structure was critical as it was all visible, including the roof, ceiling and walls.

The roof sheeting required expansion joints because of the length. These have been regularly spaced to allow for expansion and contraction, with an overlap at the joint between the top sheet of the panel and the one below. As the structure is visible, the connections of the members of the truss were detailed to be clean and simple (see illustrations on page 138).

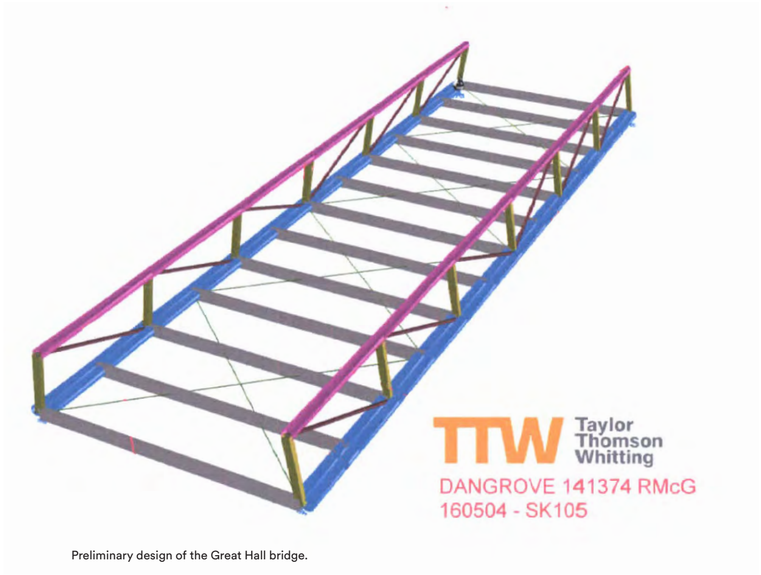
Evolution of the bridge

There is a bridge across the Great Hall. The idea at tender was to use two large upturned steel trusses. Initially, in order to reduce cost, the bridge was not included, and the only provision in the contract was for access to a future bridge. However, when the client saw the hall, she reinstated the bridge.

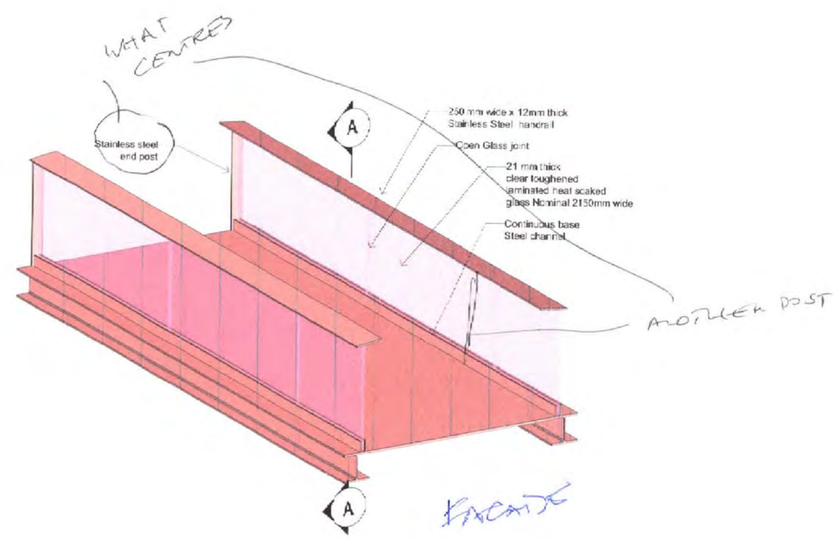
The architect felt the heavy truss solution was not acceptable visually and revised the design to a bridge with finer detail. The solution was to use high strength rods to precamber smaller beams upwards, effectively forming a cable trussed bridge. It's quite simple in principle, but some of the complexity comes through the detailing of the connections.

Moving artwork

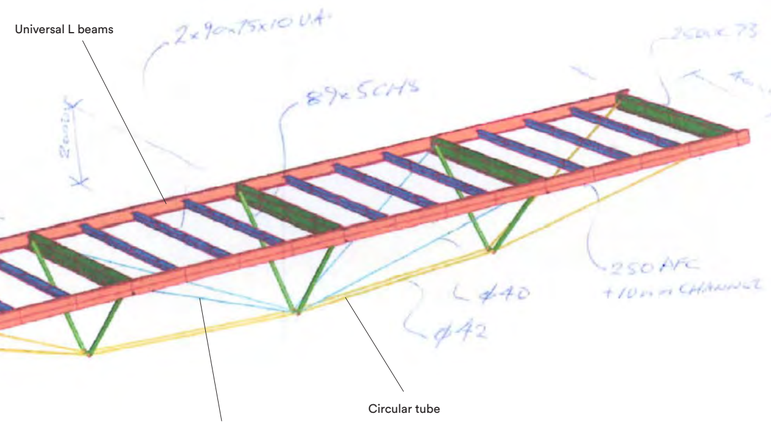
At one stage, there was talk of a gantry crane running the length of the building, but it was costly, did not service the storage areas, and was also impractical due to the height and position of the bridge. Instead, forklifts, cherry pickers and scissor lifts are used to move artworks around the floor, and a large goods lift between floors.



Preliminary design of the Great Hall bridge.



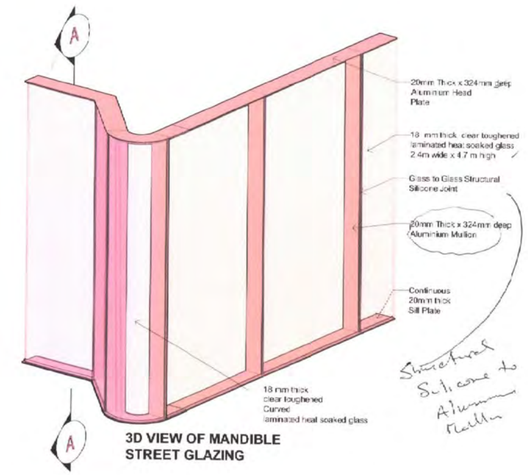
Bridge handrail detail.

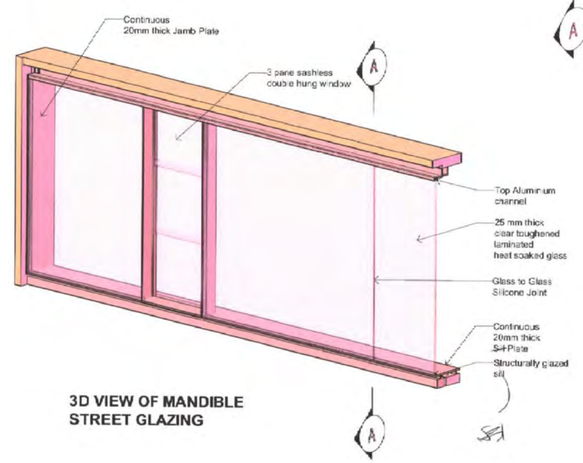


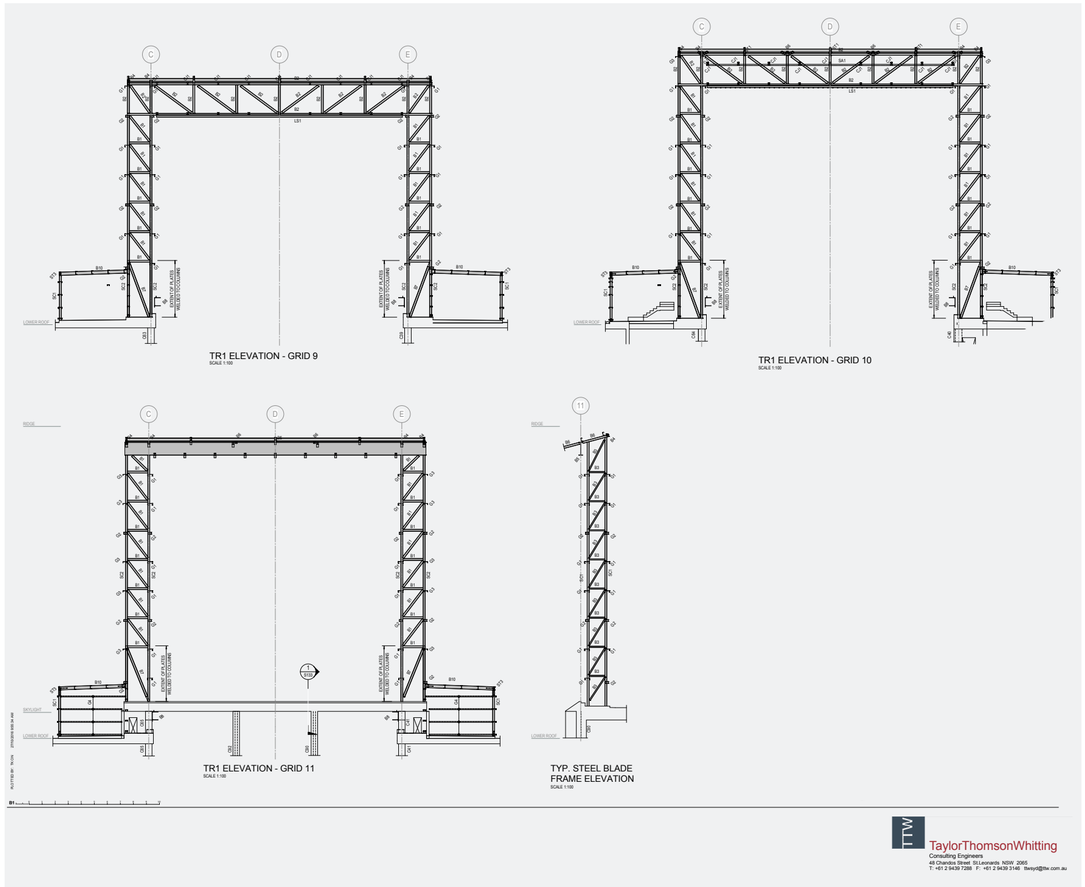
Final design of bridge.

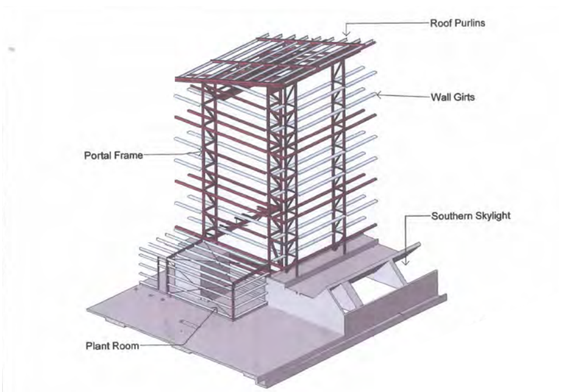


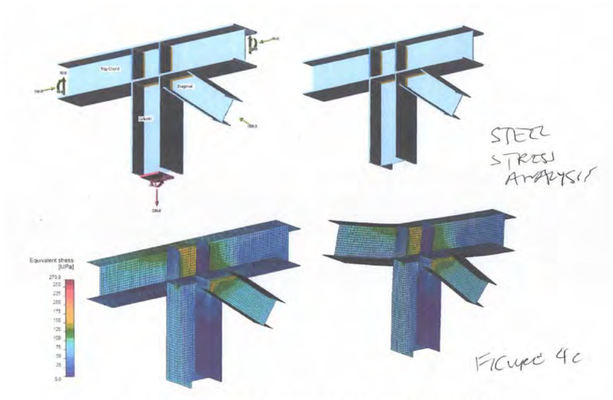
Bridge tensile elements node.











Clockwise from top: Typical upper floor sections; truss structural steel stress analysis; southern corner truss detail.

Final structure

The final structure of the building has achieved the architectural intent. It is both straightforward and flexible. Anyone using the facility can easily view the structure as an integral feature of the spaces and the architectural experience.

Contractor's facade consultant

TTW acted on behalf of the contractor as their facade consultant, based on the brief prepared by the client. In developing the final solution, they worked closely with the builder and the architect.

This scope covered the design of the glazing and the waterproofing details. Areas of glazing covered were the Mandible Street glazing, the courtyard glazing, the northern skylight sloped glazing, the southern skylight glazing, the glass balustrades to the bridge and the security glazing to the reception area.

The glazed elements on the Dangrove project are grand in size and elegant in their simplicity. The recent availability of large pieces of glass is fully utilised to minimise framing.

In collaboration with the architect and contractor, the TTW facade team completed the detailed design through the production of full-scale details and provided structural design certification. Much of the detailing incorporates 20-mm-thick aluminium plate. Aluminium was used as it is more resistant to corrosion and provides sharper corners.

The Great Hall clerestory glazing consists of translucent polycarbonate sheeting. Polycarbonate is not directly covered by the Building Code of Australia (BCA), so the TTW facade team produced a performance solution to demonstrate compliance with the BCA first-principles performance requirements. This involved benchmarking European test results against equivalent Australian Standards for strength, waterproofness and air leakage. The Rodeca system used was fully certified to German codes.

The Mandible Street glazed wall consists of 25-mm-thick laminated glass spanning 3.5 metres with butt sealed vertical joints. The head, sill and jamb supports consist of 20 mm solid aluminium plates with the head connection being designed to accommodate the relatively large concrete roof slab deflections. A three-pane sashless double-hung proprietary window system is incorporated into a deep reveal in the Mandible Street glazing.

The terrace courtyard glazing is similar in span and style to the Mandible Street glazing.

The security glazing forms the entrance to the building and provides a hint of the grand spaces inside. The original design was greatly simplified by adopting 4.7-metre-tall full-height glazing supported by 300-mm-deep, 20-mm-thick aluminium plates, structural silicone glazed to the glass, which also provides lateral restraint to the plates.

In all facades, the spider fitting was illuminated to give a simpler, less cluttered design.

The link bridge balustrades are structurally glazed, and also with a feature, flat plate handrail. The design challenge for these balustrades was to meet the aesthetic while being Deemed-to-Satisfy BCA compliant, all on a relatively high-movement bridge support structure. The feature handrail is fabricated in lengths to match the glazing and has slotted connections to allow bridge movements to occur without attracting significant loads that may otherwise buckle the handrail. The glazing is similarly sized and detailed to allow for bridge movements to occur.

Practice profile

Award-winning engineering consultancy Taylor Thomson Whitting (TTW) is a privately owned Australian company established more than 60 years ago. Equipped with world-class talent, proactive leadership and the latest technologies, TTW engineers innovative and long-lasting designs for unique projects across all sectors, and sees complex problems as opportunities to find the best solutions. TTW has a staff of 300, and undertakes $A5 billion-worth of projects annually.

Key people

STRUCTURAL
Richard Green: director
Mark Ellington: project structural engineer

FACADE
Neil McClelland: project facade engineer

10

Building Compliance

Philip Chun BC NSW Pty Ltd

Dangrove proves what can be achieved through intelligent design and considered and careful review, repeated until architectural clarity, engineering simplicity and Building Code of Australia (BCA) design compliance are all achieved.

The role of the private certifier

My role as a private certifier in this process is to assess compliance, and I can give advice about what does not comply. There is a clear distinction between the roles of the private certifier and the design team. The designers can be creative, propose alternative construction and innovate. I must remain detached, and consider the public interest in decision making, while respecting the law and the proponent's right to carry out a development. The challenge is to keep an open mind, with one eye on the proposal and the other firmly fixed on the prescriptive and performance provisions of the BCA.

What a private certifier does is a mystery to many people including those in the construction industry; it is so misunderstood that some of us joke that at parties, in a bid to be socially included, we prefer to say we are a lawyer or even a tax collector than admit to our true profession. We are usually neither engineers nor architects by training but, rather, generalists charged with ensuring the design complies with the building code (with some reliance upon certification of design by engineers and others) and is eventually 'fit to occupy'. We carry out inspections during construction, and are onsite for around 1 per cent of the construction time. We are not there, as many people assume, as quality controllers; that was more the role of the clerk of works or site superintendent, a position that virtually no longer exists in our system.

It is a logical progression that a poorly documented building will produce a poor quality building. By the same token, most will agree that truly great design does not occur by accident. Great design is achieved through determined interrogation of the ambitions of the brief, and intelligent and creative, crafted response.

The design is a live, evolving entity; like crafted steel heated and cooled many times, the design revisits the brief, codes and standards until (figuratively) the bolt holes, rivets and struts that are needed for compliance with codes and standards no longer inhibit the ambition of the brief.

I'm sure there is much more going on for many of the designers, but from our (possibly simple) vantage point, early and repeated communication seems to be a key part of meeting the public expectation for a safe building, while also achieving spectacular results.

To understand more clearly the role of the private certifier in the design process, it is worth looking at how the industry started as well as looking at it in a more local context.

Early instances of building compliance

It seems that tolerance for construction failures of public buildings was as low in ancient China as it is today. History recognises Li Jie, a Chinese architect, who consolidated and revised much older treatises on architecture and building methods into *Yingzao Fashi* ('Treatise on Architectural Methods' or 'State Building Standards'). Emperor Huizong of Song published the book in 1103, and recognised Li Jie by appointing him director of palace buildings.

Yingzao Fashi provided a single set of architectural and building standards for architects, builders and literate craftsmen to use, and was adopted by engineering agencies of government. The materials commonly used were rammed earth, brick and stone, cast iron and timber. Buddhist pagodas from the Southern Song dynasty survive today, including

the 60-metre-high Liuhe Pagoda, or Six Harmonies Pagoda, in Hangzhou, which was completed in 1165 AD. It was possible to be an innovator and an agent for positive change in ancient China.

The associated reduction in occupant deaths as a result of building collapse must have been welcomed by builders in an age where retribution was likely swift and potentially final. Similarly, the Hammurabi tablet law in ancient Mesopotamia (now Iraq) stated the builder should be executed if a building collapse caused death.

I wonder if the ancient Chinese department of public building works also had a clerk of works role. Someone who worked with the design and construction team and was onsite for at least a few days a week to ensure those rammed earth walls were being tamped down enough times or the quality of the timber used was termite free before installation.

The Australian situation in context

During the mid-1990s, Australia adopted a performance-based national building code, the Building Code of Australia. Our national government believed that great efficiencies could be realised by allowing innovation and inventiveness, driven by technology, to boost economic growth. Instead of only providing one prescribed method of compliance with the BCA, the performance-based code identifies the performance required, allowing freedom for designers to utilise innovative methods of achieving compliance that are alternative to the prescribed methods in part or whole.

Evaluation and acceptance of performance-based building solutions is often not a simple matter. The assessment process is normally carried out in stages of increasing complexity, allowing appropriate input from stakeholders and other specialists in an area of design, such as engineering. It is not unusual for a complex performance solution to be peer reviewed prior to acceptance. The performance solution report is the final outcome report lodged with the authority for acceptance and approval (or refusal). Justification for acceptance will often include the use of scientific calculations, tests, written argument, comparative analysis (against the deemed to comply code) and expert opinion. While performance design solutions result in permitting more innovative design, it is also true that there are accepted normalities that are influenced by government and fire authorities and professional practice limitations.

When it comes to implementing a performance-based building code, most countries have not provided one. Most, including the United States, allow the use of an innovative design or material only with the consent of a committee or city official, such as a fire chief or city building official. The Australian experience of this type of regime was that it stifled innovation, making new products infinitely harder for the proponents to promote and gain wide acceptance. In Sweden, the building surveyor's role is split, with a fire safety engineer having responsibility for the fire-related components of the building.

Prior to the Australian uniform national building code, great inconsistencies existed between the building regulations or codes from one city or municipality to another. In many cases these inconsistencies formed barriers to innovation, advancement of technology and creative expression.

On top of this, proponents of new design or construction methods had to deal with inconsistency of approach between the various relevant building code officials, as well as differing levels of expertise and understanding of risk, creating a highly inconsistent bar for new innovations to be accepted

As a new material or construction method was developed, often at incredible personal cost to the innovator, a barrier would be thrown up to prevent its use. The new product had to fight an endless battle – from city to city – to gain acceptance nationally.

Our system has not been without problems. There is a constant struggle between those who see nothing but chaos and failure, and want the alternative methods removed or more heavily codified, and those who wish to continue to ensure greater energy and creativity is breathed into our buildings.

The BCA recognises government-sanctioned product assessment schemes. If a product has passed the relevant assessment, no local jurisdiction can refuse its use on building code grounds without providing very good reasons for incompatibility. As a result, instances of pure bureaucratic obstruction have significantly diminished.

Building codes are informed by disaster. They hum along for a decade or so with minor changes and occasional important upgrades, such as energy efficiency. Ultimately it is the disasters that bring about rapid change, often leaving carnage in their wake.

Philosophically, we live in a permanent state of false security. From a building code perspective, earthquake data is of any value for about 100 years. Wind speed data is available for a little longer. We rely on extrapolation and statistical models to extend that knowledge into a much longer timescale that is essentially a form of scientific estimation. In Australia, this has worked so far, apart from Cyclone Tracy (Darwin, NT) in 1974 and the Newcastle, NSW, earthquake in 1989, which we were totally unprepared for, in both predictive terms and with regard to building regulations and standards. Otherwise, statistical models have worked well so far – with some luck – with revision to the standards when an earthquake or storm exceeds expectations. And this is before the input of climate change parameters, where predicted impacts are so broad that regulation of impact will at best be an educated guess.

Our homes are largely made of materials that readily burn and we fill the spaces with soft floor coverings and furniture, yet we are surprised when fire takes the life of a member of our community. The BCA addresses this by requiring that changes to the code be balanced against the economic impact. If no loss of life were acceptable, the BCA would require us to live in sterile concrete or masonry bunkers with no furnishings or floor coverings, which we would find unacceptable as citizens. However, the community cost of regulation will at some point become so high that the level of risk we are prepared to accept may need to be revisited.

Building regulatory control sits on a knife edge. Engraved upon one side of the blade is the community desire for flexibility and innovation at low cost. Engraved on the other side is the expectation that government will protect the public from all risk as well as provide the community with insurance schemes and means for legal recompense.

Evolution of the role of the building certifier

For generations, our cities, municipalities and shires provided the services of a public official known as the building surveyor. The duties were many and varied and included assessment of building permits against the local building standards, ordinances and building acts and regulations, together with issue of building permits prior to construction, a small number of inspections and, in some state jurisdictions, monitoring of conditions of the planning consent.

During the 1980s, there was a sharp decline in the employment of clerks of works. The clerk of works role was related to the quality of construction through the focus upon the delivery of construction that met the contract specification for the building. In brief, the clerk of works was employed by the superintendent to ensure the client got the level of quality they had specified and were paying for under contract. The decline of the clerk of works role appears to have coincided with a development industry push to reduce procurement time and hence reduce development cost. The traditional model of 'architect-led design' and 'architect as superintendent during construction' was gradually replaced with the design and construct contract (D&C). In addition, there was a movement for large companies to employ more tertiary qualified staff – this was intended to ensure quality was maintained, but with less oversight of decisions from the architectural team. Significant was the deferral of design responsibility to the head contractor. The clerk of works no longer had a place in the quality pie. The public is essentially oblivious to this chain of events, and still today expect the private certifier (onsite less than 1 per cent of construction time) to fill this void, a blind exploited ruthlessly by politicians.

In the late 1990s, the state of New South Wales was undergoing a construction boom. There was great concern over the increased time that town planning assessment was taking to issue development consent (or refusal). Consequently, some reforms were made to the town planning system, the most significant being changes to the building permit process that typically followed the development consent.

The planning reforms redefined the role of the municipal building surveyor, enabling private individuals (and also municipal employees) to be recognised as an accredited certifier/principal certifying authority. The intention was to effectively speed up the process of the building permit issue, and duties include the regulated progress inspections and occupation certificate that allowed the building to commence its use. The system was effectively a mirror image of the traditional role of the municipal building surveyor. As the role involved being onsite for less than 1 per cent of the construction time, it was regulatory rather than in the area of quality control, which was considered the responsibility of the builder. Indeed, the owner controls quality in the first instance through the selection of the designer and the builder. The loss of the clerk of works has been noted by various formal inquiries over the past decade, with no indication of the return of role imminent. This is unfortunate, as I feel that, although it would not replace good design documentation, the contribution of an independent quality monitor onsite for most of the construction period would solve many concerns and instil greater public confidence.

Local councils and private certifiers compete for business. Under law, the private certifier must act in the public interest and have the same penalties as a local government employee in terms of corruption and accountability. At its best, the system is brilliant and its objective of improving timeframes has worked very well. At its worst, it seems comparable to the chapters of failure that were covered up, or made prominent, under the old system.

Understanding Dangrove

Private certifiers who practise earnestly take pride in the completion of projects that are designed well, are highly functional and constructed very well. Suffice it to say that being able to contribute to a project like Dangrove is a high point in the professional life of a private certifier.

In the case of Dangrove, there was no formal clerk of works, but the architects attended site and kept the pressure on the head building contractor to achieve the quality outcome that had been so well documented. Without that documentation and constantly applied pressure to maintain quality, the outcome would not have been the same, and would never just happen by chance.

Builders must work to a price and are constrained by the availability (cost) or shortage of highly skilled subcontractors. In a sense, everyone feels that they are the meat in the sandwich! Perhaps that is how it should be. Our observation is that everyone benefits from knowing that others have some oversight over the work they do, and value quality. Even the best people will drop their standards eventually if they think that quality is not valued and nobody is watching or cares about quality output. So a rational and measured level of scrutiny is a good thing for everyone.

The difference with Dangrove was that a market rate does not exist for a building of this remarkable design and quality of finish.

Regardless, the expertise and 'attention to everything' on a daily basis by the head contractor and their site staff resulted in equal responsibility for what was achieved. The builder's head construction manager onsite displayed a constant and absolute determination to achieve the result that was required and great credit for the result lies with his site leadership.

It can be very disappointing to witness the dumbing down of incredible shapes and forms into modular cost-effective construction. The D&C model, at its worst, squeezes out inefficiency (and profit) at the expense of architectural achievement. Not to say that compromises should not be made. The skill and expertise is in deciding where to

compromise and where to stand strong. Again, that is a credit to the team of designers. It is immensely satisfying when the heart and soul of a design passes through the D&C machine and lives.

The challenges of Dangrove

Dangrove had its challenges. One example was the use of roof trusses replacing what would traditionally be columns. These mammoth structural steel, fabricated trusses act as column and roof framing. The roof was designed as a skillion, pitched to a high point, around 30 metres above the ground.

The walls were proposed to be steel framed but clad in a translucent polycarbonate that provides light during the day to the Great Hall. While breathtaking to enter, the problem for designers was to assess the material, and where reasonable to do so, put forward a case for acceptance under the performance provisions of the BCA.

The process included:

- Design engineers had an opportunity to identify elements of their design work not typically accepted as deemed to comply or not strictly conforming with Australian Standards adopted by the BCA.
- The accredited certifier identified what they believed to sit outside the deemed to comply provisions of the BCA.
- An accredited and experienced fire safety engineer prepared a fire safety engineering brief, summarising the identified design non-compliances and documenting the proposed methods of analysis and trial designs to be tested.
- The certifier, fire brigade and other stakeholders were able to comment and have the brief amended in a collaborative manner. As a result, the acceptance criteria was agreed, which is critical to the process.
- The fire safety engineer then followed through on the trial designs and produced an outcome report called a ‘fire safety engineering report’, which was again referred for comment to the fire brigade, certifier and stakeholders.
- Finally, the report was finalised and subsequently approved by the certifier as part of the building permit.
- The builder had to adhere to the report closely and inspections were required, including an invitation to the fire brigade commissioner to inspect and provide a final report.

Bearing in mind that Australia had its first significant aluminium composite panel cladding (ACP) fire in Docklands, Melbourne, in 2014, the approval of any wall system made of combustible or partly combustible materials was, shall we say, challenging.

To be absolutely clear, Dangrove does not have ACP external walls. The material used is actually a polycarbonate which has known performance in fire conditions. This is where the training and experience of the professional fire safety engineer was invaluable.

From a certification perspective, the team goes back to the core principles of the performance requirements, the assessment by the fire safety engineer, consideration of life safety for building occupants and opportunity for fire brigade intervention.

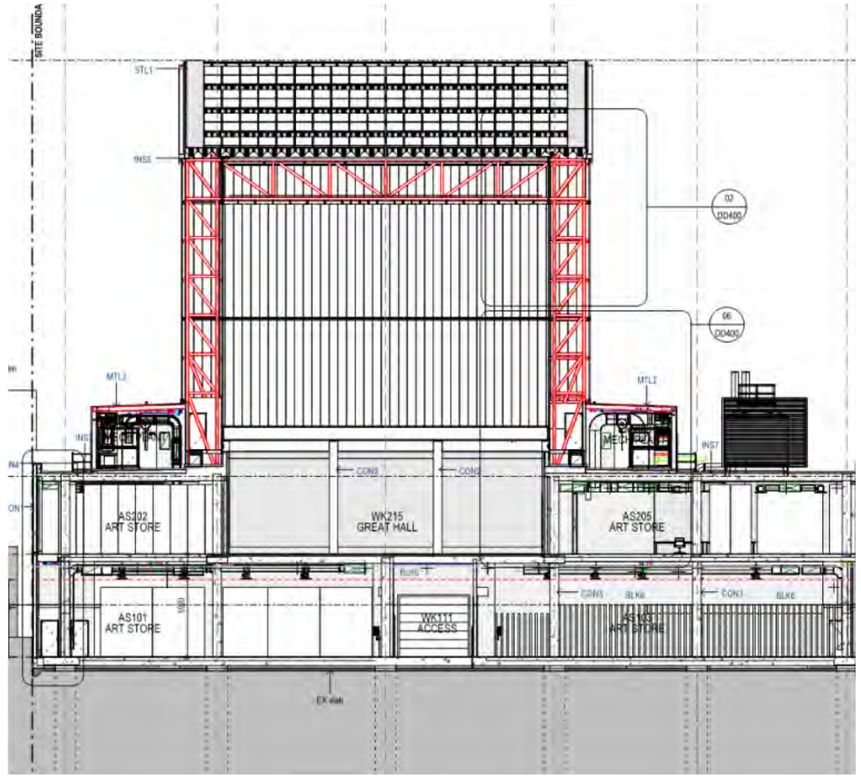
Professionally and personally, engagement to work on a project like Dangrove is a welcome challenge. As a young construction worker, I grew up listening to stories by people who worked on the Snowy Scheme, a major post-World War II hydroelectricity and irrigation project in south-east Australia, and new Parliament House, Australia’s national parliament building, designed by Mitchell/Giurgola & Thorp Architects and opened in 1988. A respect and admiration for those people was formed for the enormity and accomplishment of their work. There are a small number of projects that I hold in the same regard. Dangrove and Phoenix Central Park (Judith Neilson’s art and performance space, designed by Durbach Block Jaggers and John Wardle Architects and opened in 2020) are two such buildings on a short list.

In the early stages, it’s the attitude of the designers – there is no possibility that cannot be explored, no option that cannot be considered.

While Dangrove had a healthy budget (which was strictly adhered to), the outcome was defined by the dovetailing of wilful determination and unrelenting high expectation. The level of innovation and quality achieved by Dangrove is not for the entry level or up-and-coming architect, but for those in full stride.

Section through building – trussed columns and roof shown in red (illustration taken from RED Fire Engineers report).





The fire and life safety of occupants and the provision for first responding fire services is something we have to consider carefully, and is always front of mind when assessing designs for compliance, discussing a performance solution with a designer or the fire safety engineer, inspecting the work during construction or preparing an occupation certificate to allow lawful occupation to commence.

Storage of artwork

Storage of precious artwork is not a simple matter. Apart from logistics, detailed consideration of the effects of temperature, moisture and exposure to light all need to be considered. But these are not BCA considerations. Regardless, the design solutions put in place 'also' need to meet BCA considerations. The building must be weatherproof, of course, but there are other dangers.

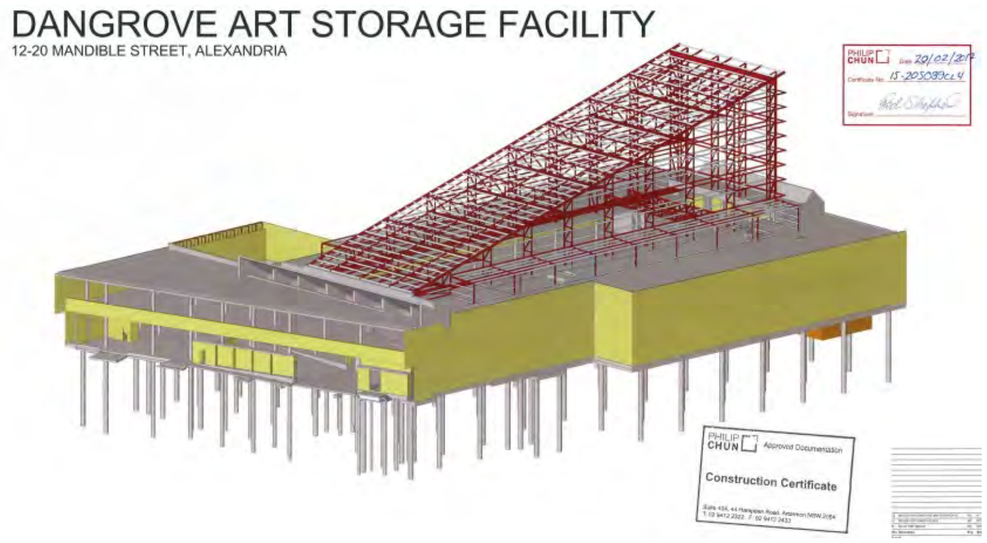
Loss of artwork through direct contact with fire is also a consideration. The use of fire sprinkler systems for life safety and property protection generally are normally required for buildings of a certain scale or risk. In the case of a storage facility for artwork, a fire sprinkler system activated by accident could become a disaster to the art world and heartbreaking for the owner.

Under the BCA, a fire sprinkler system was not required at Dangrove provided the storage areas were sectioned off (compartmented) using fire-rated masonry and fire-rated concrete construction. The BCA provided those fire compartmentation limits and independent expert opinion was also sought to support the interpretation.

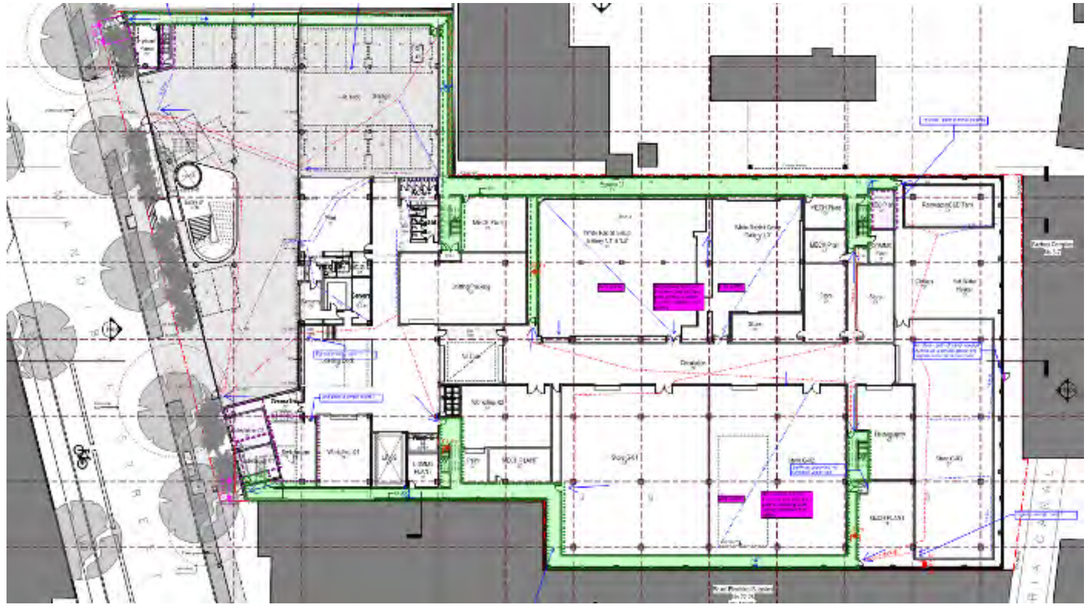
Passive fire-rated construction was used to limit fire spread between the ground floor storage rooms and other parts of the building. In addition, rooms – fire rated from each other – were created at the storage level. This would greatly reduce the risk of more than a single compartment being destroyed by direct flame attack. On the first floor, other rooms were also fire rated for the same reason.

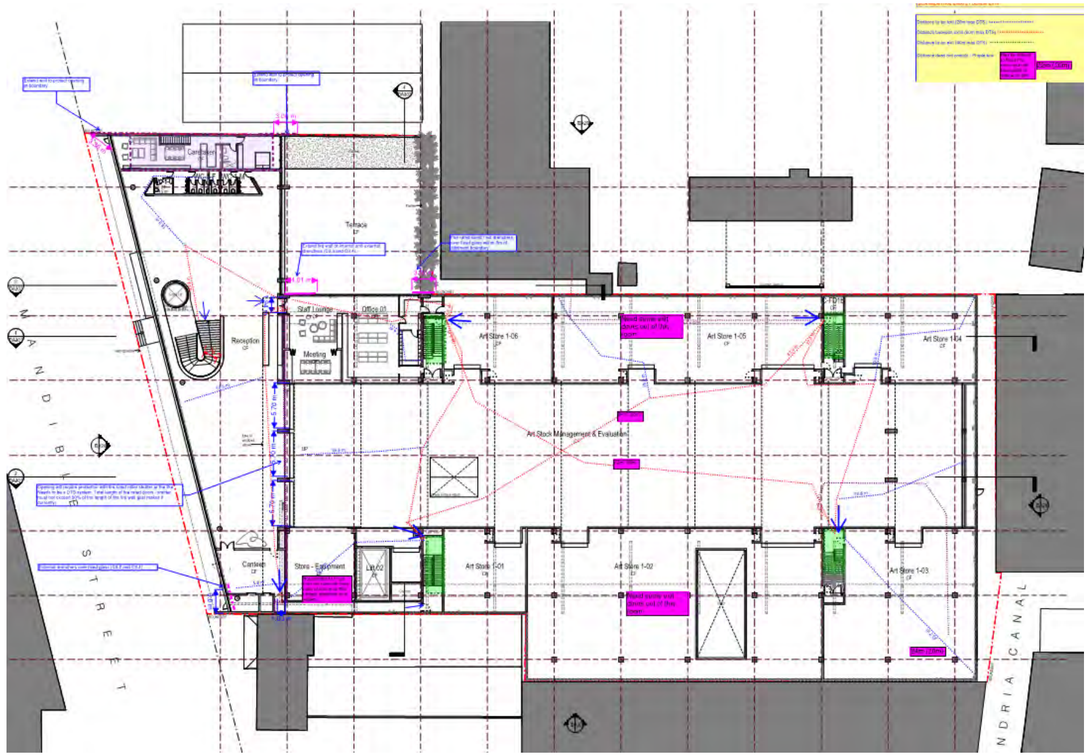
Safe exits from Dangrove

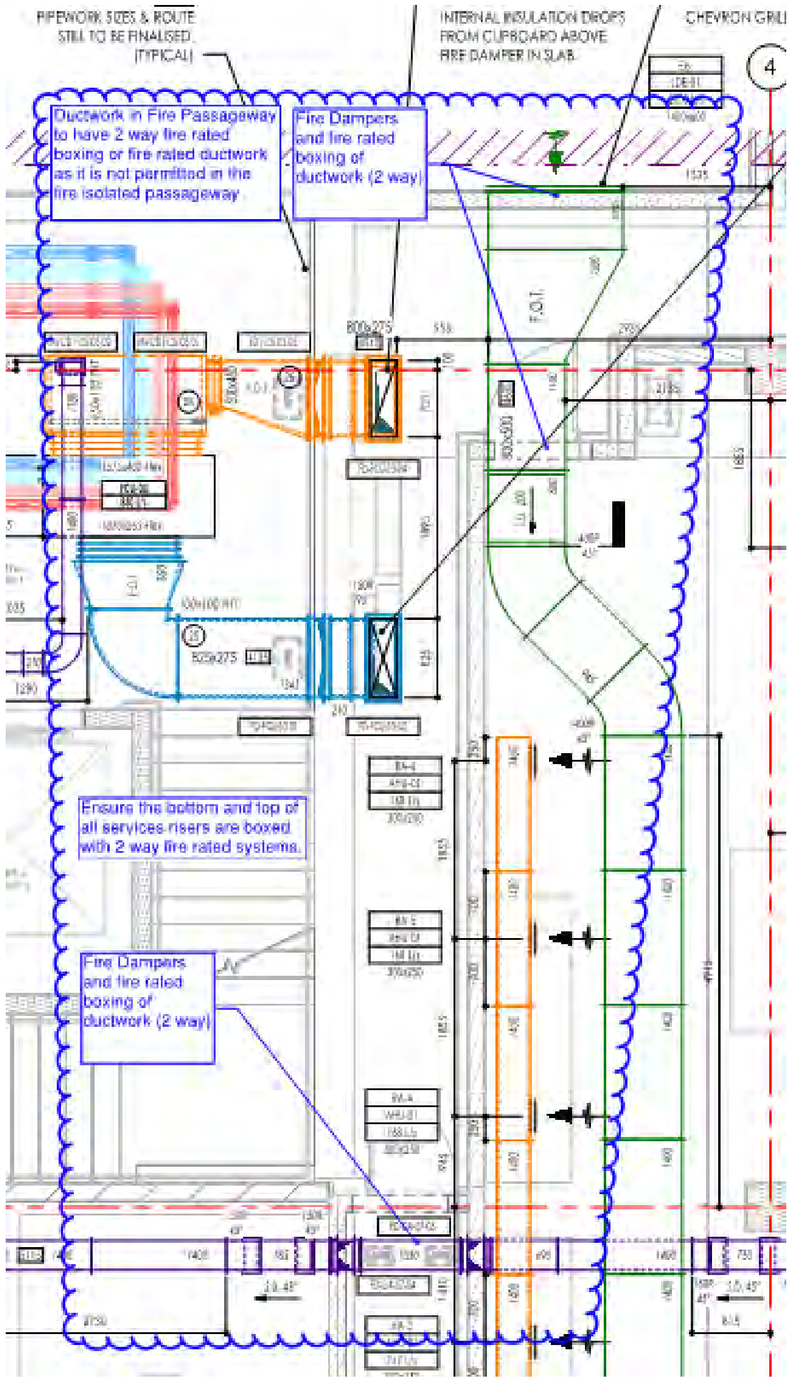
The Dangrove site is irregular in shape, and benefits from only one street frontage. This made the provision of safe exits challenging. Two independent exit systems were designed using an air pressurisation system that ensures they both remain free of debilitating smoke while occupants are leaving the building. Significant floor space had to be sacrificed to make this work, but it will serve the building well into the future. One alternative would have involved exit tunnels excavated into the ground of the former industrial site or, alternatively, suspended egress tunnels that may have reduced the capacity for storage in some other areas of the building.



This page: Plan approved under Construction Certificate 4 (image taken from Taylor Thomson Whitting drawing). Opposite, above: An early egress assessment mark-up for the ground floor. Air pressurised and fire isolated exits are marked in green (plan by Tzannes Architects). Below: An early egress assessment mark-up of the first floor (plan by Tzannes Architects).







Mark-up of engineering drawings for BCA compliance.

Assessment of the egress system was carried out in stages, the first stage being to understand the use of parts of the building. Added to that was the expected maximum occupant numbers (provided by the client) to occupy the building or parts.

From this we used the provisions in the BCA to calculate the number of exits required and the distance from each part of the floorplate:

- To an exit.
- To a point of choice, from which two exits are available.
- Between exits, measured through the point of choice.

The aggregate width of exits on each storey must also be considered, to ensure they are sufficient for the expected population using that storey at any one time.

Non-compliance required redesign or referral to a fire safety engineer for consideration of possible performance solutions instead of the Deemed to Satisfy (DtS) recipe book. In the case of Dangrove, part of the solution was to incorporate an extra sensitive smoke detection system known as a multi-aspirated smoke detection system (MADS). The fire safety engineer went into great detail to examine the most likely fire size, fire growth, smoke produced, detection time, cues for occupants and time to evacuation. It was all very logical and scientific. The project placed great reliance upon the expertise of these engineers. Fire brigade intervention was also considered as it relates to the performance solution and building design. Input from Fire and Rescue New South Wales was considered carefully as part of the process.

The lead-up to a building permit

The checking and rechecking of drawings in the lead-up to a building permit often raises issues that would otherwise be picked up during construction, although it is seen as much more cost effective to detect issues before the building permit is issued. The figure opposite shows an example of notes Philip Chun made on a mechanical drawing during our assessment.

The assessment revealed non-fire-rated mechanical ductwork crossing a fire-rated egress passageway, which is not permitted under the BCA. The solution on the identified non-compliance issue, provided by the design team, was to create a two-way fire-rated horizontal shaft through the passageway for the ductwork. The shaft is often classed as builders' work rather than that of the mechanical services contractor. Regardless, early identification of problems allows items such as the head clearance to be checked through the passageway and a fire-rated system to be researched and specified. The cost of fixing these compliance issues can be inflated the later they are detected, and in some cases may be missed completely or result in poor building outcomes and last minute efforts to provide viable and cost-effective remedies. The key outcome is co-ordination of disciplines to achieve compliance with the BCA as early as possible. Review of documentation saves time and money and delivers better building outcomes.

At completion of Dangrove, we had issued six staged building permits, two partial occupation certificates, and one final occupation certificate.

Our database shows we spent 444 hours attending to the lawful approval of the building, including inspections, plan checking, meetings and advice during construction.

The team of professional designers and builders produced a truly spectacular building, which we expect will fulfil its needs.

Practice profile

Philip Chun, founded in 1990, is one of Australia's largest multi-disciplinary certification consulting companies, providing building code, fire and life safety, accessibility and assessment of essential fire safety measures to the construction and development industry. We serve commercial and government clients in all areas of building compliance and across a vast range of industries from housing, public infrastructure and transport, to health and defence.

Philip Chun specialises in complex and challenging projects and delights in our role ensuring the safety and amenity of the building occupants, using the performance provisions of the BCA in the way they were originally intended. We believe that in practice, communication is the key to the support of incredible innovation and is essential where design is to push the bounds of innovation and creativity.

Key people

Robert Marinelli: managing director
Rod Shepherd: associate

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Accessibility

Philip Chun

The role of the access consultant

The Dangrove project presented a unique opportunity to explore the accessibility of areas, such as storage and back-of-house, that, for most buildings, are deemed to not require access for people with disabilities.

Access consulting in Australia, at the base level, is concerned with meeting the minimum requirements of building codes, regulations and standards to achieve barrier-free access into the key public areas of a building. While great advances have been made in recent years with codes and standards to accommodate a wider range of disabilities in their requirements, accessibility is still often seen as an inconvenience, and is compromised in many cases.

Accessibility, in the case of architecture, refers to the degree of ease with which one can use a building. The quality of the experience is also an important factor that can shape quality of life and inclusion. Broadly speaking, there are three types of disability: sensory, physical and intellectual. Each type requires a different compensatory behaviour.

The most basic role of the access consultant is to ensure that compliance with minimum standards is met in the design and construction of a building. However, a performance-based approach can be adopted that goes beyond the minimum standards and embraces the concept of universal design, catering to the widest range of users possible, regardless of disability. While universal design strives to stay away from disability issues per se, and focuses on the abilities of the community as a whole, it does ultimately become assimilated with accessibility issues within the built environment.

In this sense, the access consultant must adopt the role as advocate, voicing their aims for the project, and any specific concerns they might have, to the design team so that people of all abilities are considered from the conceptual design stages through to the built form. While accessibility legislation generally provides a standardised built environment that can be expected by people with disabilities, the challenge is to tailor this standard specific to the design intent for the building.

In Australia, we are fairly unusual in having a proactive approach to the provision of access for people with disabilities. In many countries, the access consultant is only engaged after litigation, when their role is to rectify accessibility issues and non-compliance rather than avoid them at the start of a project.

Reviewing a design

When reviewing a design for accessibility, a wholistic approach needs to be taken. I like to start the review from the macro-level, looking at how one approaches and enters the building, and then take the review down to the micro-level, looking at the specific arrangements of rooms and other features. Of course, in between these two points is the journey through the building. This is what makes each project unique. The level of review becomes more detailed as the design progresses; the initial review often looks at overall spatial arrangements while the final review examines items such as detailed dimensions of fixtures and fittings, and details of such things as handrails.

Within the initial review stages, it is important for the access consultant to build rapport with the design team to ensure that a solid understanding of the design concept is realised. This gives an indication on how inclusion is going to be achieved, and draws attention to specific items. The design team is usually the link between the access consultant and client, so is an important relationship to establish.

Typically, an access consultant works primarily with the design team, but also collaborates closely with the building codes consultant/certifier. This relationship sometimes involves negotiating and bargaining with respect to inclusion and accessibility matters to ensure that usability, as well as compliance, is promoted within the design.

Strict compliance with codes and regulations is not always achieved within the parameters of the design intent. The access consultant, then, must understand from the design team what the intent is, consider its validity in the context of compliance, usability and the different disability groups, and make suggestions for improvements and changes. Sometimes, what we call a performance-based approach to accessibility is adopted to achieve the overall design intent for the project and, in this case, it needs to be presented to the building codes consultant for approval.

It is important for the access consultant to be able to communicate the rationale behind their decisions and recommendations, and also to be able to defend and argue for these to be implemented into the design where compliance may be compromised, or becomes a grey area.

A performance-based approach to Dangrove

Dangrove presented a unique opportunity for a performance-based approach to accessibility. While most buildings comprise front-of-house and back-of-house areas that, from an accessibility perspective, have quite different requirements, the design of Dangrove saw the lines between these areas blur. Typically, barrier-free access is created with the front-of-house, or public, areas of a building, with the back-of-house staff areas being less critical. With no clear distinction between front- and back-of-house at Dangrove, there was an opportunity to explore how the extent of access can affect inclusion.

A ramp of gentle gradient provides easy access into the building from the footpath along Mandible Street. Stairs are also provided for a more direct route, but the decision to provide a ramp of gentle gradient, primarily for people using wheelchairs or pushing prams, eliminated the requirement for tactile indicators that can interfere with wheelchair manoeuvring and balance. This is the first best-practice approach to accessibility that is noted on arrival at the building. En route to the entrance, one passes the accessible car parking area that is on-grade with the recessed entrance area, another best-practice approach that eliminates the need for pram ramps.

The foyer of the building offers generous circulation areas for wheelchair users and a visual connection to the vertical circulation. Again, this is a best-practice measure that aids wayfinding by eliminating decision-making for the users. Direct circulation areas promote usability for all. On arrival at the upper level, the lift opens directly into the reception area, again assisting wayfinding. From this point, access through the building continues to meeting areas, gallery areas, staff areas and amenities.

During the design process, some decisions on accessibility were made that were specific to the way in which the building was to be managed and used.

For example, a performance-based approach to the provision of door circulation areas was adopted throughout the building, based on the specific use of rooms and their main occupants. This can be seen within the workshops and art stores. Complying clearances to facilitate independent access for people using mobility aids are not achieved at these doorways. Due to the nature of the work carried out in these areas, and the high security requirements, staff accessing them are required to have a high degree of mobility.

With work health and safety issues arising from the use of equipment such as forklifts, people with a disability can be escorted through the building by staff, and only staff members operate the doorways. One has to remember that these areas are typically deemed ‘exempt’ from requiring access for people with disabilities; the fact that people of all abilities can enter the spaces, albeit with assistance, is considered a best-practice approach that extends beyond minimum compliance requirements. Additionally, as the doorways will always be operated by staff, no disability discrimination issues arise as all guests and visitors are treated equitably.

The managed approach to accessibility extends to staff areas, with nominated accessible offices being provided and available on an as-required basis. This ensures that staff members with disabilities, or who acquire a temporary disability, are afforded access to workspaces suitable to their needs.

Creating an inclusive environment

While the ‘best-practice approach’ and ‘managed approach’ to accessibility may seem to contradict each other, within the context of Dangrove they work together to offer a truly inclusive environment that can be experienced by all users of the building.

Society is now more accepting of the concept that disability is a product of the built environment rather than being an inherent quality of the individual. This is a positive shift in attitude – if inclusion and quality of life are to be promoted through accessible environments, the needs of people with disabilities must be accommodated during the conceptual stages of the design process.

As an exceptional example of this approach, Dangrove demonstrates that inclusion can be achieved through a collaborative approach in the design process – one in which a good rapport between a range of consultants and the architect was established at an early stage.

Practice profile

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Key people

Lindsay Perry

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Fire Safety Engineering

RED Fire Engineers

Fire science, a relatively new science at around 150 years old, is the rigorous study of how things such as furniture, forests and buildings burn. Fire engineering is the application of fire science to prevent or limit fire and smoke spread. By understanding fire science, we can predict how heat and smoke impact occupants, firefighters and structures – and therefore select appropriate fire safety systems.

A building's fire safety 'design' includes obvious features such as sprinklers, detectors and warning systems, the slightly less obvious such as escape routes and fire walls, and the nearly invisible such as the materials that make up the actual building and its contents.

A successful fire safety strategy should prevent fire growing from one stage to the next before people are able to get to safety. Buildings should be designed to delay fire growth and spread to give the fire brigade time to rescue occupants and put the fire out.

Using fire science, we can predict how long before a room becomes 'untenable', how long occupants need to escape, how long firefighters need to intervene, and how long before structures fail. As with all engineering disciplines, there are an infinite number of ways of designing a building's fire safety strategy. The best fire engineering designs aim to balance safety goals with spatial and cost constraints, as well as architectural ambitions.

The Building Code of Australia (BCA) tells us what fire safety features a building needs, depending on the type, size, height, proximity to boundaries, actual use of the building and so on. The code usually works so that if there's a fire, people have time to get out. We know the code isn't perfect, but it's good enough. Occasionally, a tragedy occurs and the code is reviewed and updated.

The concept of a modern, 'performance-based' building code was introduced in the late 1980s and adopted in Australia in 1996. The code allows unique buildings to be designed using 'fire engineering principles' rather than strictly adhering to the prescriptive 'deemed-to-satisfy' method. Fire engineering supports innovative, unique buildings like Dangrove, which has very specific functional design outcomes that required a creative but technically sound approach to fire safety. If prescriptive fire safety is painting by numbers, performance-based fire engineering is Mark Rothko.

Most buildings, even modern ones, are designed largely using rules of thumb that were developed over centuries and decades for an infinitely wide range of buildings. But with the benefit of fire science, 'prescriptive' rules give way to 'performance-based' engineering design in order to meet a wide range of objectives. Interesting buildings can be designed with a much more targeted approach.

And Dangrove is a very interesting building.

The initial approach

The concept design for Dangrove was prepared before we came on board. Dangrove was originally intended to be designed to comply, as far as possible, with the prescriptive 'deemed-to-satisfy' (DtS) Provisions of the Building Code of Australia (BCA). This meant that the building would be largely made out of concrete, with compliant egress travel distances, 'fire isolated' stairs and smoke detection systems. It's a tried-and-true formula that gets occupants out of the building during a fire, limits fire spread, and allows the fire brigade to do their job. However, it quickly became apparent that the unique layout of Dangrove couldn't comply with the DtS Provisions because:

- The corridors are so long that a pressurisation system is required to keep smoke out. However, technically, the pressurisation system needs to account for all the doors being

open at once. This means the required airflows become so high that the doors can't be opened (if they open outwards into the corridor) or would open with such a high force that they would be a safety concern (if they open into the storage rooms, for instance).

- The viewing gallery had immense polycarbonate external walls. Polycarbonate is combustible, which is not permitted for DtS buildings.
- The fire compartments were larger than most of the DtS size limits. The only remaining DtS option would be to treat the building as a 'Large Isolated Building', but this would have required sprinklers throughout as well as a perimeter road for emergency vehicles, which could not be achieved for this site.

Other relatively minor aspects, such as the building having reasonably long internal travel distances and a non-compliant hydrant booster assembly layout (due to space constraints at the front of the building), also needed to be resolved through a fire engineering Performance Solution.

On top of that, smoke and water are the most destructive elements to art, so in this case, conventional systems could not be used.

The solutions

Due to its use as a storage building, fire compartments are prescribed fairly high fire resistance levels (FRLs). Technically the requirement is written as '240/240/240 FRLs' but we'll call them 'four-hour' fire separations from here on.

Due to thermal mass required to stabilise the temperature of the storage rooms, the concrete walls easily met the four-hour FRLs required to divide the facility into smaller compartments.

However, each storage compartment was still oversized – and the client's brief was that sprinklers could not be used, to avoid water damage to the artworks.

We explored alternative fire suppression technologies. Active 'water mist,' 'gas suppression' and 'Novec 1230' water replacement systems were options. However, none were considered viable. Water mist still introduces water, albeit a much smaller amount than sprinklers. Gas suppression requires large volumes of space to store the compressed gas canisters (which are typically either nitrogen/argon/carbon dioxide or a proprietary chemical such as FM200). It was also feared that the force of gas expanding into the storage rooms would potentially ruin the artwork. Novec 1230 is a proprietary fluid that is used in special hazard fire suppression systems. It gets distributed through pipework in a similar way to traditional sprinklers. The fluid is non-reactive and non-conductive, yet has similar suppressing properties to water. This allows it to be used in sensitive areas such as galleries and computer rooms.

The design team came to us for advice regarding an innovative fire protection technology used at the Vatican, Viking Ship Museum in Oslo and the British Museum archives, as well as automated cosmetics and food storage warehouses throughout Europe. This system is known as a 'permanent hypoxic atmosphere'. This is a fancy way of saying, 'Let's remove the oxygen level in the room to the point where art won't burn, but humans can still breathe.' We had been following the development of this technology for more than 10 years, and were keen to implement the solution here. The design team questioned whether occupants would be able to safely operate heavy machinery. Our research has shown that low oxygen environments can be a risk to people with certain pre-existing health conditions, and who would require ongoing health checks. Recommendations are that for every hour occupants spend in this environment, they spend the same amount of time outside it, which would affect productivity. The final nail in the coffin for this system was that the mechanical system to the storage rooms required a high fresh air exchange rate, which would require immense amounts of energy to continuously remove oxygen from the fresh air supply.

In the end, we settled on an advanced 'aspirating' smoke detection system, VESDA, which actively samples air from the room through a network of pipes (as opposed to traditional 'point' type smoke detectors, which sit below the ceiling and wait for the smoke to come to them). The system has the ability to detect very low concentrations of smoke in the air, providing early warning to occupants and notifying the fire brigade during the initial 'smouldering' phase of the fire.

The exit corridors

At the time of its design, Dangrove was bounded by properties on three sides with a road to the front. The building's footprint occupies the entire property. That means the egress

FIRE COMPARTMENTS

The largest fire compartment is the C1 compartment highlighted in light grey, which spans across the car park and open entry stair, lobby and viewing gallery. The art stores are all smaller compartments, fire separated to 240/240/240 (colloquially 'four-hour separations'). By reducing the potential for fire spread from one store to the next, occupant life safety as well as a high degree of property protection is achieved.

GENERAL NOTES:

THIS COMPARTMENT DRAWING IS TO BE READ IN CONJUNCTION WITH THE BCA AND FIRE ENGINEER'S DOCUMENTS.

WHERE TWO COMPARTMENTS OF DIFFERENT FRL SHARE A COMMON WALL, THE FRL OF THE BOUNDING WALL SHALL BE THE HIGHER OF THE TWO AREAS UNLESS OTHERWISE DETERMINED BY THE FER.

ALL LOAD BEARING BOUNDARY CONSTRUCTION MUST ACHIEVE 240/240/240 UNLESS OTHERWISE DETERMINED BY THE FER.

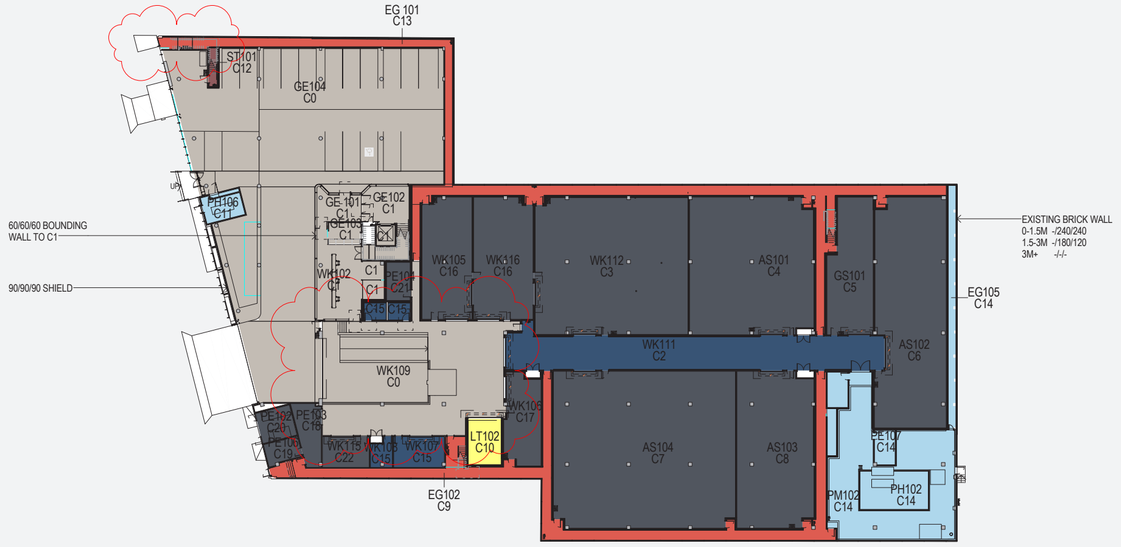
ALL NON-LOAD BEARING BOUNDARY CONSTRUCTION MUST ACHIEVE -/240/240 UNLESS OTHERWISE DETERMINED BY THE FER.

FLOORS TO BE 240/240/240 UNLESS OTHERWISE DETERMINED BY THE FER.

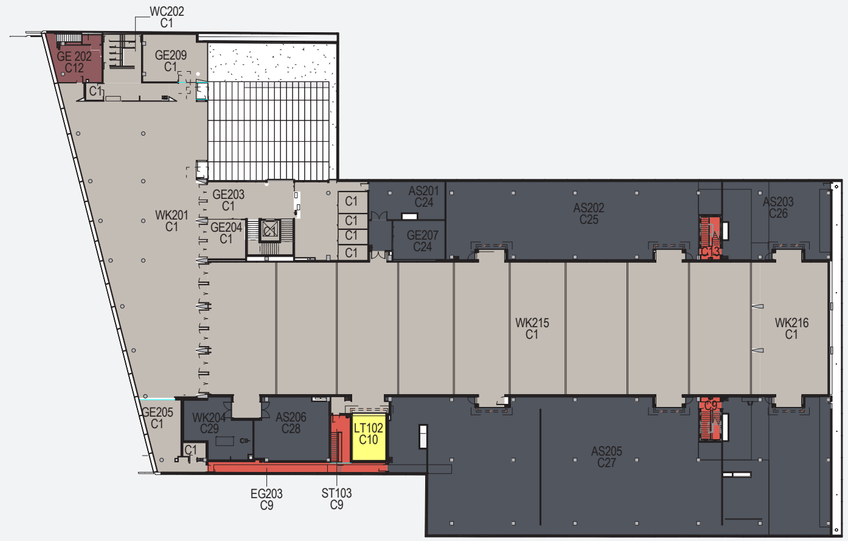
INTERNAL COLUMNS SHALL BE 240/240/240 EXCEPT WHERE DIRECTLY BELOW THE ROOF, WHICH ARE EXEMPT, AND ALSO WHERE PERMITTED TO HAVE A REDUCED FRL BY FER.

LEGEND

C#	DENOTES COMPARTMENT NUMBER	
	240/240/240	
	240/-/-	
	240/120/120 - /120/120	LOAD BEARING ITEMS NON LOAD BEARING ITEMS
	120/120/120	SUBJECT TO FIRE ENGINEERING TO GREAT HALL COMPARTMENT (NOTE BOUNDARY CONSTRUCTION)
	120/120/120	NOTE BOUNDARY CONSTRUCTION ABOVE
	90/90/90	NOTE BOUNDARY CONSTRUCTION ABOVE
	60/60/60	



1 Level 1 - Fire Compartment



2 Level 2 - Fire Compartment

system needs to bring occupants from the building's extremities down to ground level and out to the road. There is a 'fire isolated corridor' on each side of the building that runs almost the entire length of the building. The corridors collect occupants from all the fire stairs and bring them to the road. The corridors and stairs connect directly to all of the art storage rooms and plant rooms. On top of acting as fire egress, these corridors have a number of other functions. They have been designed to separate the storage rooms from the external skin of the building in case of facade failure; as a services corridor, containing water pipes; to provide an air pocket to improve the temperature stabilisation of the storage rooms and therefore decrease the mechanical load; as security, to allow maintenance and servicing access to the plant areas without accessing the internal facility.

The fire corridors are more than 60 metres long, with up to ten doors opening into them on each level, and the DtS provisions of the BCA therefore prescribe an exit pressurisation system to keep smoke out of the corridors while occupants travel along them. Because of the multifunctional uses of the corridors and access requirements, the corridors required a Performance Solution to achieve pressurisation, fresh air exchange for safe service access, and an increased number of compartments accessing the corridor due to the depth of the site.

From a mechanical engineering perspective, there's no viable way of designing an exit pressurisation system with so many doors opening into the corridors. This was the first departure from the building code that was identified, and one of the first things we were asked to look at. The problem is that pressurisation systems need to maintain a minimum average velocity of 1 metre per second through each door they serve, without forcing so much air on the doors that they're too hard to open when closed. With more than a few doors opening into the corridors on each level it becomes very difficult to 'balance' a pressurisation system.

Our solution was that rather than pressurise the corridors and stairs to keep smoke out, we would dilute the smoke. There is a section in the Australian Standards for smoke management systems on designing such a system, but we needed to research it to convince ourselves that it was the right way to go. Quite often in fire engineering our designs are based on creative hunches that are formed by turning a problem on its head. Our thought process was basically, 'If we can't pressurise the corridor to keep smoke out, what if we allow it to enter, dilute it and blow it out the end of the corridor instead?'

Our system pushes fresh air into the corridors and pulls out the contaminated air using multiple fans. Our theory was that this system would dilute and purge any smoke that enters the corridors. So if a door is left open after an occupant escapes a burning room, the smoke will be diluted with fresh air that reduces the temperature and toxicity of smoke, while improving visibility.

We designed our 'purge' system using the mechanical design software Contam. This allows us to predict what airflow rates are required and where to locate the fan injection points in order to dilute the smoke and reduce its temperature. The mechanical contractor proposed a particular model of fan for this application. Based on the fan curves for these fans, we were able to cross-check the calculations using a separate piece of software, PFS. This allowed us to set pressure limits for the Variable Speed Drives (VSDs) fitted to these specific injection and exhaust fans. The flow rates through the corridors were tested at the end of the project and confirmed that the design worked.

Firefighters could use our purge system to help clear smoke out of the art stores after a fire. That can't be done with a traditional exit pressurisation system, and was therefore an additional advantage of our design.

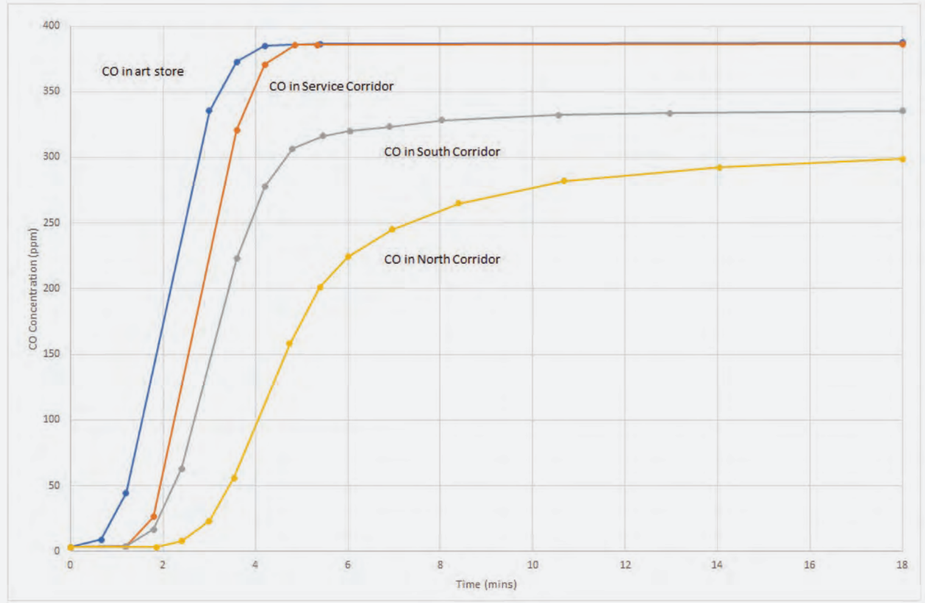
The Great Hall

Key challenges – polycarbonate walls and size of the Great Hall compartment
When we were knee deep in the design, combustible external walls started emerging as a massive fire safety issue on buildings around the world. Not all plastics are the same: some char when heated, some warp and twist and melt. Some plastics have fire retardants added. They all release different amounts of heat, and different types of smoke. Some plastics need to be constantly heated in order to sustain burning, others will form a burning puddle called a pool fire.

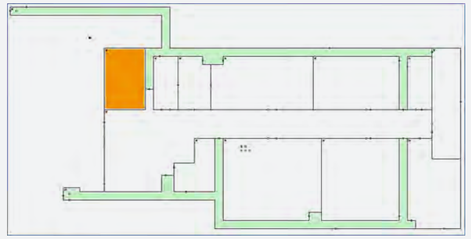
The walls of the upper level viewing gallery are giant waffles of plastic. These walls constituted the second major departure from the code, and one that we were asked to research. We looked at what would happen if a fire started near the polycarbonate wall, and found that the plastic would melt and run away from the initial heat source. Any 'pool fire' created would be secondary in size and effect to the original fire. Cellular polycarbonate wall systems are combustible, however the risk is lower than other plastics such as

SMOKE TOXICITY

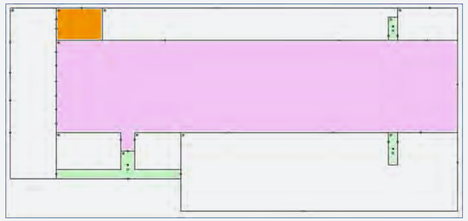
Carbon monoxide concentration was used as a proxy to estimate smoke toxicity in each space within the model. The graph shows the predicted steady state that occurs in the art stores, corridors and other spaces during a fire in one of the art stores. The steady state values were used to demonstrate occupants have time to escape. The simple concentration-time product of (350)(2) = 700 ppm.min for occupants who walk the full length of the building via the fire-isolated corridor is significantly less than the 30,000 ppm. min limit given in the reference *Fire Toxicity.* Sensitivity studies were also run with doors open, in which there was still significantly less toxic smoke throughout the corridors. Visibility was estimated to exceed 9 metres except in short 'dead-end' sections of the corridors. Occupant wayfinding in the corridors is not expected to be affected by the diluted smoke.



CO levels in art store, adjacent corridor and other parts of the building – primary scenario.



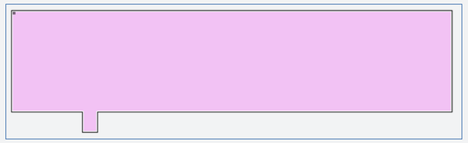
CONTAM Model geometry level 1.



CONTAM Model geometry level 2 (lower half).



CONTAM Model geometry level 1 mezzanine.



CONTAM Model geometry level 2 (upper half).

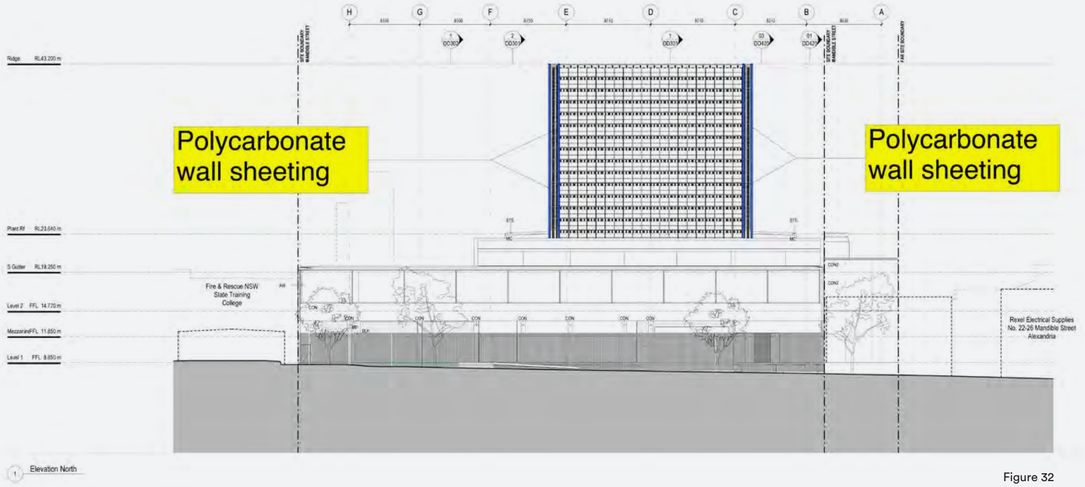


Figure 32



Figure 33

POLYCARBONATE WALLS, PIR INSULATION AND NON-FIRE RATED VIEWING GALLERY ROOF SUPPORTS

In a fully DtS compliant building, the use of polycarbonate or PIR insulation as part of an external wall would not be permitted as neither material is deemed to be non-combustible. The Fire Engineering Report justifies the use of these external wall systems as part of the Alternative Solution.

expanded polystyrene or polyethylene. On a molecular level, if you burn a kilogram of polycarbonate, you will get less heat than from burning polystyrene or polyethylene. But the other point is that the cellular polystyrene is a thin walled system, and tests have been carried out to show that it melts at a very low temperature and tends to shrink back from the heat source and open up a hole. The results would be different for a 200 mm-thick sheet of polycarbonate, but because it's so thin, you can trust that it's going to vent smoke to the outside, which reduces the risk to occupants and firefighters. Characterising the burning behaviour of the plastic was important to make sure fire didn't spread via the external walls.

Due to the worldwide attention brought by a spate of facade fires in high-rise buildings, including Lacrosse in Melbourne's Docklands and the Grenfell fire in London, this issue was probably the most contentious one we faced. We met with Fire and Rescue New South Wales to allay their concerns, and ultimately gained their acceptance of the design. At the time, any type of combustible material was seen as unacceptable; the only aspect of Dangrove's design Fire and Rescue were concerned about was the use of polycarbonate. We had to take a rational science-based approach when dealing with them – they needed to understand the material and the way it performs. It was stressful in that we knew the client, architect and the whole design team were depending on getting this passed. There are sometimes unwritten policies you don't know about, or you can be judged on the way you present yourself and not necessarily on the technical argument. We were concerned the same thing could happen here, so took our technical director along to meetings with Fire and Rescue. Our technical director has 45 years experience and had been one of the authors of the report into the collapse of the World Trade Center. We were able to present the science in a simple fashion that led the brigade to be convinced by the research we presented to show that the material melts at a very low temperature and tends to shrink back from the heat source, allowing the smoke to escape.

Size of the Great Hall compartment

The Great Hall and Re-Drawing Room equated to 38,000 cubic metres of volume which was nearly twice the limit for a DtS fire compartment. Our analysis of the polycarbonate walls benefited the assessment of the oversized fire compartment risk, because we showed that heat from a fire would vent to outside. Plus, most of the Great Hall is empty space, not full of stored material. The amount of storage in the Great Hall would be limited in order to maintain access to the storage compartments on each side. Our risk assessment looked at the amount of fuel that could possibly burn in this compartment, and we concluded that the fire risk is less than in a DtS fire compartment. We also relied upon early detection of a fire by the VESDA smoke detection system, and Dangrove's management, to show that the fire compartment size could be justified.

Summary

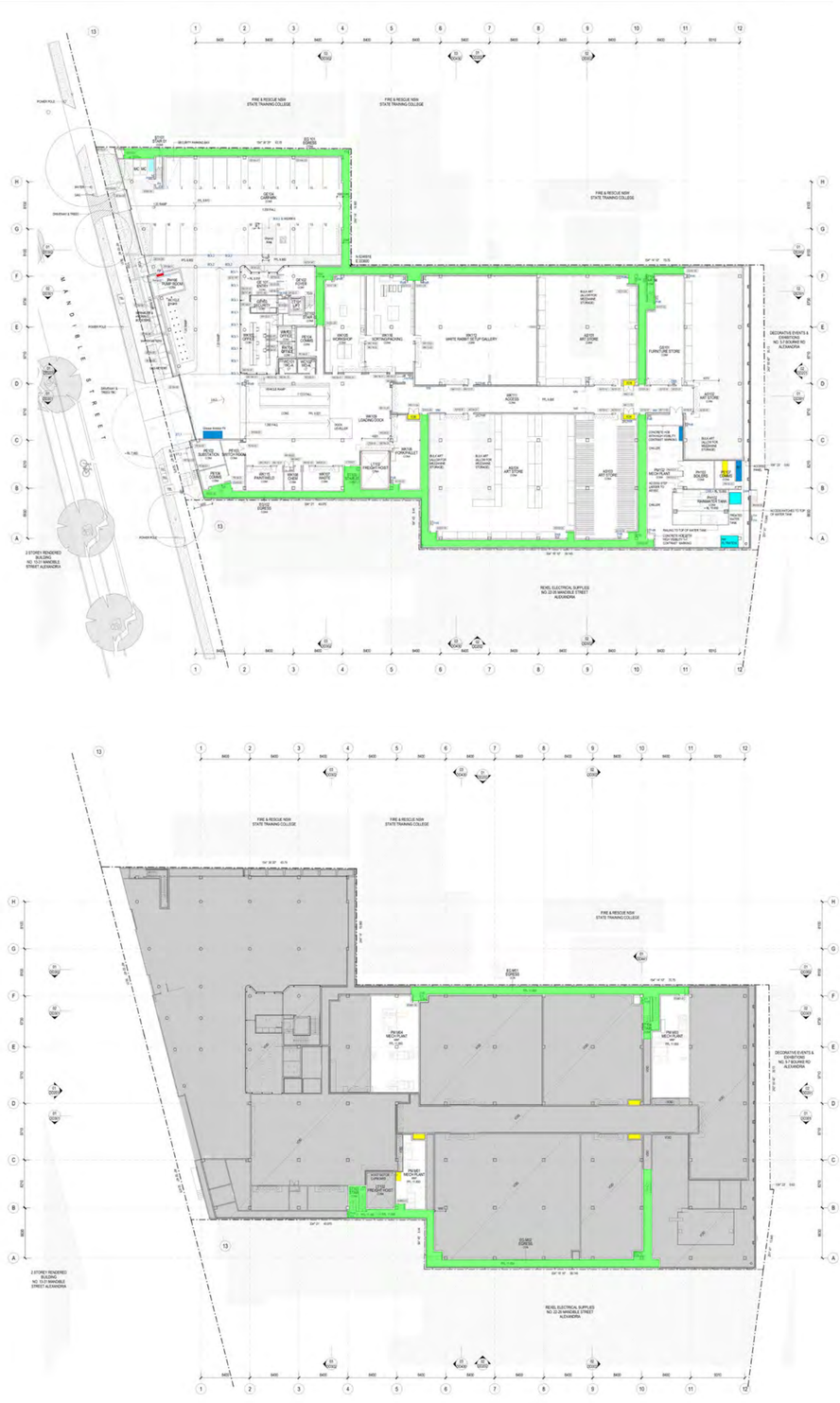
DtS can't always be applied – a good engineer can use the science of fire engineering and come up with an alternative solution to find creative ways of assessing risk and fire safety. A fire engineering Performance Solution is a combination of science, technical systems, human behaviour and risk management. Sometimes we go down dead end paths, such as searching for the perfect suppression system when just closing the doors is the most pragmatic way of limiting fire spread and damage. Dangrove is an example of achieving creative solutions through a sound technical response.

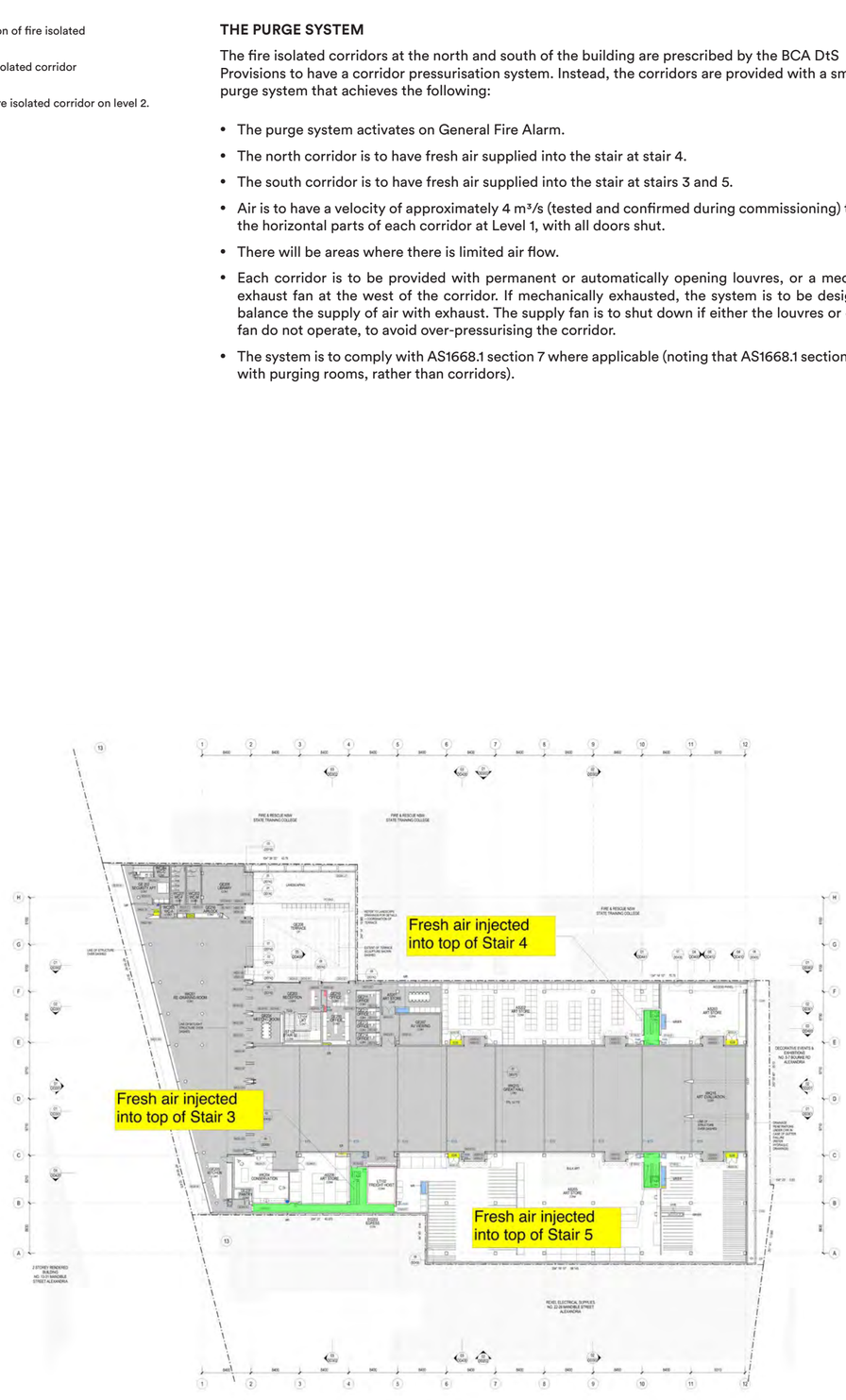
Practice profile

RED Fire Engineers is a diverse firm of consulting fire safety engineers. We have internationally trained engineers located in five offices in Australia and Sweden. Our projects include museums and art galleries, tunnels and most other types of building.

Key people

Ida Ginstrup
Ulf Johansson
Blair Stratton
Eric Swainson
Pelle Zetterström





Opposite, above: Location of fire isolated corridor on level 1.

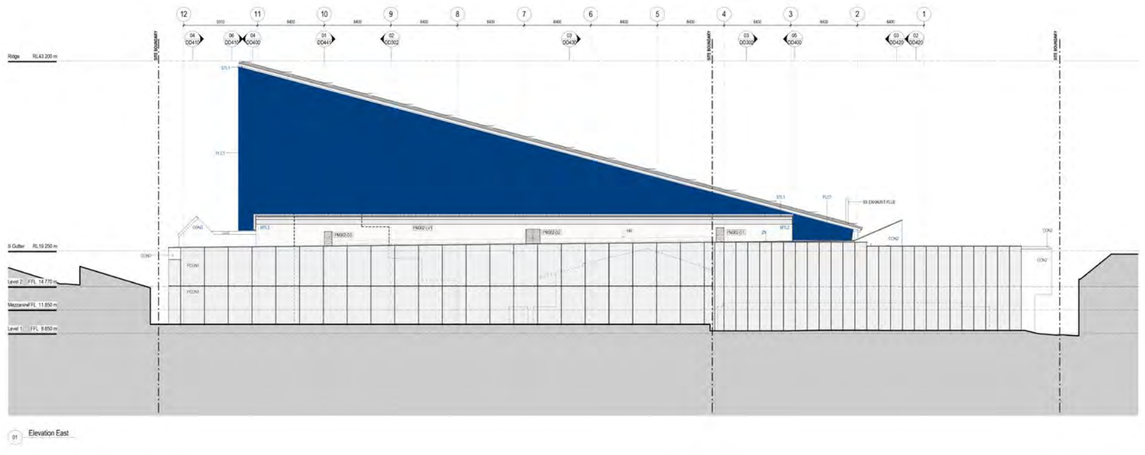
Below: Location of fire isolated corridor on mezzanine level.

This page: Location of fire isolated corridor on level 2.

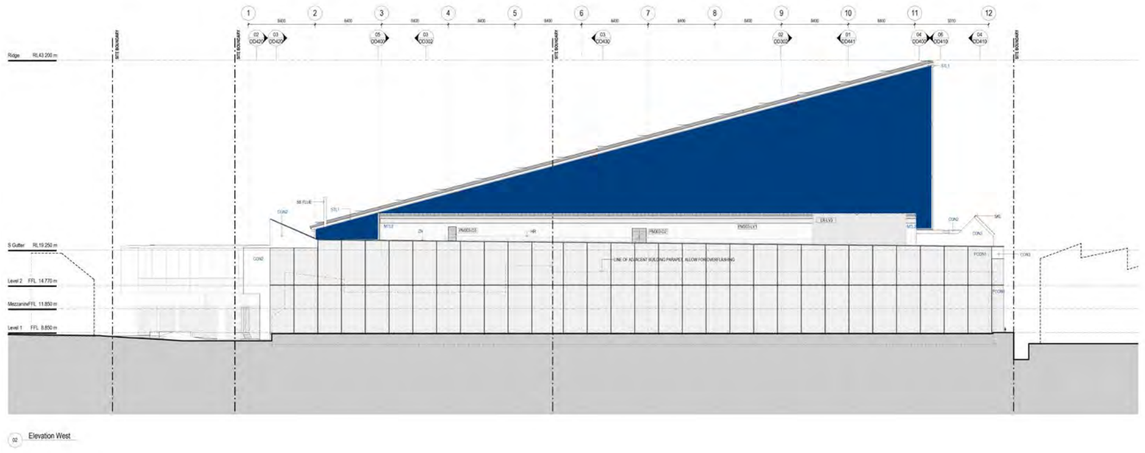
THE PURGE SYSTEM

The fire isolated corridors at the north and south of the building are prescribed by the BCA DtS Provisions to have a corridor pressurisation system. Instead, the corridors are provided with a smoke purge system that achieves the following:

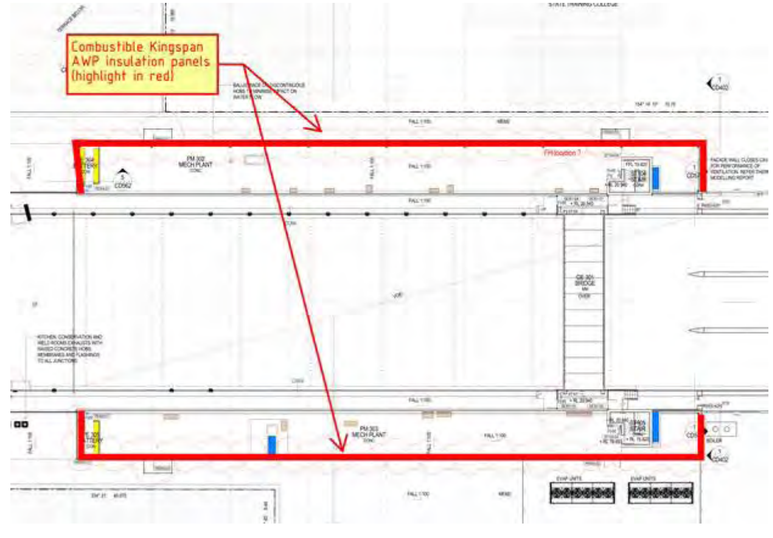
- The purge system activates on General Fire Alarm.
- The north corridor is to have fresh air supplied into the stair at stair 4.
- The south corridor is to have fresh air supplied into the stair at stairs 3 and 5.
- Air is to have a velocity of approximately 4 m^3/s (tested and confirmed during commissioning) through the horizontal parts of each corridor at Level 1, with all doors shut.
- There will be areas where there is limited air flow.
- Each corridor is to be provided with permanent or automatically opening louvres, or a mechanical exhaust fan at the west of the corridor. If mechanically exhausted, the system is to be designed to balance the supply of air with exhaust. The supply fan is to shut down if either the louvres or exhaust fan do not operate, to avoid over-pressurising the corridor.
- The system is to comply with AS1668.1 section 7 where applicable (noting that AS1668.1 section 7 deals with purging rooms, rather than corridors).



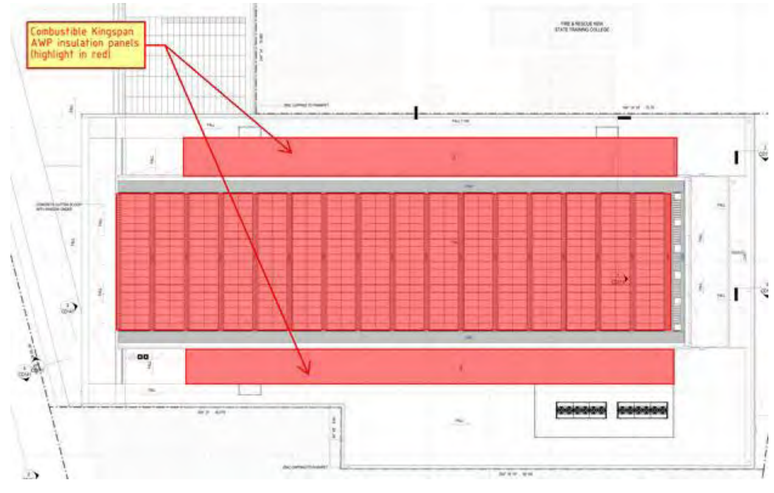
East elevation showing location of external polycarbonate sheeting.



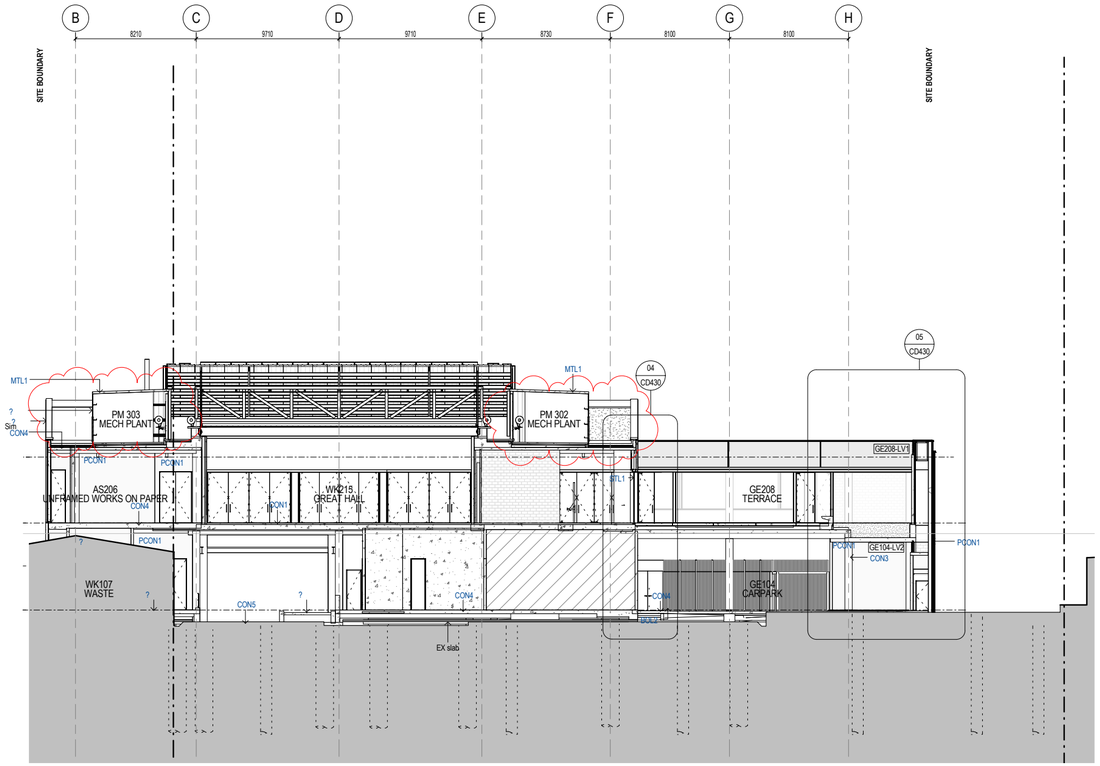
West elevation showing location of external polycarbonate sheeting.



Kingspan AWP insulation to external walls of the mechanical plant room at lower roof.

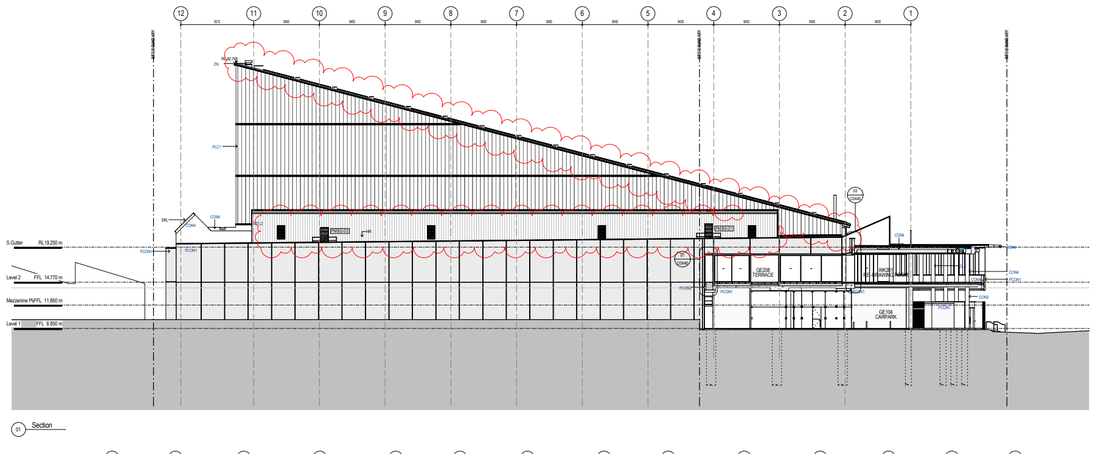


Kingspan AWP insulation to ceiling of the plant room at lower level and above Great Hall.



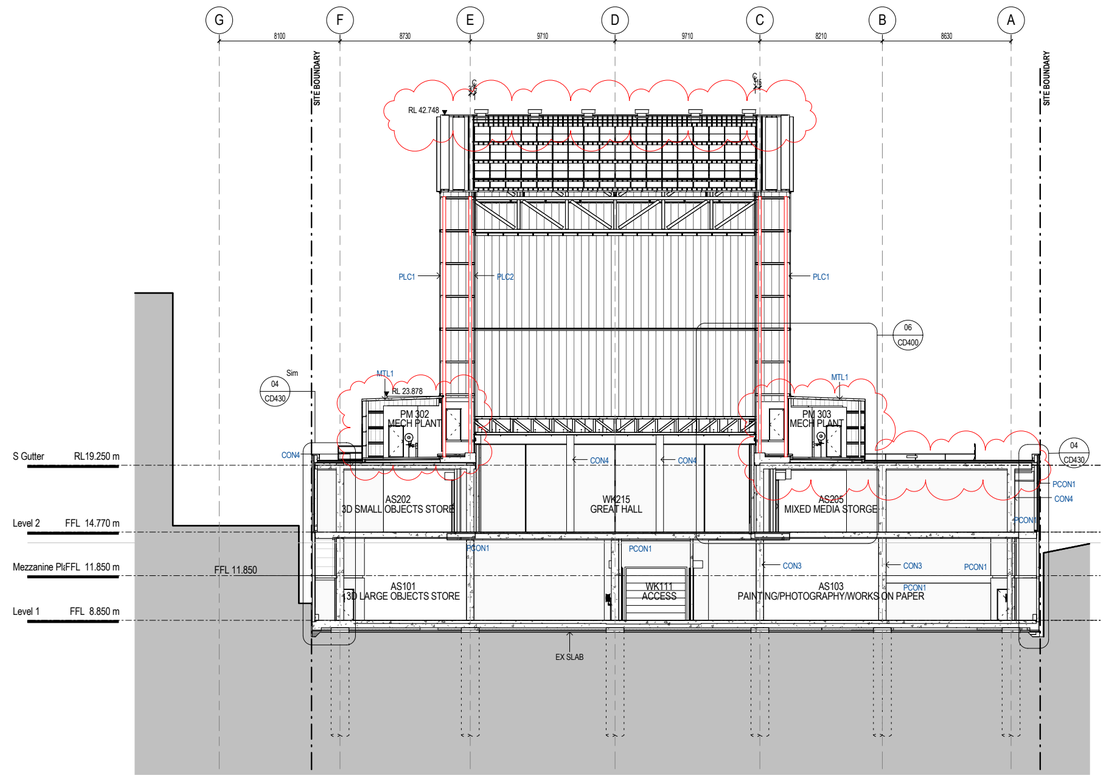
03 Section

North elevation non-fire-rated steel truss structure.



01 Section

East elevation, non-fire-rated steel truss structure and showing roof slope.



02 Section

THE NON-FIRE-RATED TRUSS STRUCTURE

The polycarbonate sheeting also surrounds external columns, which are proposed to be non-fire-rated. The assessment considered the impact of a building fire, including one that involves the polycarbonate sheeting, upon the structural stability of the columns. The non-fire-rated truss structure is shown in red in the figure above.

13

Facade Engineering

Surface Design

The role of the facade engineer

The facade is one of the largest and most important elements in a building. It is critical to assign a specialist facade engineer to assist with the development of the design and to follow through to confirm compliance at completion. The development of the performance criteria in co-ordination with the other engineering disciplines, along with client and architectural requirements, needs a specialist who can distil those into a set of documents which the market and facade contractors can understand and deliver efficiently and effectively.

Surface Design was engaged in July 2015 to give design advice for the facades of the Great Hall. In mid-September 2015, we provided initial design and construction 'for tender' documentation, consisting of a facade performance specification and design intent details for the multiwall polycarbonate cladding component of the project. This documentation was finalised and delivered in October 2015 and tender followed. Our services were maintained through the procurement stages as peer reviewer for the client side, reviewing the subcontractors' detailed design (review of their shop drawings and engineering calculations) and quality of manufacture and installation. The facade was installed in 2017.

As the facade engineers for Dangrove, we provided a range of engineering services including review of the following:

- Options and systems available.
- Architectural intended designs for feasibility.
- Structural design of the components and systems.
- Integration and co-ordination of the facade with the structure, such as movement joint locations, size and connections to structure.
- Co-ordination with mechanical performance requirements.
- Co-ordination with acoustic requirements.
- Thermal performance calculations and assessments.
- Weatherproofing detailing development and review of performance test data.
- Advice on materials selections for durability, compatibility and maintenance requirements.
- Assistance in developing procurement strategies through understanding of the market capabilities and cost planning stages.

During procurement, fabrication and installation, we oversaw the quality control procedures through factory fabrication to site installation, conducting and witnessing various tests and sampling along the way.

In terms of design, we assessed structural loads and environmental criteria, including:

- Gravity and wind loads.
- Rainfall and weather resistance.
- Air pressures within the building.
- Heat loads and cooling effects.
- Atmospheric factors, such as those affecting corrosion and durability.



The use of polycarbonate cladding

Polycarbonate cladding has been used in a variety of buildings both in Australia and internationally. The material presents a lightweight, durable and robust alternative to glass while also presenting suitable architectural characteristics appropriate to the spatial and experiential architectural concept. It was for these reasons the Dangrove art storage facility adopted the German product Rodeca, a commercially available polycarbonate cladding.

Polycarbonates are used in many industries and household items, including: electronics, such as display screens; automotive and aeronautics, including jet fighter cockpit canopies; security glazing, typically combined or laminated with glass; optical lenses, DVDs, motorbike windshields, goggles, scuba masks, helmets and riot shields.

As a thermoplastic, the material is malleable and easily worked onto moulds or extrusions and pultrusions. The properties of the material are due to the chemical bonding and structures of the polycarbonate; the long chains made up of groups of carbon, hydrogen and oxygen, bonded covalently in a specific arrangement, provide its strength, stability and transparency among other physical properties.

The polycarbonate molecules absorb UV radiation, which is a critical attribute for the protection of the artwork at Dangrove. Conversely, the absorption of this energy in a polycarbonate chemical structure can initiate photo ageing and photo oxidation leading to yellowing of the material. This can be managed through a UV protection film co-extruded onto the outside surface of the cladding. The degradation of any material must be understood and managed; when considering facades, this informs their design, maintenance and replacement strategies.

The multiwall polycarbonate panels at Dangrove include interlocking joints which help provide an efficient, structurally sound, weathertight, UV-absorbing, well-insulated facade system. The double skin facade system allows future replacement as well as a back-up defence system for weather resistance and enhanced thermal performance.

Visually, the polycarbonate creates a translucent screen to the rib-like structural steel skeleton of the Great Hall. This results in a present yet weightless feel to the structure which, at the same time, protects the internal spaces housing the artworks.

The development of polycarbonate

Polycarbonate was developed through the mid 20th century by chemists at Bayer in Germany and, separately, at General Electric in the USA. Bayer marketed the material as Makrolon while the GE product was marketed as LEXAN under a separate division called GE Plastics. Further developments in the following years led to improved properties including improved visual quality ('clearness') and more companies from around the world developed their own production of the material for various uses.

The development of synthetic plastics and other materials through the 1800s and 1900s stems back to the synthesis of benzene in Germany. In 1825, benzene was first extracted from whale oil by Michael Faraday, who was better known for his work in electromagnetism. This period of development in plastics and synthetic materials is sometimes referred to as the 'synthetic chemical revolution', and represents an acceleration in technological advances.

The advances in polycarbonate production and cladding include the development of extruded multiwall systems with interlocking joints, similar to tongue and groove style joints, and the additions of coatings, such as UV protection films or thermal performance coatings, which have improved performance and reliability of the systems. These interlocking joints and UV protection films have been adopted at Dangrove.

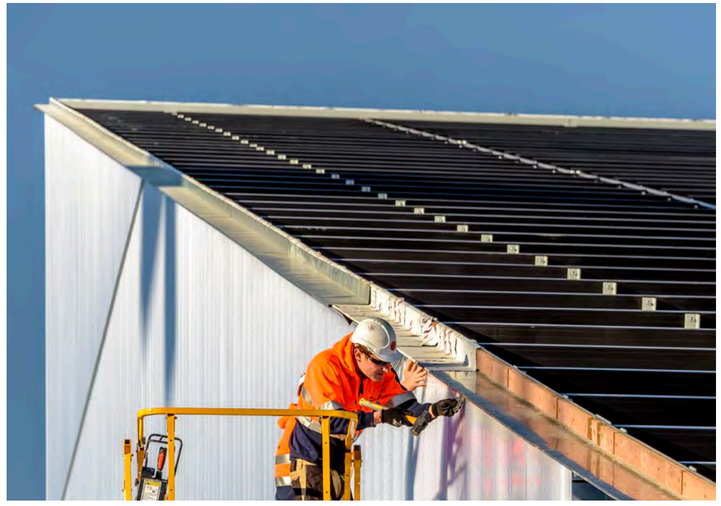
Rodeca, which was used on Dangrove, can be found on many notable projects around the world, including Vienna Airport and, in Australia, at Sydney's Ravenswood School for Girls and GMHBA Stadium in Geelong, Victoria. During the design phase, the team investigated other types of polycarbonate cladding from Europe and the United States.

Polycarbonate cladding on the Great Hall

The polycarbonate cladding for the triangular prism-shaped structure included a double skin facade. To the south it is a rectangular-shaped facade, and to the east and west are elongated triangular walls. The walls are approximately 20 metres tall, and the double skin facade includes a nominally 1.8-metre-deep cavity between inner and outer skins. The cavity houses the zone for structural steel (designed by structural engineers TTW). The inner and outer skins were proposed as a proprietary multiwall polycarbonate cladding product and system. Various suppliers were considered, and their systems compared by Surface Design.

The facade is fixed to the primary steel structure and includes movement joints, sill and head details, corners, fixings, cappings, flashings and the like. Through the design stages,

The interfaces of the polycarbonate facade and roof were designed in great detail in the initial stages of the design to validate the architectural intent and the required performance. This required careful consideration of the geometry, installation methods, access and sequences. Here we see the installer progressively installing the rigid flashing, weather proofing layers and visual capping components from elevated work platforms.



various strategies for performance of the facade were considered, including durability and maintenance, thermal performance, waterproofing, air tightness and ventilation of the cavity, structural performance, fixings methods and installation methods, accommodation of movements, weatherproofing, acoustic, fire performance and visual impacts.

Systems and design development

The design of any facade or facade system requires knowledge and understanding of the project constraints, the client's and architectural design aspirations and the physical capabilities of the proposed materials, along with detailed communication and exchange of ideas to bring these sometimes conflicting requirements together to a final design and, ultimately, a constructed project.

Several translucent facade cladding materials had been considered by the architects before Surface Design's engagement; these were mainly glazing materials. The polycarbonate had a visual quality that is generally not available in glass products. It is softer and less reflective and provides a certain visual character. Low reflectivity was considered important for this project with visibility from afar, major roads and airport nearby. Furthermore, as the design developed with the structural engineers, the primary design decision to use polycarbonate was because of its lower overall weight on the structure, and polycarbonate's ability to reduce UV light entering the facility.

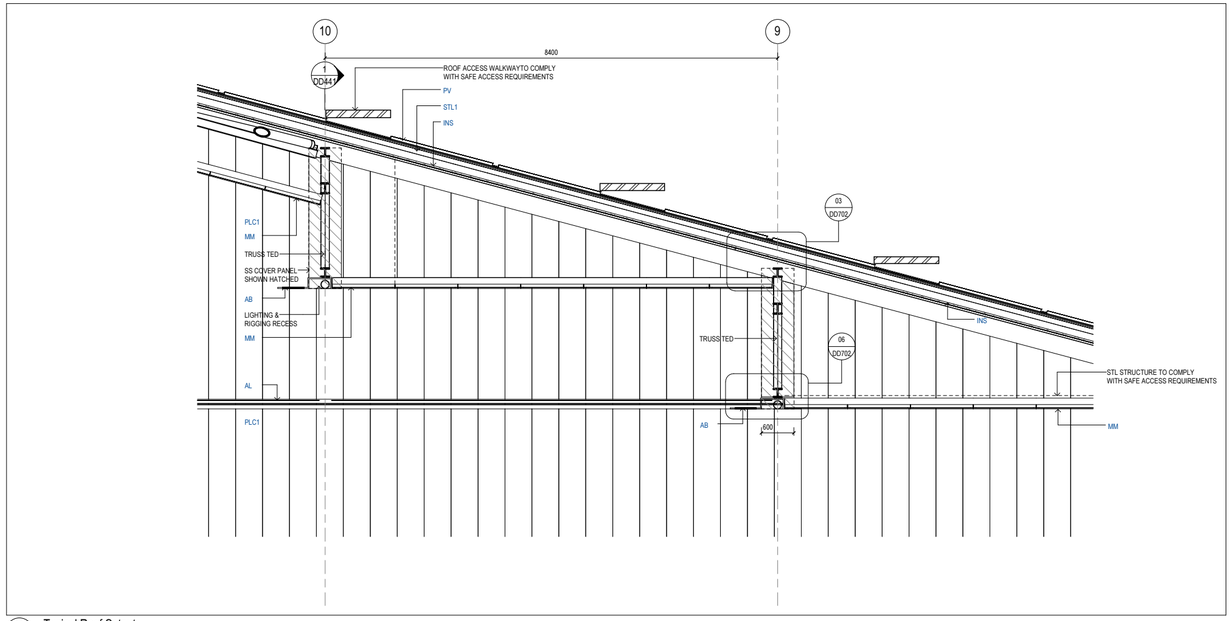
The durability and maintenance of polycarbonate

From a durability perspective, polycarbonates have a history of UV degradation, including discolouration and embrittlement, as do all polymers. Through the early stages of this design, research into the performance of these multiwall polycarbonate products due to UV exposure revealed that certain manufacturers' products have a 'UV protective barrier' co-extruded with the multiwall polycarbonate materials. This is effectively a proprietary protective coating to improve durability under UV exposure. Some manufacturers presented accelerated weathering test data (including exposure to UV light); these results were favourable and informed some of the design decisions.

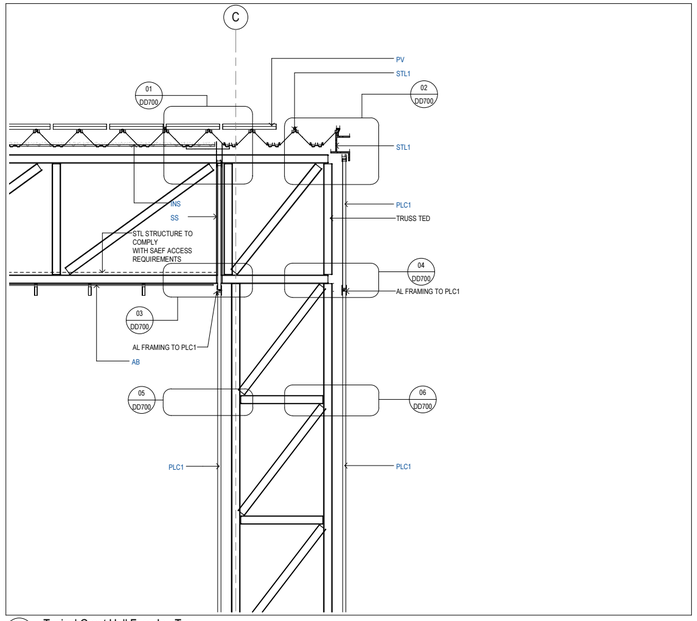
The brief, set out in the Principal's Project Requirements (PPR) document, required a 100-year life for Dangrove. There was a requirement that the polycarbonate wall experience minimal colour change – a sign of deterioration. This was discussed at length through the early design stages, with the eventual realistic expectation based on the existing accelerated weathering performance data reviewed and accepted by the design team.

There were discussions between Surface Design, Tzannes, Aver and the client about the design life and the related concerns about the longevity of the polycarbonate in Australian conditions. While the client's aim is for a 100-year life for the building, established data does not demonstrate that this is possible for the polycarbonate cladding. This informed the design team to develop a facade that could be replaced with minimal disruption to the operations of the storage facility. The double skin system is intended to provide this

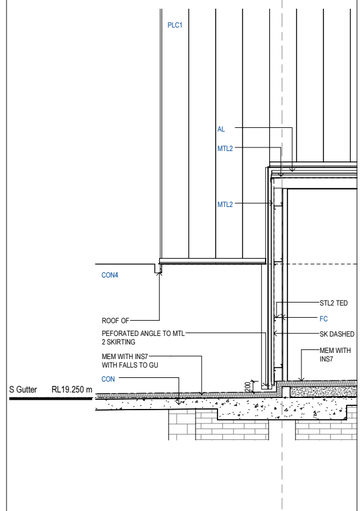
The design was developed geometrically and technically through the early stages to inform the final design. These images show the architectural 1:50 scale sections that indicate the key interfaces and geometrical requirements that were co-ordinated with the facade details, structural systems and internal finishes.



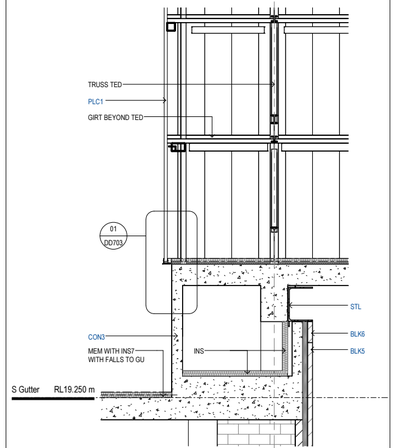
01 DD301 Typical Roof Setout
Scale 1 : 50



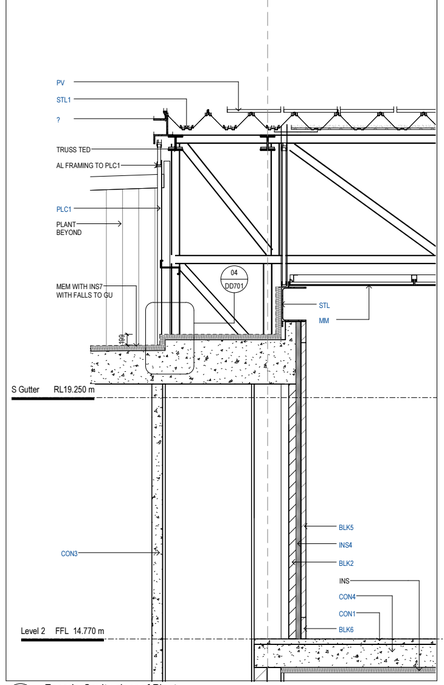
02 DD302 Typical Great Hall Facade - Top
Scale 1 : 50



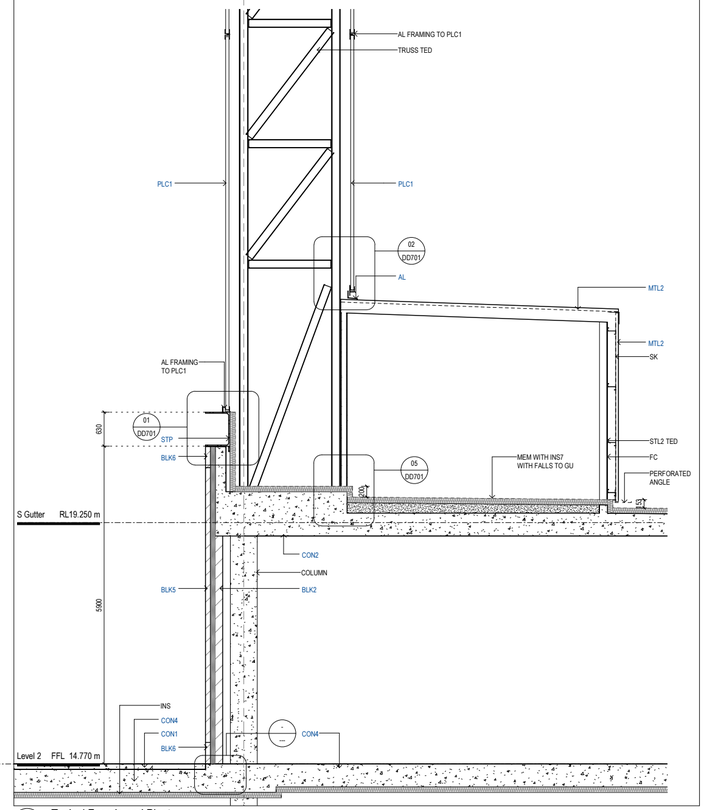
03 DD104 Facade Elevation - South
Scale 1 : 50



04 DD104 South Facade Cavity
Scale 1 : 50



05 DD103 Facade Cavity clear of Plant
Scale 1 : 50



06 DD302 Typical Facade and Plant
Scale 1 : 50

through the adoption of the internal skin as a temporary weatherproof facade. The detailing allowed for easy replacement, which was discussed as 'compensating' for the reduced life.

Protection of the artworks
The Great Hall provides a space where artworks can be evaluated, and the facade must act as a protective barrier. While there was a concern for UV degradation of the polycarbonate, the material effectively eliminated UV light exposure to the inside of the Great Hall, resulting in a UV-safe environment for the artwork.

The high levels of performance for weatherproofing and air tightness set for the facade were achievable in various proprietary jointing systems. These systems have previously been validated through laboratory testing with test reports and results available from the manufacturers. Surface Design reviewed and compared these test results (typically from international standards) to Australian Standards and Australian conditions to confirm suitability for use on this project.

Thermal performance
The double skin polycarbonate facade provides a highly insulated system which allowed the mechanical engineers to design systems to control humidity levels and temperatures within the art storage spaces efficiently and reliably.

The U value of each skin is in the order of 0.7W/m^{2}K with the total build-up of the double skin achieving a U value in the order of 0.3W/m^{2}K or an R value of 2.8m^{2}K/W, equivalent to 100-mm-thick standard Rockwool insulation. The polycarbonate skins are external to the steel structure, therefore minimising thermal bridging through the facade.

This thermal performance also contributes to thermal comfort within the space and minimal risk of condensation forming on the facade elements.

To assist further with thermal performance, the cavity of the double skin was designed to be ventilated and drained. This would allow hot air that built up within it to dissipate. We co-ordinated closely with the architect, sustainability and mechanical engineers (Steensen Varming) to develop various solutions for this. The schematic design solution was the use of an open grille at the top and bottom of the cavity to allow free airflow (see design drawings on pages 180 and 182). However, this grille was not integrated in the final construction by the contractor due to concerns of insect and dust migration into the cavity.

Weather resistance
Waterproofing credentials of the polycarbonate skins were demonstrated through existing physical laboratory testing on full-scale prototypes. The Rodeca product has been verified through German testing laboratory Prüfinstitut Schlösser und Beschläge Velbert PIV to EN 1026 (air permeability test) and EN 1027 (watertightness test). These testing reports were compared to the project requirements and Australian Standards for compliance.

The systems are considered to be 'face-sealed' via gaskets. During the schematic design stage, Surface Design developed a system as a drained sill and head style detail. Vertical expansion and contraction is accepted at the head of each panel, however the proprietary 'face-sealed' joint detail was adopted by the contractor in the final construction.

The use of a drained double skin facade provided a prudent solution to waterproofing the Great Hall; the cavity could be treated as a wet zone in case of any inadvertent water ingress through the outer skin, perhaps through the breakdown of the face seals or interfacing elements, such as roof flashings.

Fire performance
Polycarbonates are combustible – a detailed and expansive fire engineered solution provided by RED Fire, which included the results of extensive overseas testing of the material used, allayed any concerns.

Co-ordination with the structure
The steel structure that supports the roof and the polycarbonate facades includes a series of trussed portal frames and lateral girt system. TTW provided movement and deflection diagrams for their design under wind loads and the like, from which we assessed the polycarbonate jointing to develop suitable detailing. Being lightweight and relatively flexible, the polycarbonate required less steel to support it than if it had been glass. The length of polycarbonate sheets was limited to approximately 6 metres to allow transportation and handling, and future replacement. These panels were eventually brought to site in containers with protective wrapping and were lifted with mechanical assistance.

The polycarbonate panels are each approximately 500 mm wide, and are joined to each other with a tongue and groove style detail (these were proprietary engineered and tested systems from the manufacturer). They are fixed at regular centres to the girts, spaced accordingly to accommodate wind loads. The polycarbonate multiwall system is nominally 60 mm thick made up of 12 layers of thin polycarbonate, braced at regular centres in a grid structure. The articulated nature of the construction allows for a relatively flexible wall that could accommodate lateral sway of the steel frames without damage or opening of joints.

Conclusion
There are not many suppliers and installers of polycarbonate multiwall systems, and the materials are not commonplace. This meant there was only a small pool of precedent projects locally, and these are relatively young buildings themselves. There is a certain level of risk with the use of any unusual and innovative material; the design team and client recognised this was the case with the polycarbonate. While comfort and reliability of design life is important, it is not as easy to quantify for a new and innovative material or system. However, the polycarbonate had advantages over glass, providing the desired aesthetic, low reflectivity, lightweight construction, flexibility (compared to glass), a reduction in the support steel required, ease of installation and replacement, redundancy in the multiwall system for both durability and structural and/or impact resistance.

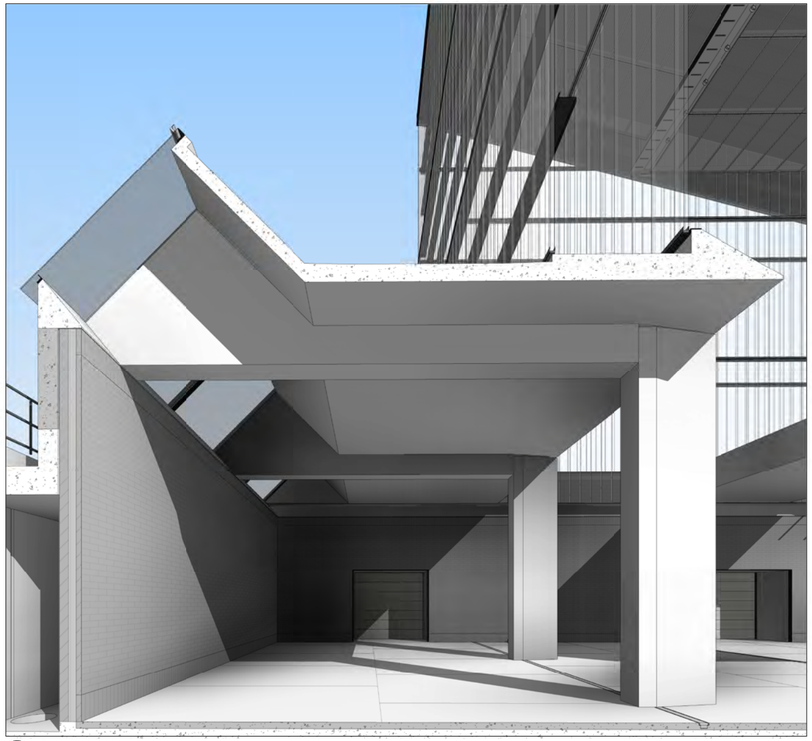
Practice profile
Surface Design, established in Sydney in 2010, is a team of professional designers from various disciplines, including facade engineering and sustainable engineering. The business focuses on environmental sustainable design, facade engineering and materials science, and has projects around Australia as well as internationally.

Key people
Robert Moisy
Beres Dowdle

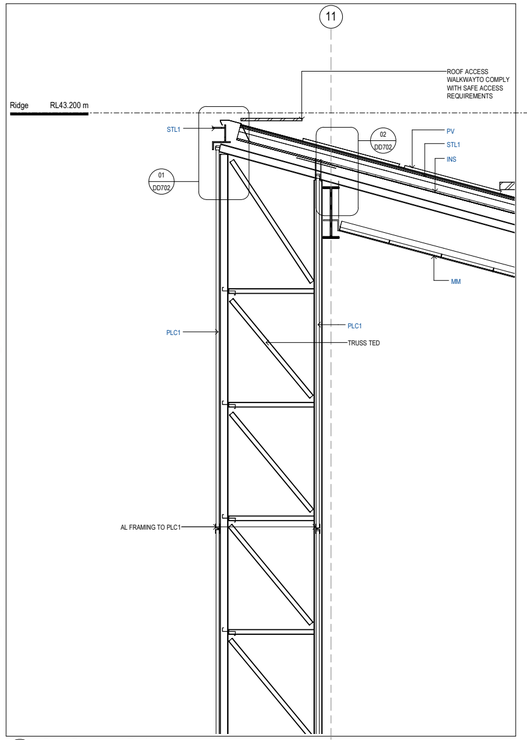


These pages: In addition to the architectural 1:50 scale sections, the team used 3-D models to understand the various facades and interfaces.

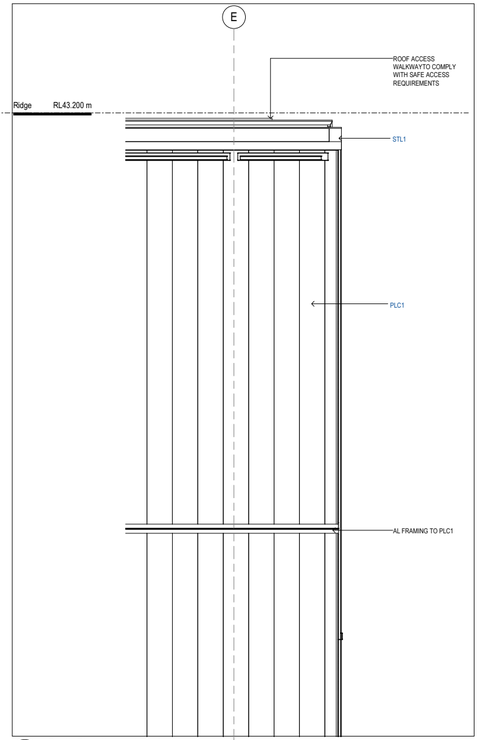
180–183: In the early design stages 1:1 and 1:2 scale detailed were developed from hand drawn sketches to CAD developed details, and included in the tendering and contract documentation for the procurement of the D&C contractors.



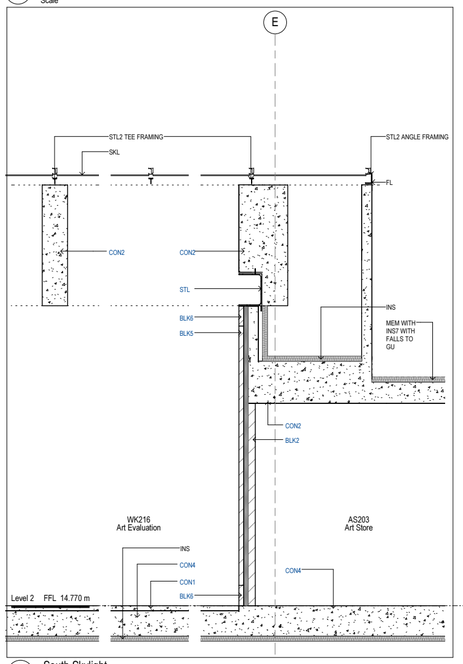
01 South Skylight View
Scale



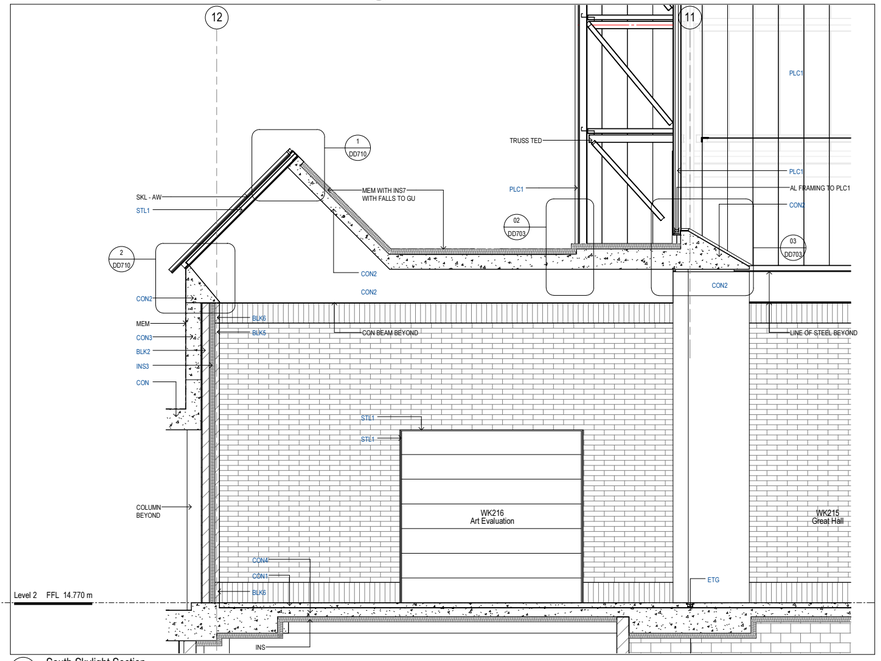
02 DD301 South Facade and Roof
Scale 1 : 50



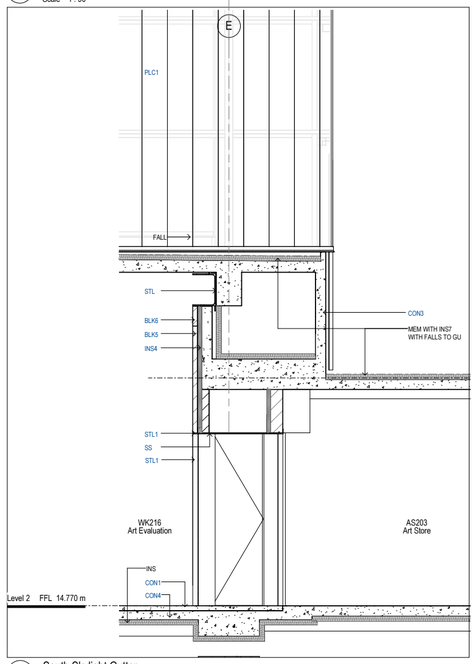
03 DD201 South Elevation and Roof
Scale 1 : 50



04 DD103 South Skylight
Scale 1 : 50



05 DD301 South Skylight Section
Scale 1 : 50



05 DD103 South Skylight Gutter
Scale 1 : 50

GENERAL NOTES

Verify Dimensions on site prior to commencement of work. Check existing RL's on site. Advise Architect of any discrepancies before commencement. Allow for adjustments to suit discrepancies.
Comply with relevant authorities requirements. Comply with Building Code of Australia requirements. Comply with relevant Australian Standards for materials and construction practice. Comply with Basix Certificate.
Do not scale from drawings.

1:50
0m 0.5m 1m 2m 3m

LEGEND

NOTE:
STRUCTURAL STEEL SHOWN IN THIS DRWAING REQUIRED UPDATING

REV.	DESCRIPTION	DATE
A	For Information Only	21.09.15

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T +61 2 9319 3744
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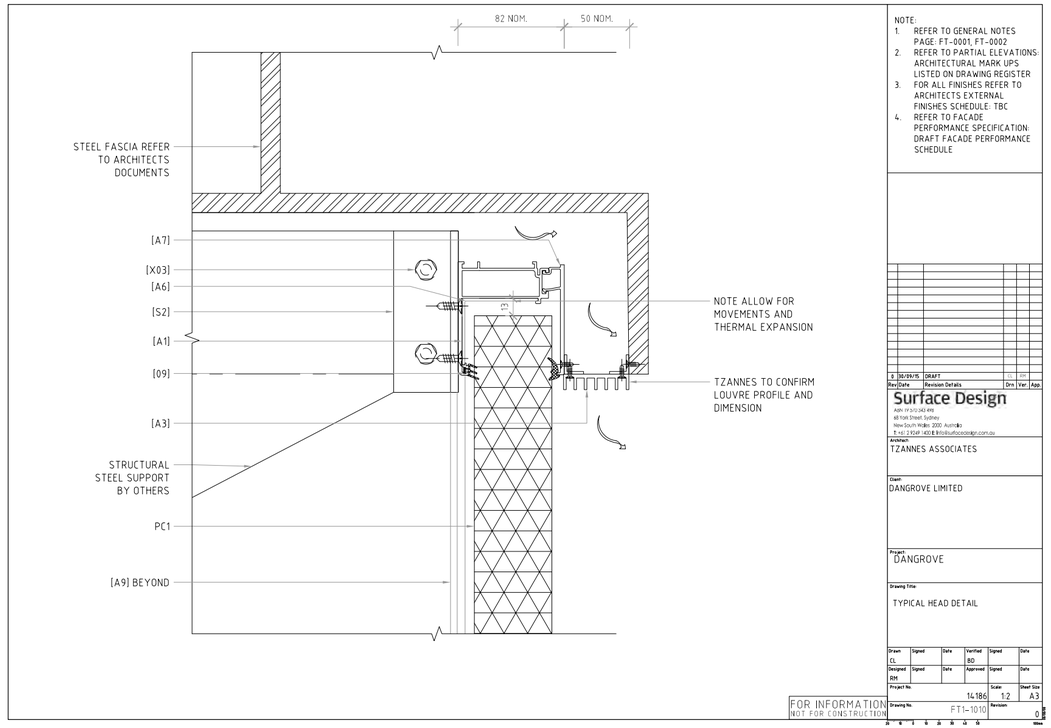
DANGROVE

12-20 Mandible Street, Alexandria NSW 2015

Facade Sections - South Skylight and Window

SCALE @ A1: 1 : 50 DOUBLE FOR A3
DRAWN: TZ
CHECKED: TZ

PROJECT	DRAWING	REVISION
14009	DD410	A



NOTE:
1. REFER TO GENERAL NOTES PAGE: FT-0001, FT-0002
2. REFER TO PARTIAL ELEVATIONS: ARCHITECTURAL MARK UPS LISTED ON DRAWING REGISTER
3. FOR ALL FINISHES REFER TO ARCHITECTS EXTERNAL FINISHES SCHEDULE: TBC
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Rev	Date	Revision Details	Drn	Ver	App
B	30/09/15	DRAFT	CL	BM	

Surface Design
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60 York Street Sydney
New South Wales 2000, Australia
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Architect: TZANNES ASSOCIATES

Client: DANGROVE LIMITED

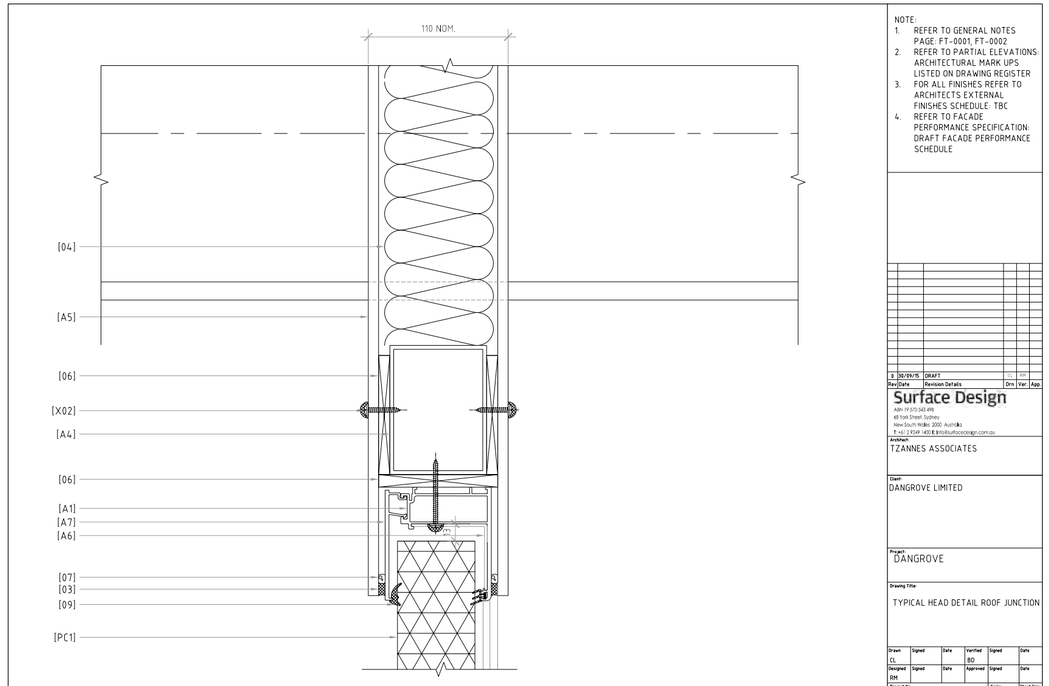
Project: DANGROVE

Drawing Title: TYPICAL HEAD DETAIL

Drawn	Signed	Date	Verified	Signed	Date
CL			BD		
Designed	Signed	Date	Approved	Signed	Date
BM					

Project No. 14186 | Scale 1:2 | Sheet Size A3
Drawing No. FT1-1010 | Revision 0

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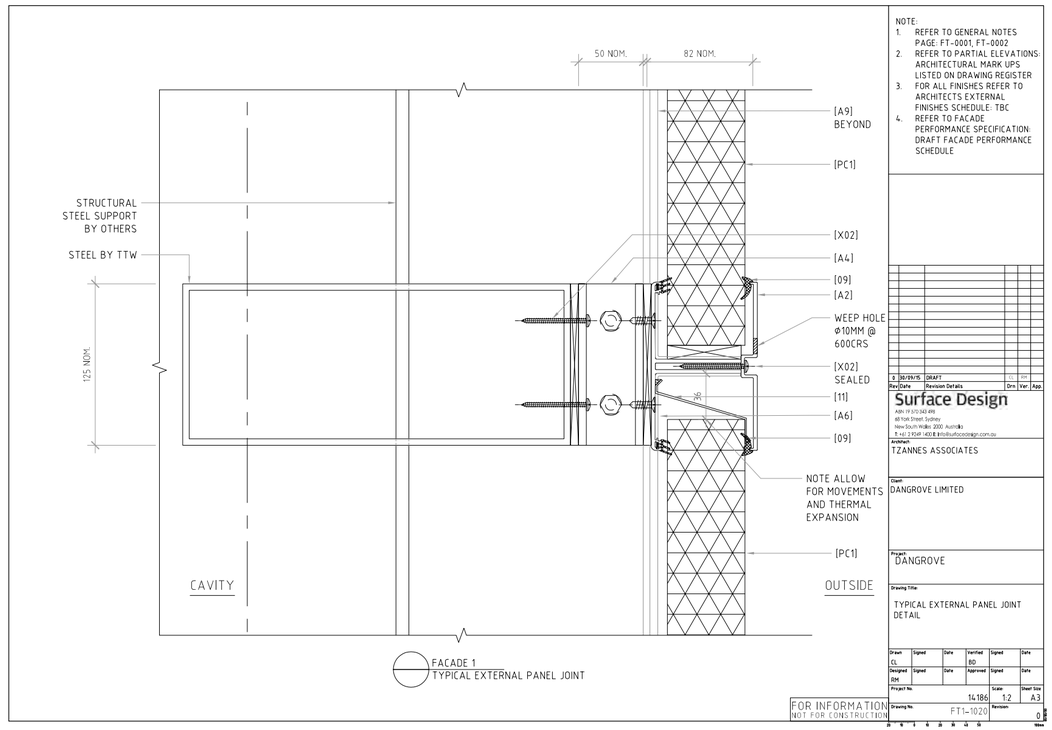
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Drawing Title: TYPICAL HEAD DETAIL ROOF JUNCTION

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CL			BD		
Designed	Signed	Date	Approved	Signed	Date
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Project No. 14186 | Scale 1:2 | Sheet Size A3
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FACADE 1
TYPICAL EXTERNAL PANEL JOINT

NOTE:
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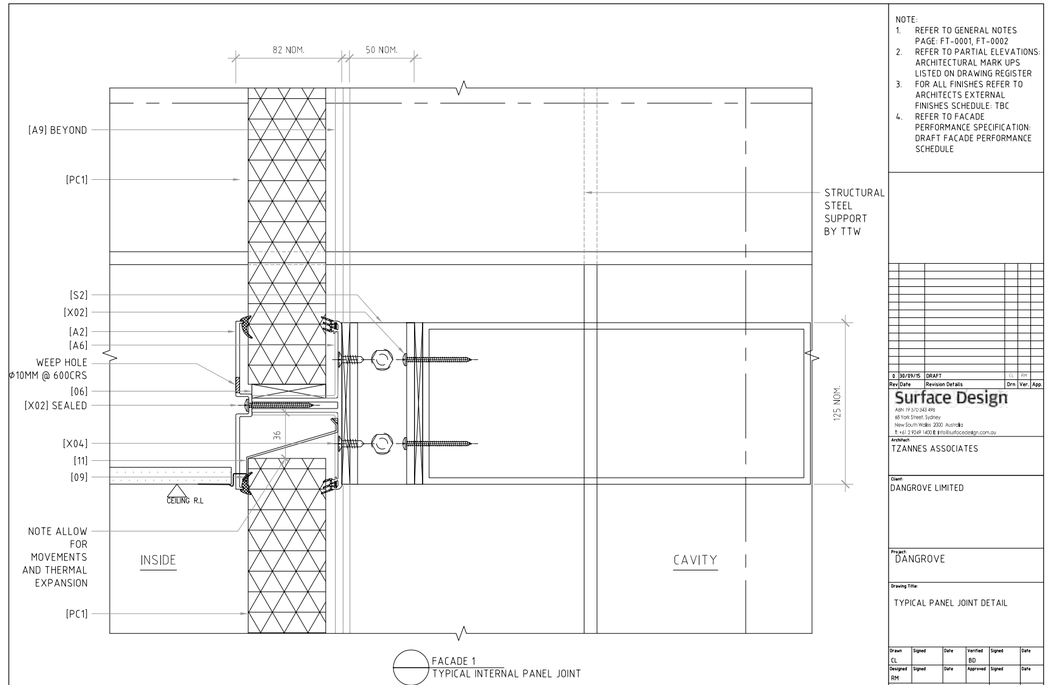
Project: DANGROVE

Drawing Title: TYPICAL EXTERNAL PANEL JOINT DETAIL

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CL			BD		
Designed	Signed	Date	Approved	Signed	Date
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Project No. 14186 | Scale 1:2 | Sheet Size A3
Drawing No. FT1-1020 | Revision 0

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FACADE 1
TYPICAL INTERNAL PANEL JOINT

NOTE:
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2. REFER TO PARTIAL ELEVATIONS: ARCHITECTURAL MARK UPS LISTED ON DRAWING REGISTER
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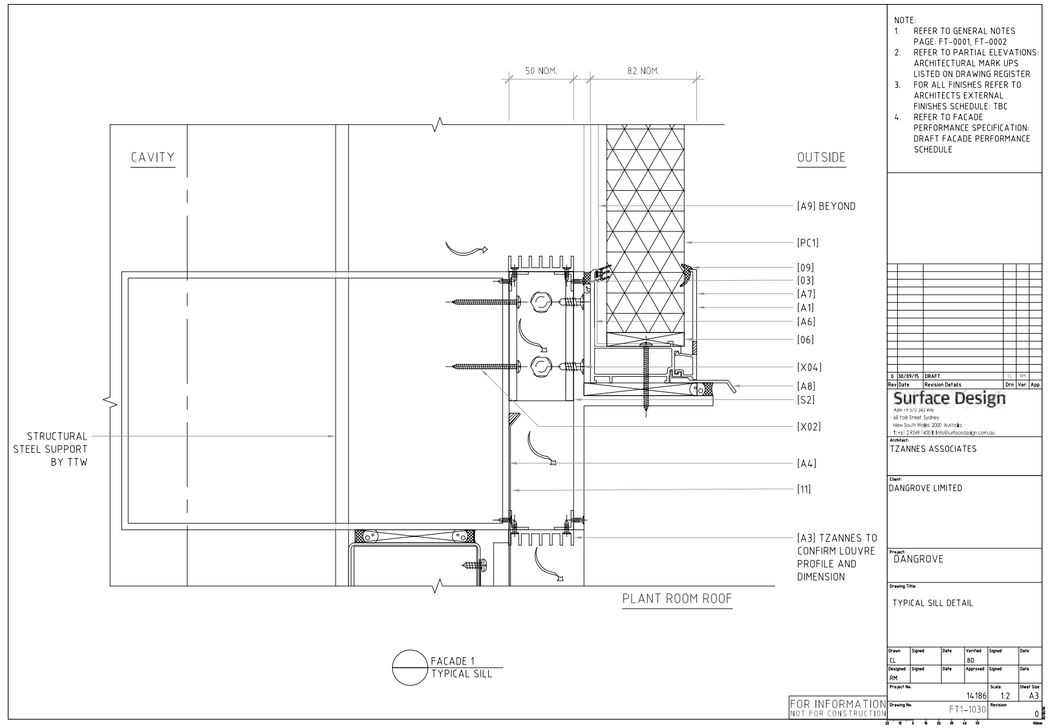
Project: DANGROVE

Drawing Title: TYPICAL PANEL JOINT DETAIL

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CL			BD		
Designed	Signed	Date	Approved	Signed	Date
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Project No. 14186 | Scale 1:2 | Sheet Size A3
Drawing No. FT1-1021 | Revision 0

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Client: DANGROVE LIMITED

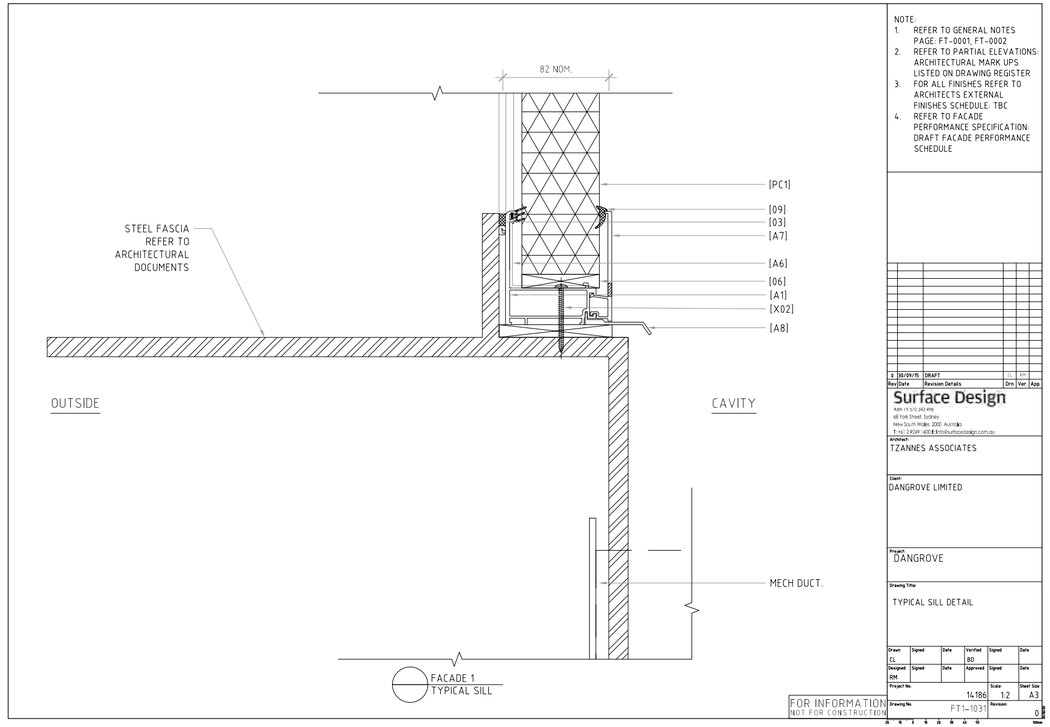
Project: DANGROVE

Drawing Title: TYPICAL SILL DETAIL

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Designed	Signed	Date	Approved	Signed	Date
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Project No.	Scale	Sheet Size
14186	1:2	A3
Drawing No. FT1-1030	Revision 0	

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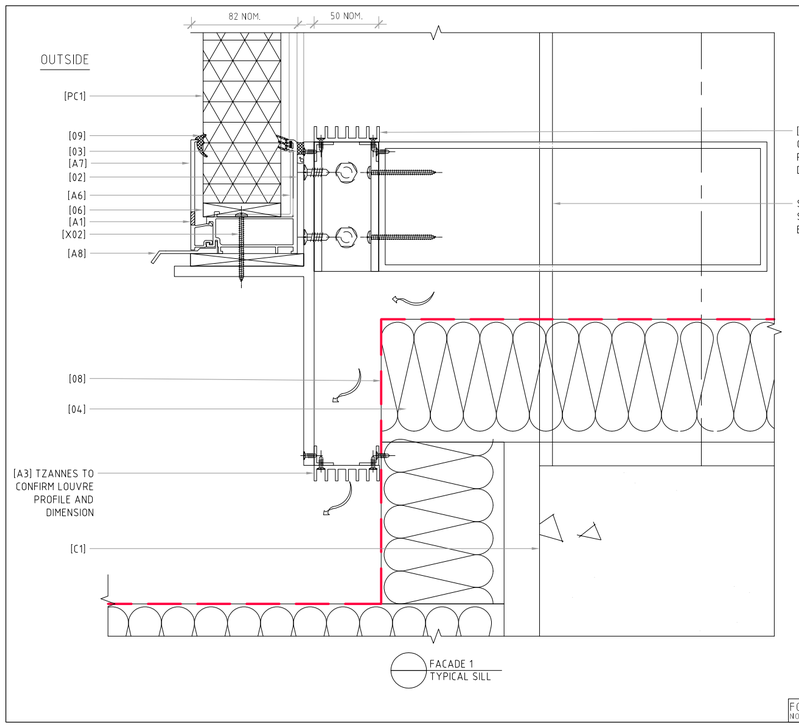
Project: DANGROVE

Drawing Title: TYPICAL SILL DETAIL

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Designed	Signed	Date	Approved	Signed	Date
BM					

Project No.	Scale	Sheet Size
14186	1:2	A3
Drawing No. FT1-1031	Revision 0	

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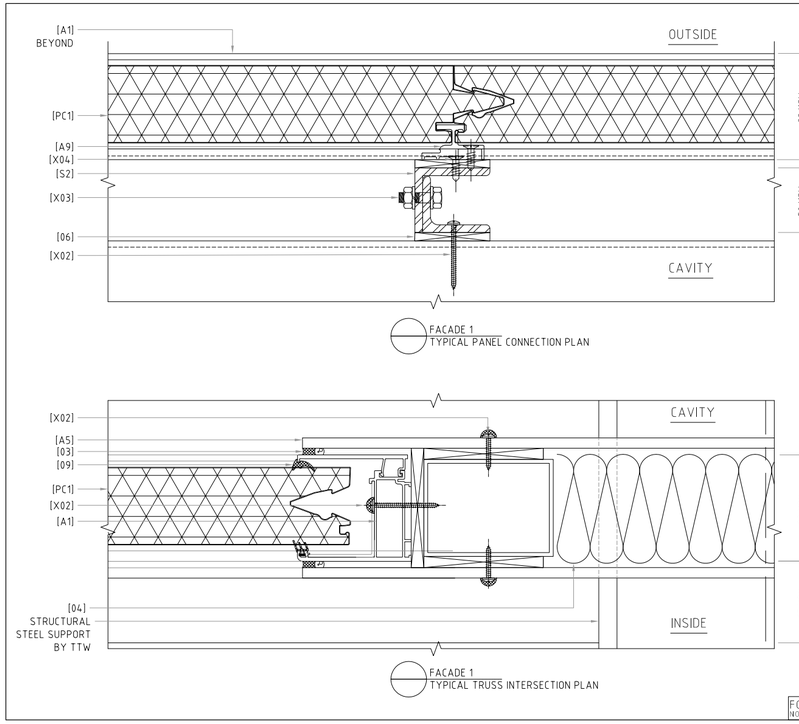
Project: DANGROVE

Drawing Title: TYPICAL SILL DETAIL

Drawn	Signed	Date	Verified	Signed	Date
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Designed	Signed	Date	Approved	Signed	Date
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Project No.	Scale	Sheet Size
14186	1:2	A3
Drawing No. FT1-1032	Revision 0	

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Client: DANGROVE LIMITED

Project: DANGROVE

Drawing Title: TYPICAL PLAN DETAIL

Drawn	Signed	Date	Verified	Signed	Date
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Designed	Signed	Date	Approved	Signed	Date
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Project No.	Scale	Sheet Size
14186	1:2	A3
Drawing No. FT1-1040	Revision 0	

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14

Mechanical Engineering

Steensen Varming

Dangrove's design principles

Our way of thinking was to employ passive mechanisms in the architecture, supplemented with mechanical air conditioning systems as the means to provide environmental conditions for Dangrove. Storage spaces are deliberately bunkered down in the building and cocooned with thermal mass, surrounded by layers of spaces so that the storage volumes are not directly exposed to external conditions.

In the cathedral-like and voluminous Great Hall, which has access to daylight, we didn't seek to maintain close control conditions throughout, but only at low levels in the occupied space. To do otherwise would have been wasteful and unnecessary.

The role of the mechanical engineer

We need to be much more than engineers. Our knowledge has to blend engineering expertise with knowledge from other fields such as cultural needs, life science, physiology, material science, organisational behaviour, environmental science and building physics.

'The engineer in his own way is an artist too – and not just a dead fish with a slide rule.'
Jørgen Varming

With Dangrove, we drew on our depth of experience and lessons learnt to guide and advise on the most appropriate mechanical systems and control strategies that not only enable the highly specific environmental conditions to be maintained, but also minimise the energy consumed to do so.

The evolution of environmental conditions in galleries

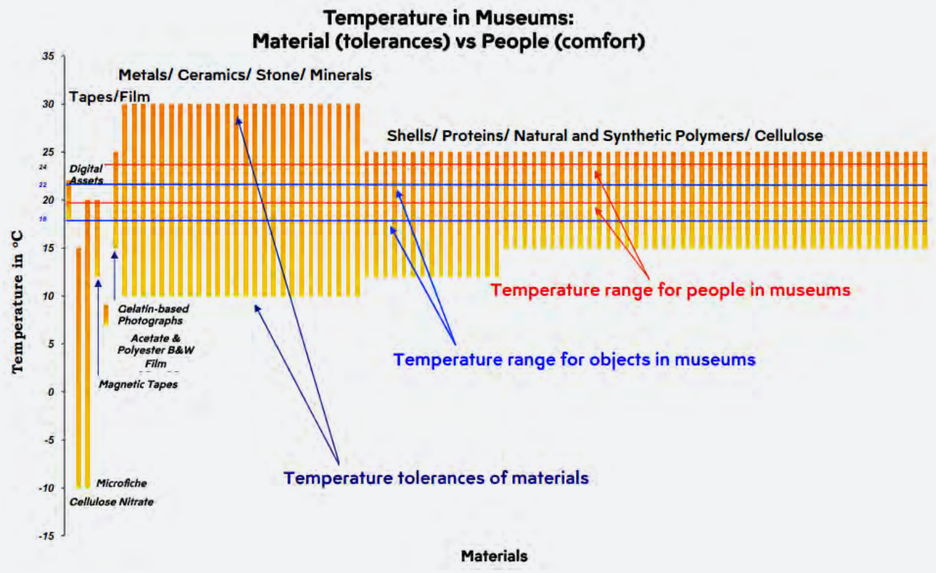
Before delving further into the design process and our way of thinking, we should first start by taking a step back to understand how galleries' environmental conditions have evolved over the centuries, and look at the thinking and science behind how best to conserve a gallery's collection.

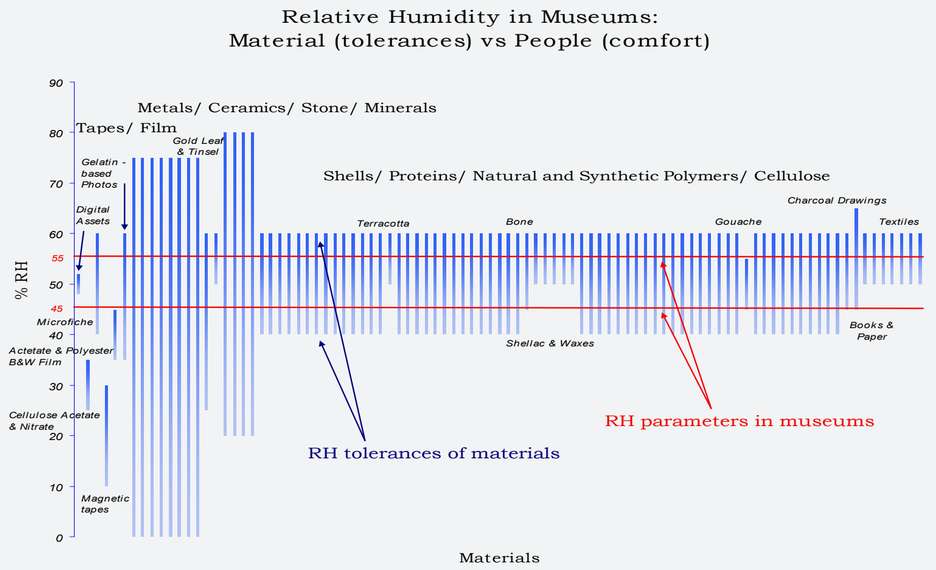
The industrialisation era of 1850 to 1900 brought with it access to abundant non-renewable power, which in turn led to the mechanical intervention for the control of environmental conditions. Coal and natural gas, predominantly, provided fuel for lighting, heating, refrigeration and ventilation. In 1902, American engineer Willis Haviland Carrier invented the first electrical air conditioning unit.

There was no longer a total reliance on passive means of environmental control – windows and skylights were not the only means of providing light and fresh air; thick external walls were not absolutely necessary as a way of modulating internal temperatures.

To the architectural world, the door had been opened to allow for more adventurous designs. Buildings could now become deeper plan, use more glass and be constructed of lighter weight materials and in climates with more extreme conditions. With this change, it could be argued that designers became over-reliant on energy-consuming plant and equipment to maintain the close environmental conditions that museums and galleries demanded.

Today, the thinking has changed; underpinned by research and a better understanding of conservation requirements, the need for strict environmental control has relaxed. No longer does temperature and humidity need to be kept within tight control tolerances; wider control bands coupled with resetting of temperature and humidity set points between seasons is now more commonplace. And with improvements in construction and





The temperature and relative humidity (RH) in museums and galleries – human comfort versus material needs. They show that, in most cases, the temperature and RH range followed by museums and galleries are not required. (From Barbara Reeve, head of collection services, Australian War Memorial.)

better airtightness in buildings, the reliance on pressurising buildings to keep unwanted air out has also reduced.

This all leads to more sustainable outcomes in which the conservation and protection of artwork is not compromised but protected through more operationally energy-efficient air conditioning systems.

This story is not one based on utilising energy-efficient mechanical systems alone, but through the adoption of techniques employed prior to the industrialisation era when buildings were solely reliant on passive means of control.

Scope of works

The mechanical services aim was to ensure that the system design, while being energy efficient, enabled the building to meet the needs of collection conservation as well as occupant comfort. At the same time, it had to be reliable, controllable and maintainable.

For open displays, the mechanical air conditioning systems are absolutely critical in maintaining control. To put into perspective how hard they work, they need to respond, for every minute, hour and day of the year, to the dynamic nature of external conditions – temperature, humidity, radiation (solar and night sky), precipitation, infiltration (the amount of outside air that leaks into a building), occupancy, pollutants (internal and external), variations in sensing (devices that measure temperature and humidity levels in the space) and actuation (opening and closing of air damper and water valves to control flow) and water quality.

The mechanical services systems conceived and designed by Steensen Varming to respond to these factors comprise:

- Thermal plant comprising water-cooled chillers, cooling towers and gas-fired boilers.
- Close control mechanical ventilation – including heating, cooling, dehumidification and humidification control.
- Localised heating/cooling systems.
- Smoke purge systems.
- Exhaust ventilation systems.
- Specialist ventilation systems serving the workshop and conservation.
- Computer-based building management systems.

All these systems were developed to design development stage. This included the provision of plant spatial information and main service reticulation routes in addition to system functional descriptions. These aspects were co-ordinated by the design team during the design process to ensure that plant space, risers and ceiling space were adequately placed, sized and arranged in an order that complemented the spatial planning of the building. This was balanced with the need for logical position of plant to optimise distribution efficiency and access for safe maintenance.

The design produced by Steensen Varming was further progressed by the contractor to detailed design stage, which involved final plant and equipment sizing and co-ordination with other services and the structure. Once the main contractor was appointed, the role of Steensen Varming changed to a monitor and review role on behalf of the client. While no longer responsible for the primary design, we reviewed the contract design documentation to ensure that these met the design intent and overall project brief.

This form of procurement is commonplace today and there are several variants to design and construction contracts. Simply put, it is a mechanism whereby the design finalisation risk and cost to construct is transferred to the contractor. It works well for some projects, but not all. At the time, we did not support this form of procurement for Dangrove – it was not our preferred delivery method as it led to changes in the design which, arguably, were not in the interests of achieving the best outcome for the project and our client. Those changes can often be motivated by the potential of cost savings rather than what is right for the project.

Design proposals

Numerous air conditioning and ventilation systems serve the building based on the functional and operational needs of each space. There are relatively simple and straightforward ones, such as toilet exhaust and plant room ventilation systems, while others are more complex and interconnected with other systems.

These are designed to cater for specific statutory requirements around life safety and public amenity as well as functional requirements around environmental temperature and humidity control; specialist exhaust systems for the workshop and conservation spaces; and the times of use that each system needs to operate. Layered onto these systems is plant required for back-up should equipment fail or need to go offline for maintenance. This means that, during such events, environmental conditions aren't compromised in critical areas such as the art storage spaces.

The real heart of the mechanical system are the air handling units (AHU) which serve the close control art storage spaces. Each storage space has its own AHU that allows temperature and humidity set points to be individually adjusted if required. Although initially the storage spaces have the same temperature and humidity set points, the design has the flexibility to allow them to be changed in the future. For instance, some objects, made of stone, steel, ceramic and such like, could be housed separately in different conditions, as illustrated in the diagrams on page 188, or the loaning body of borrowed artwork could specify certain conditions. Various options and configurations were modelled and tested to ensure the optimum plant configuration was achieved against the range of operating scenarios.

The AHUs serving storage spaces are required to deliver stable temperature and humidity conditions – with a maximum rate of change of 2°C and 3 per cent RH per hour – 24 hours a day, 7 days a week, 365 days a year. They comprise face and bypass dampers, supply air fans, heating and cooling coils, panel and deep bed filters.

When dehumidification is needed, typically in summer months when outside conditions are more humid, the cooling coil temperature is lowered to remove moisture. A portion of the entering air bypasses the cooling coil to hold the discharge temperature needed to maintain room temperature. The result is the same temperature and humidity conditions as in a traditional reheat coil method, while using less energy.

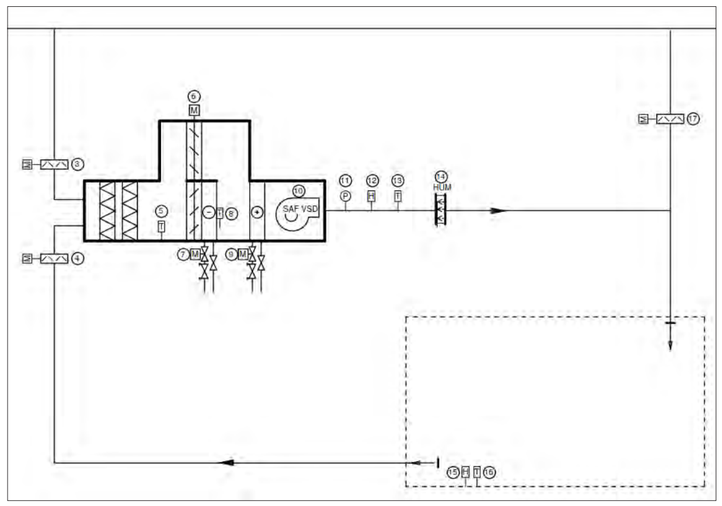
Dew point temperature (or combined temperature and humidity) sensors are installed directly downstream of the cooling coil to provide stable humidity control. Dew point control is our preferred method of control based on many years of experience and, in terms of reliability, stability and energy efficiency, is far superior to humidity control alone.

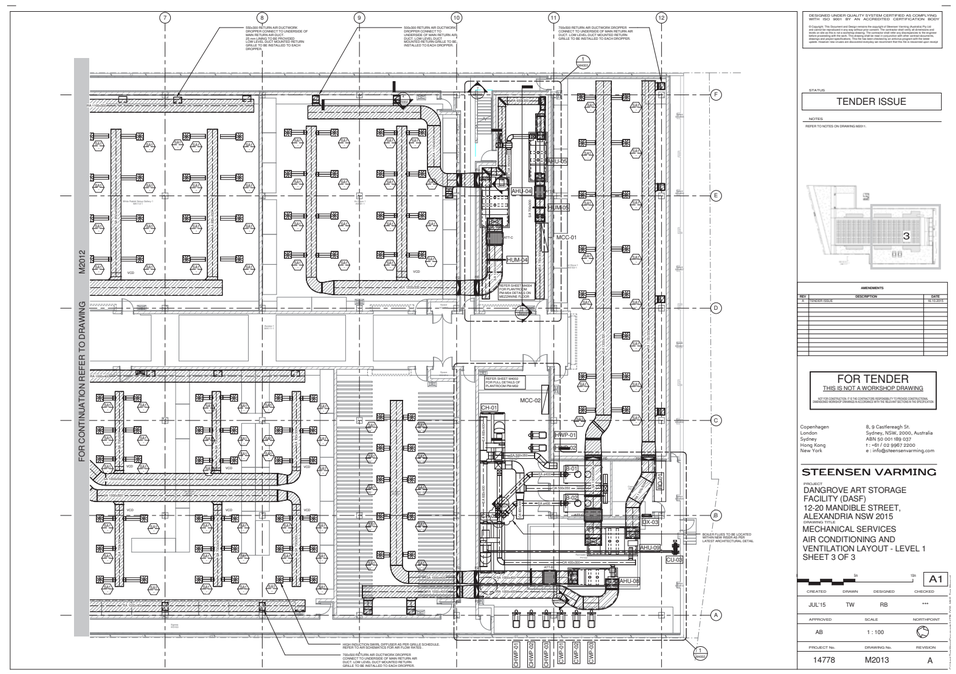
Air handling systems serving storage spaces do not incorporate an economy cycle mode due to the strict temperature and humidity control requirements.

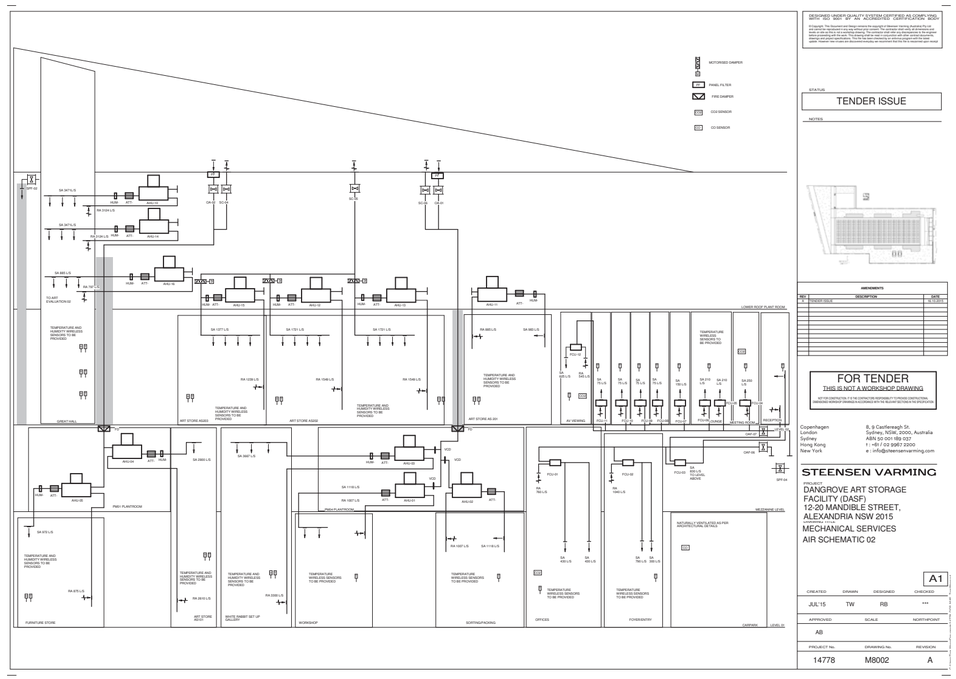
Duct-mounted ultrasonic humidifiers are installed in the supply ductwork downstream of the supply fan and supply duct attenuator. Humidifiers add moisture to the supply air stream and are typically called on during winter months when the moisture content of ambient air is lower.

All air handling supply, return, outdoor and relief fans are fitted with variable speed drives complete with high level interface (HLI) connection to the building management system. These variable speed drives allow the air volumes to be adjusted for balancing purposes. This was done during the commissioning phase to establish the correct air volumes needed. Other forms of balancing rely on using dampers, much like a tap, to control the volume

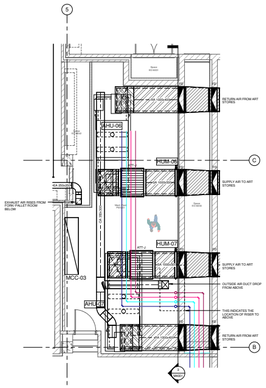
This page: Schematic diagram of the storage air handling unit components. Each component of the system is referenced and linked to the functional control description which defines how the plant components are to operate under a range of scenarios. Opposite, above: Example of an air conditioning and ventilation layout. Below: Air schematic diagram illustrates the connection and interrelationship of the building's ventilation systems.



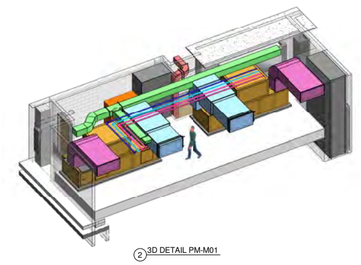




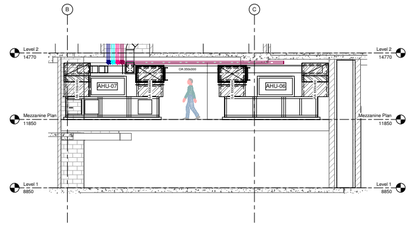
These pages: Plantroom details. The mechanical services were all documented and co-ordinated in 3-D using Revit BIM software. 3-D images were incorporated into the drawing layouts to provide a greater level of information and communicate to the tendering contractors the arrangement and co-ordination of the various mechanical services.



1 PLANTROOM PM-M01
1 : 50



2 3D DETAIL PM-M01



3 PLANTROOM PM-M01 SECTION
1 : 50

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STATUS

TENDER ISSUE

NOTES

AMENDMENTS

REV	DESCRIPTION	DATE
	TENDER ISSUE	16.10.2015

FOR TENDER
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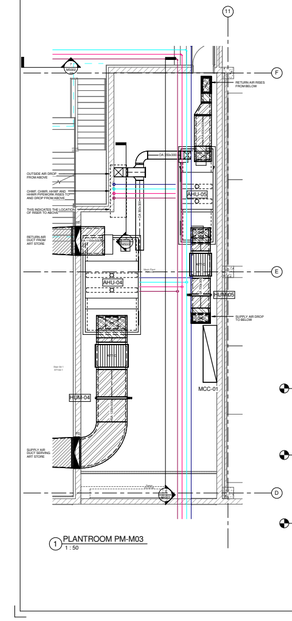
STEENSEN VARMING

PROJECT
DANGROVE ART STORAGE FACILITY (DASF)
12-20 MANDIBLE STREET, ALEXANDRIA NSW 2015

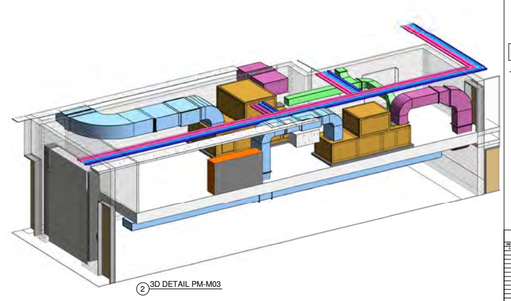
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MECHANICAL SERVICES
PLANTROOM DETAILS - PM-M01

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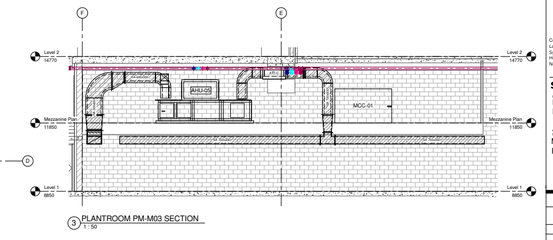
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APPROVED	SCALE		NORTHPOINT
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1 PLANTROOM PM-M03
1 : 50



2 3D DETAIL PM-M03



3 PLANTROOM PM-M03 SECTION
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TENDER ISSUE

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AMENDMENTS

REV	DESCRIPTION	DATE
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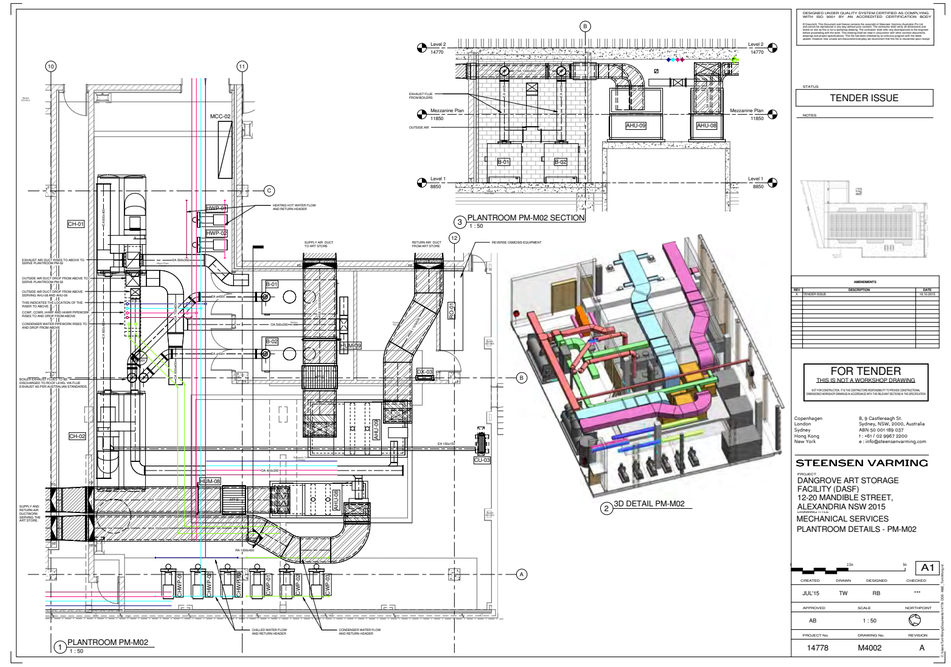
STEENSEN VARMING

PROJECT
DANGROVE ART STORAGE FACILITY (DASF)
12-20 MANDIBLE STREET, ALEXANDRIA NSW 2015

DRAWING
MECHANICAL SERVICES
PLANTROOM DETAILS - PM-M03

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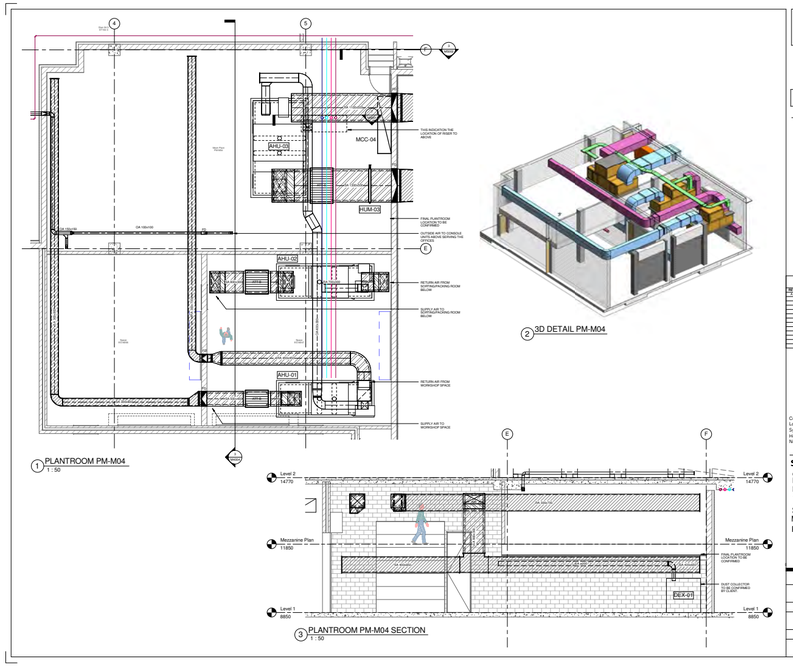
CREATED	DRAWN	DESIGNED	CHECKED
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APPROVED	SCALE		NORTHPOINT
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14778	M4003		A



1 PLANTROOM PM-M02
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3 PLANTROOM PM-M02 SECTION
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2 3D DETAIL PM-M02



1 PLANTROOM PM-M04
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2 3D DETAIL PM-M04

3 PLANTROOM PM-M04 SECTION
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DRAWING
MECHANICAL SERVICES
PLANTROOM DETAILS - PM-M04

mm to A1

CREATED	DRAWN	DESIGNED	CHECKED
JUL'15	TW	RB	***
APPROVED	SCALE		NORTHPOINT
AB	1 : 50		
PROJECT No.	DRAWING No.		REVISION
14778	M4004		A

of air, through creating a resistance and pressure loss. However, these are not the most effective or energy-efficient way of balancing.

The AHUs serving the storage spaces have an innovative function in which they are configured to incorporate an automated (non-statutory) smoke clearance mode. This provides extra coverage for the protection of objects from smoke damage, and is an approach we first developed and implemented in the Art Gallery of NSW offsite storage building located in Lilyfield, NSW.

In normal mode, air is delivered to the space by way of high-level supply and low-level return (with grilles located both high in the space and low to the ground). In smoke clearance mode, dampers open and/or close to reverse the air direction whereby supply fans shut down. The supply ductwork is used as a smoke clearance path, mechanically driven by a smoke clearance fan. Make-up air is by way of natural means through door openings.

This configuration was changed and reconfigured by the mechanical contractor during the design and construction stage of the project. This, together with some other changes, had an impact on the final commissioning and post-occupancy evaluation (POE) stage, where it took time to get the plant operating in a stable manner to the brief requirements.

Construction phase activities

Once the design stage was complete, Steensen Varming undertook a number of periodic site inspections throughout the construction period.

The aim of these site visits was to review the quality of the installation and to engage with the main contractor and subcontractors regularly. This ensured a dialogue was maintained, queries that arose from the construction process were quickly answered and that the design intent was being met.

While Steensen Varming undertook site visits to review the overall installation, it should be noted that the responsibility to ensure the installation was in accordance with the requirements of the design and Australian Standards lay with the head contractor.

As part of the site visits, a site inspection report was produced. This served two purposes, the first of which was to give the client and overall project team an update on the progress of the mechanical installation; the second, and potentially more important, was to document and identify any defects within the installation that required remedial works. At the initial stages of the project this involved taking pictures and writing a report. However, in the final third of the construction phase, this was done directly to the Aconex Field, which is a cloud-based operation management system for managing information and processes on projects. This enabled the person undertaking the site visit to document any defects as they walked around, with the room name and level noted. This allowed the site teams to quickly find the defect and remedy it, rather than wait for a site visit report to be produced. While this software worked well for the majority of the time, there were instances where, due to the location in the building, it was not possible to get a mobile phone signal, meaning that it was not possible to upload the images and/or comments as the site visit was taking place. This would result in, at times, a mixture of both electronic and more traditional site reports.

Following the installation phase of the works, the project moved to the commissioning stage. At this stage in the process, the final systems were reviewed and set up to ensure that they were functioning as required. This included the contractor and independent commissioning agent attending site to review all the systems, and taking measurements such as air and water flow rates and comparing it to the design data available. This ensured that the systems were working according to the design, with any discrepancies identified and fixed prior to handover.

If we could have done things differently on this project, we would have held the contractor to account in regard to the design of the system. The project was a design and construct project – however, a number of the contractor drawings and technical submissions were a straight copy-paste of the schematic information from the tender package. As such, when there were instances that the equipment did not function as intended, the contractor did not accept our advice on how to proceed to address the issues of concern. We recall discussions with the builder and mechanical contractor around the configuration of the gallery/art storage handling units (AHUs). They had proposed changes to their configuration, which we did not agree with. We raised our concerns in the early stages of the construction phase as this departed from our design intent, and we had concerns as to the balancing of air flow within the AHUs. We expect that this was a contributing factor to the issues identified during the commissioning phase.

From discussions with Ralf Wilson, Dangrove's facility manager, we understand that modifications to the air conditioning system operation have occurred post-occupation. While we were not consulted or involved with these changes, we understand from Ralf that energy savings were subsequently achieved.

The humidity control function had been changed and played with over time, and was causing continual cycling of the air handling units from humidification to dehumidification mode as the units attempted to maintain a constant humidity set point. This continual cycling leads to excessive energy usage and wastage, and is a very inefficient control strategy which, in our view, was the major contributing factor to the high power bills Dangrove was receiving. The design had proceeded with our input but, as per the example above, in some instances, our advice was not taken onboard.

The control logic had been changed from what had been originally specified and, based on the explanation provided, we suspect that the systems were controlling to humidity rather than dew point control as originally specified. This is evidenced through the unstable and cyclic humidity logs.

The fact that conditions remain stable without the need to provide air conditioning 24 hours a day is pleasing to hear, and is a great result and accolade for the project. This is testament to the founding design principles employed in which the benefits of passive measures such as incorporation of thermal mass have now been validated.

While the humidity control still remained an issue at the time of writing, we do believe that through further consultation and review of the control logic that we can achieve stable and energy-efficient humidity control. We have offered to be involved in this fine tuning process.

Our overall reflections on the project are that it was a joy to work with Judith Neilson, Tzannes and the design team to turn this dream into a reality. Not often do you get the privilege and opportunity to work on a project of this nature with such freedom of creative thought and spirit. Normally, cultural facilities in Australia are delivered by governments, and rarely through private bodies. As such, they are bound to a degree of governance structures, numerous stakeholders and budget, all of which has the potential to stifle innovation and design outcomes. With Dangrove, we had a unique environment inspired by Judith's vision for what this building was to be and what it was to provide for the collection, her guests and the artists whose works are stored there.

Practice profile

Since the company was established in Copenhagen in 1933, Steensen Varming has enjoyed a long history of completing successful cultural projects, including museums and art galleries around the world. Steensen Varming are practitioners in mechanical and electrical engineering, lighting and sustainable designs that enhance spatial design. Working in close cooperation with architects, designers, scientists and engineers, we have developed the knowledge to seamlessly assimilate form and function, art and technology. In addition to the Vitruvian principles of solidity, utility and beauty, we have put in place our own guiding triad to produce intelligent, valuable and elegant solutions.

These encompass architectural and urban design, the private, corporate and public sectors, modest upgrades and World Heritage sites.

Key people

Chris Arkins
Craig Prince
Tava Sitauti

15

Lighting Design

Steensen Varming

The return brief and concept design

Dangrove is a unique building that removes the boundaries between collection storage facility, curatorial testing ground, exhibition display gallery and events space, all within the bold yet simple architectural geometries that belie the technical challenges that had to be resolved in order to deliver an intuitively operable facility of quiet, impressive scale.

The distinctive design of the building demanded an unorthodox lighting design approach that enhanced Dangrove's unique synthesis of architecture and the client vision for a facility of evolving functionality.

The objective was to deliver a coherent lighting design that considered the building's diverse uses and the visual interactions between each space. Steensen Varming's return brief outlined the objectives, quantitative and qualitative criteria for each space according to its use, the need for staff and visitor visual comfort, and advised on the best practice parameters for the lighting and preservation of art collections. The individual use requirements of the offices, collection stores, collection care and conservation, display flexibility and curatorial mock-ups of the White Rabbit Gallery and display areas, as well as grand events staged for important guests within the Great Hall and Re-Drawing Room, had to be considered. The overarching objective was to deliver maximum functionality with minimum visual intrusion.

Following the return brief, the concept design articulated the approach of treating daylight and electric lighting as a wholistic experience, and established the control strategies for each area, the collection display experience, and the expression of the visually dominant features of the building's facade and the front-of-house areas where the building's form, materiality and scale had to be expressed without dominating the primary focus of the facility, the care and display of its collection.

To meet these criteria, the highest quality lighting equipment, typologies and most up-to-date technologies were chosen to align with the sustainability objectives of the building, to deliver the optimal collection display and operational flexibility, safety and intuitive navigation, and enhance the visual comfort for staff and the experience for visitors.

Luminaires were specified for their ability to deliver high quality lighting under a range of display conditions including exhibition testing, display, performance and events, and the interface with daylight. A broad range of accessories and ease of operability, durability, material longevity and museum quality colour rendition were critical for optimal display lighting conditions, while minimising damage from optical radiation in accordance with international conservation standards.

Calculations were carried out to verify compliance with standards and the feasibility of the design intent. Then drawings of locations, details, specifications, circuiting and a control strategy were issued to a level where the design team were confident that the design could go to tender and enable the design and construct contractor to cost and complete the design.

Elements of the project

More straightforward elements of this project, such as back-of-house and storage lighting were easily bedded down in the early design stages prior to tender, while the more innovative elements were continuing to be developed. Control strategies were also easily implemented with the utilisation of a DALI control system that was appropriate for the time, being the proven and trusted control system for lighting projects where simple 'set and forget' programming is acceptable.



Great Hall installation and Garth Knight performance, utilising performance lighting for white wall-washing, and track downlights.



Throughout the storage spaces a linear LED lighting system was designed to provide a uniform light within a ‘cold-shell’ floorplan in anticipation of, and to inform, the further development of storage rack and equipment locations and heights. This is not a significant challenge but always comes with an element of risk to a successful layout. It can be easily assuaged if the design intent is understood and constant consultation is maintained during the evolving design of the storage racking design and location.

The White Rabbit set-up gallery demanded an approach that delivered museum standard lighting of a flexibility that would support Judith Neilson’s vision of a space that invited curatorial experimentation and reinterpretation of the collection’s content and changing interrelationships. The specification of a track lighting system that serviced a flexible lighting product range was essential for the exhibition design and installation team to be able to easily relocate luminaires and easily reinterpret lighting scenes and strategies to align with evolving design schemes during White Rabbit exhibition mock-ups.

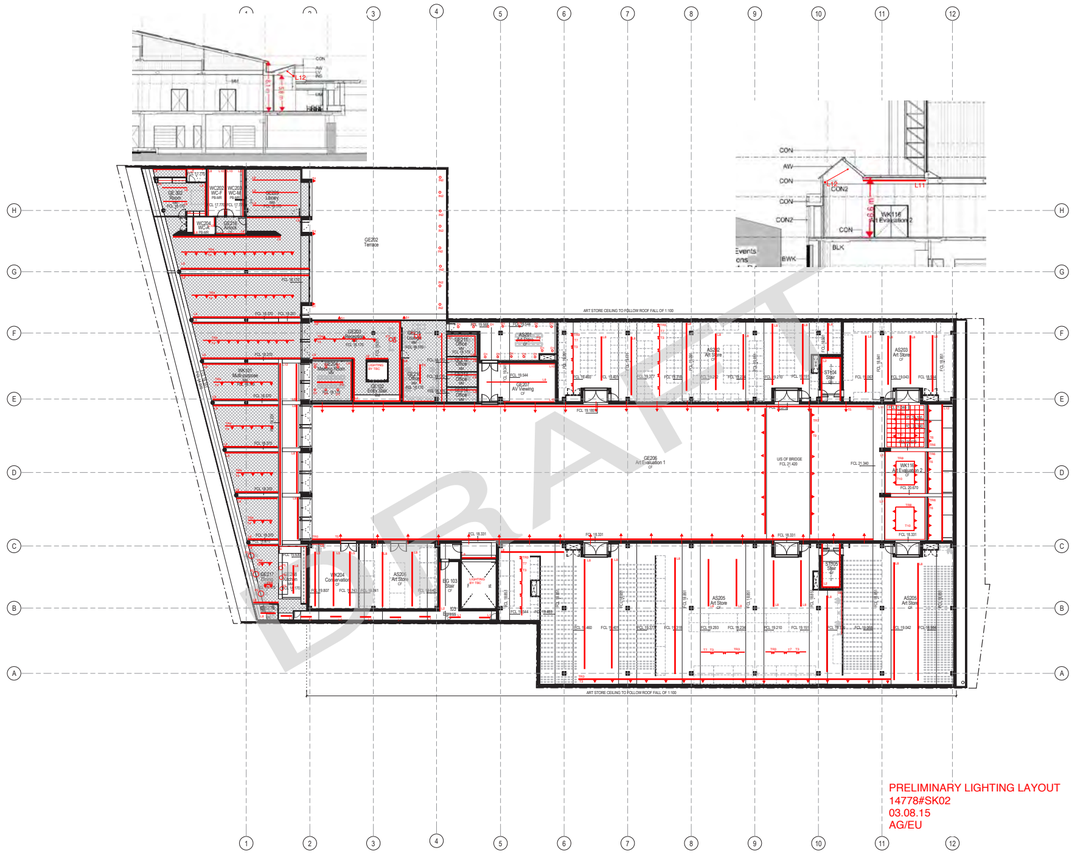
The Re-Drawing Room design inspired a series of linear luminaires that followed the line of the structural beams and the mechanical services to deliver a uniform layer of ambient light with the added flexibility of an additional track-mounted lighting system to highlight future key objects and furnishings. During the D&C stage (Design and Construct, a procurement method in which the contractor is responsible for design finalisation), the linear system was removed entirely at the direction of the architect, who felt the visibility of the system was more visually invasive. Due to the locations of mechanical services, this also minimised the potential for equipment clashes and difficulties that might arise with future maintenance access. Consequently, the linear system was replaced by track lighting only. This change in design direction was perfectly acceptable in terms of flexibility for the lighting of individual objects, but it did require an increase in the quantity of fittings needed to achieve the uniformity and functional ambient light levels, impacting on budget.

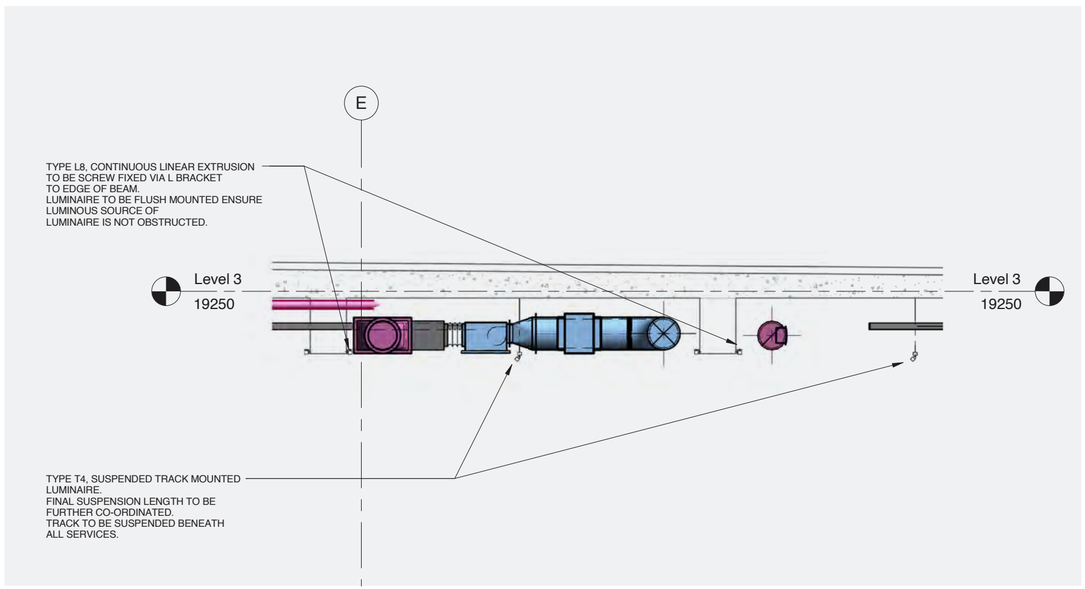
The external lighting for the sculpture terrace required a minimal approach while providing some flexibility for the final aiming and focusing of light upon a sculpture that was yet to be delivered to site. Experience in exhibition lighting design and a well-aligned understanding of what was required was of greatest benefit during one of the few lighting mock-ups. This was invaluable in making the decision to continue with the originally specified luminaires rather than compromise with a value engineered product that proved to be unacceptable due to its high level of glare identified during a mock-up of the originally specificied luminaire against the contractor-proposed alternative.

This page: Re-Drawing Room track lighting and daylighting through windows and skylights.

Opposite, above: Removal of L8 linear lighting designed to provide general lighting from the Re-Drawing Room as indicated in the sketch above consequently required increase in track lighting to provide general lighting as well as spotlighting of objects.

Below: Section indicates side mounting of T8 to beams in Re-Drawing Room. Removal of T8 also minimised risk of potential clashes with services during construction and the possibility of future maintenance issues encountered in confined spaces.





An early change to the concept

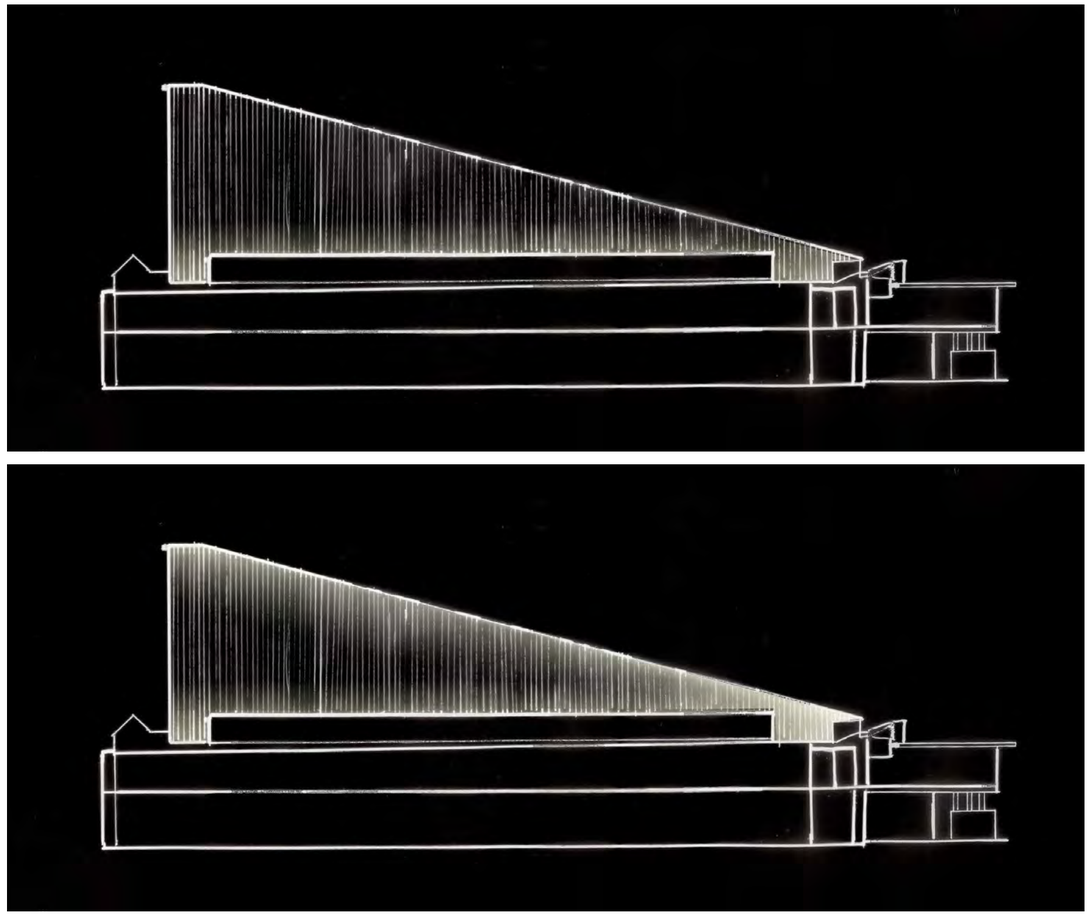
One of the early changes to the initial lighting concept was the elimination of the facade lighting. This was proposed to be located within the two polycarbonate skins, to create a soft glow at the base of the building's polycarbonate wedge as seen from outside. The conceptual intent was to also provide a gentle internal bleed light from the top edge of the interior display walls, producing a soft visual transition from display walls up through the polycarbonate walls above. The polycarbonate support structure had not been fully designed; there were concerns that this structure could diminish the effect, but it was determined that this could be resolved. However, after an initially positive response to this facade lighting concept, the client decided that she did not want the building to be a beacon and the concept was therefore not pursued. In the end, the interior bleed of light between the display and the polycarbonate walls was not a significant deviation from the original design intent and does not negatively impact on the architectural experience, nor that of viewing the collection on display. From an external viewpoint, the internal lighting does imbue the building with a faint glow at night when the lighting is on; however the building never overtly announces its presence, and when the internal lighting has been turned off, the building recedes further into the background, in keeping with the client's wish for it to be more discreet than originally conceived.

Finalisation of other, more complex elements of the lighting design could not be fully resolved, and could only be taken to a point where the design team were confident that the design would function according to intent. Design finalisation was to be completed during construction by the D&C contractor. Once the contractor was on board, the priorities naturally lay with the structure of the building, and lighting took a back seat. At this stage, the lighting had to be shoehorned into an already constrained budget and program.

Projects should be inherently budget- and efficiency-sensitive, but the risks associated can be compounded in a D&C process where the contractor takes on the responsibility of design finalisation.

This page, below: Internal facade uplighting. The concept for the facade lighting was designed to be mounted within the polycarbonate skin of the facade. Options were proposed for uplighting only, as indicated here, as well as a combination of uplighting and downlighting, indicated in the image below. Initially approved in principle, the concept was later rejected to minimise the building's visual presence within the night-time setting.

Bottom: Internal facade uplighting and downlighting. The facade lighting concept was proposed before the internal structure of the polycarbonate walls was fully understood; detailing the design would have required complex co-ordination with the structure. Further simulations would also have to have been carried out to understand how the structure impacted on the shading and shadowing which may have affected the conceptual intent to provide a uniform soft glow to highlight the form of the building.



Mounting location of performance lighting used to provide uniform wall-washing of the interior display walls of the Great Hall – one of the design innovations of the project. The sketch was part of the site investigation report indicating how the side mounting of performance luminaires was to be altered to align with design and in accordance with manufacturer recommendations to minimise potential damage to fittings and enable more flexible aiming and positioning of luminaires. It is unclear if the plugs to the rear of the fitting were proprietary or made onsite, which has the potential to risk damaging fittings and the control system.



The Great Hall

Of particular design importance and complexity was the Great Hall. The innovative lighting design for the Great Hall took on an unorthodox approach in the use of performance lighting (discussed in more detail below) in response to the unique size and shape of the space, but the building's spatial conditions could not be sensibly replicated, and mock-ups could not take place until the construction had progressed far enough to provide a testing space to verify the pre-tender simulations.

The continued design development of this area also meant that it could not be accurately costed; this played a part in the unexpected increase in costs creating a risk of perceived conflict with budget and construction efficiency. Risk exists when value engineering re-prioritises, misinterprets, omits or simplifies an aspect of a lighting design or infrastructure without an understanding of the impact these changes may have on outcomes or opportunities that are crucial to the quality and success envisioned for the project.

During any value management process, it can be far too easy for the quickest and most cost-effective solution to be adopted when the best solution is to dig even deeper to resolve challenges. Omissions of part of the design may occur for any number of reasons, but the substitution of cheaper products may not be the best, reliable long-term solution when it comes to longevity and serviceability over the building's lifetime. Especially if there is no first-hand evidence of a product's longevity, the resulting consequences may be ongoing maintenance and repairs of any part or all of the lighting system.

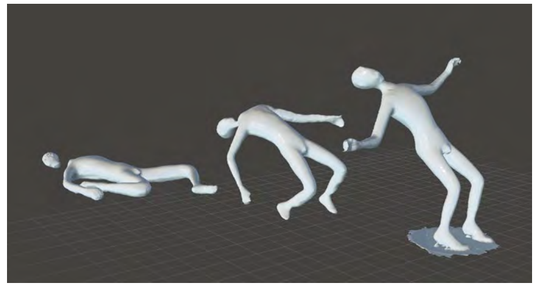
In this instance, lighting design finalisation for the Great Hall impacted on the overall project budget. To help meet the budget, Steensen Varming was asked to seek an alternative performance lighting product. After carrying out extensive research, one that met the budget and was understood to be of a similar reliable quality as previously proposed was specified.

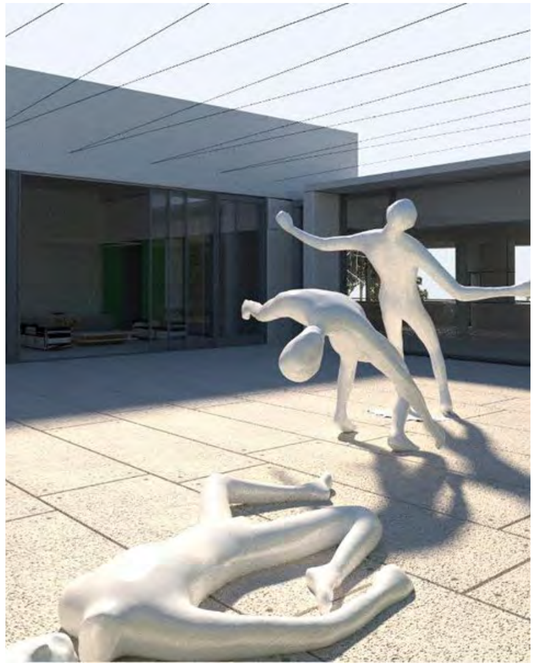
On the whole, the alternatively specified performance lighting has continued to operate as expected. However, after following up with the client, it has been noted that some fittings had failed over time. It must be made clear that the cause of the failures has not been proven, but these sorts of unforeseen issues can create ongoing costs to the client and are often best avoided by earlier design finalisation to allow accurate costing for specified products.

During site investigations, it was also found that performance fittings had been mounted on their sides, and advice was provided for additional armatures designed to allow correct mounting and flexibility of aiming. If not resolved, these issues can create delays in aiming and focusing, and also long-term cost to the client if equipment fails or cannot meet the flexibility challenges.

Over the course of the project the team embraced similar challenges and worked well together to find ways to rein the budget back as much as possible by refining quantities and finding acceptable alternatives to specified equipment to progress the design as originally intended.







Artworks in a virtual space

During the early, pre-construction stages of the project, point cloud scanning of key objects was undertaken to create visualisations of artworks within a virtual space. This assisted the client to understand the spatial- and light-infused qualities of such a distinctive space. It also aided the preliminary lighting design by giving the lighting team a feel for the scale of the objects in the space. The sequences of images on these pages show this process from scan to rendered spatial test in possible locations. The first series is of Wang Jianwei's *Flying Bird is Motionless*, 2006, and the second is of Chen Wenling's *Red Memory – Smile*, 2007.

Lighting the Great Hall

The spatial volumes and materiality of the Great Hall greatly informed the design approach of treating lighting and daylighting as one wholistic experience. Understanding these relationships was vital in ascertaining the general visual comfort within the Great Hall and assessing the risk of the transmissive polycarbonate wall becoming the brightest dominating light source in the space. As part of this wholistic approach, Steensen Varming lighting and sustainability teams worked together to assess the quality of daylight and its relationship to interior surfaces, glare ratio and rapport with electric lighting. Steensen Varming first undertook extensive luminance simulations that indicated the ratio of the daylight emissions at various times of day through the polycarbonate walls, and the luminance of the concrete display walls and floor from reflective light throughout the space at different times of the day (see images on page 206). The visual tolerance to glare was decided to be acceptable if no more than 1:10, the solid display wall and floor luminance being 1 and the combined transmissive and reflective luminance of the polycarbonate walls being 10. This was a highly important consideration and of great concern to Steensen Varming, but the architect was confident in the layering of materials. All simulations corroborated the architect's expectation of how well their design worked in controlling direct solar ingress and how the experience of the daylight space would still subtly vary throughout the day and the seasons. The simulations also confirmed that the potential visual glare for visitors trying to discern the details of artworks displayed on the concrete walls or silhouetted in front the polycarbonate light transmissive surface was low enough to be mitigated by an easily achievable amount of supplemental electric lighting where required.

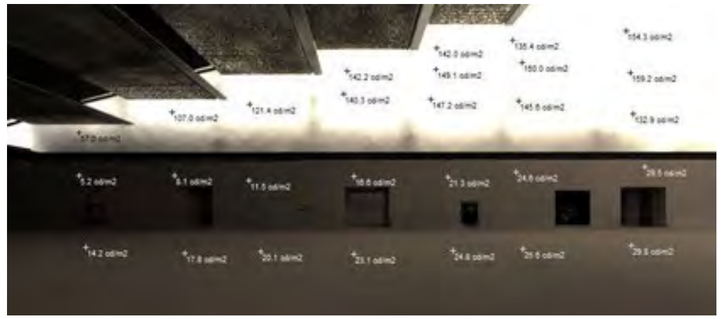
This page, clockwise from top: Scan of *Flying Bird is Motionless*, 2006; *Flying Bird is Motionless* rendered in one possible location on the sculpture terrace; mesh render. When Dangrove was deemed to go to a Design Excellence competition because of its size and volume, Tzannes produced high quality photomontage images and fly-throughs of the project as part of a process of convincing Council that the project was already an example of design excellence. Steensen Varming advised that we could scan selected artworks from Judith Neilson's collection using a point cloud scanner to create 3-D models which could then be inserted into Tzannes' architectural model. This way, the works could be seen in the architectural fly-through and 2-D renders. The renders of the works in these images are generated from those point cloud scans.

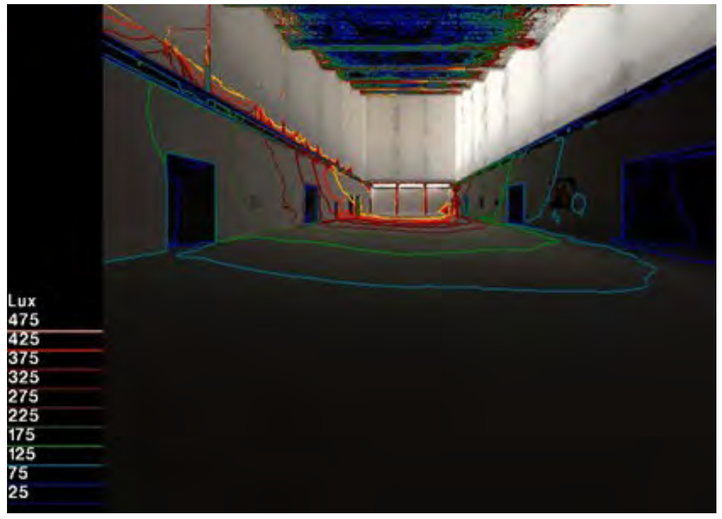
Opposite: Collection objects, including *Red Memory – Smile*, 2007, rendered into Revit model of the Great Hall. Dangrove commissioned Steensen Varming to carry out point cloud scanning of selected artworks in Judith Neilson's collection. The 3-D images generated by these scans were integrated into visualisations of the key spaces produced by Tzannes to accompany their submission to Council.











This page, above: Daylighting simulation of polycarbonate and display wall surface luminance values at key locations, March 12pm, clear sky with sun. Luminance is the amount of light reflected from or emitted through a surface. Luminance simulations were carried out for key times of day and year to understand the ratio of light between the display walls and the polycarbonate walls directly above. From these, the lighting designers could assess the perceived brightness of surfaces and whether visitors would experience glare when viewing artworks on the display walls as well as other display locations within the space.

Below: Daylighting simulation of polycarbonate and display wall surface illuminance (lux level) values, June 3pm, clear sky, with sun. This image is an example of the illuminance (lux level) simulation results from daylight ingress shown as false colour renders which are used to interpret the overall brightness of different surfaces within the space relative to each other as perceived by the observer. This is a good example of how the daylight emitted through the polycarbonate wall on the right of the image sheds more light on the display wall opposite than the wall below. From this we can assess if electric lighting is required to supplement the daylighting and provide visual balance between the display walls.

The height of the Great Hall's display walls complements the monumental scale of the Great Hall itself and are perfectly sized to display large scale contemporary art. The standard approach in a museum is to mount all lighting equipment in the ceiling, but Dangrove's Great Hall ceiling does not align continuously with the top of its display wall and so this strategy was initially abandoned. The first design concepts for the lighting of these walls considered a lighting infrastructure cantilevered 2 metres out from the display wall for the mounting of a lighting track below for the flexible installation of movable track luminaires. This was in direct response to the traditional approach of mounting lights at a 1:3 ratio from the display wall for optimal wall-washing (3 being the height of the wall). Although this made logical sense, the 2-metre cantilever was not only visually overbearing in size but could potentially inhibit the flexibility of displays in front of the wall while obstructing the sight lines of other artworks within the space and disrupting the clean architectural surfaces.

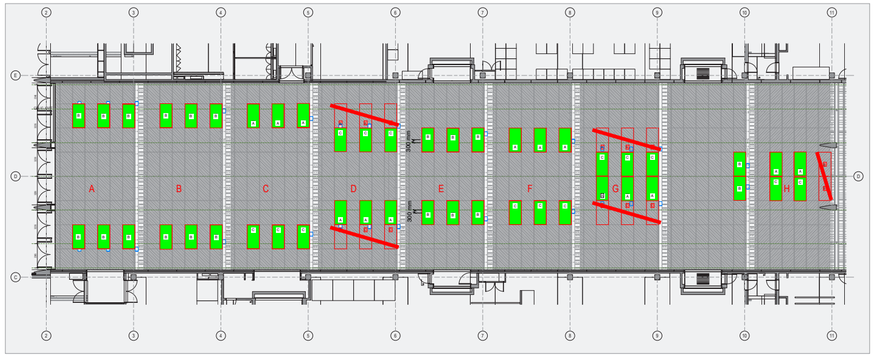
The solution was found by returning to a ceiling-mounted strategy, looking beyond the accepted architectural luminaire range. Architectural wall-washers anticipate a consistent ceiling mounting height utilising a single beam distribution, and are therefore not able to light a wall from varied heights. The solution was to adapt a stage lighting design approach to light the display walls from the stepped mesh ceiling, with theatrical DMX controlled performance luminaires with high light output, in-built focusing and shutters for optimum light distribution control. The usually relocatable theatrical lighting fixtures were permanently mounted to adjustable lighting bars concealed above the ceiling mesh. Each fixture is individually aimed and focused to uniformly wash the display walls, acting as a background layer to the lighting of artworks while reducing visual contrast between display and daylight penetration. The mounting location and flexibility for initial aiming of these performance lights was a critical factor in the success of the design and its harmony with architectural intent to minimise visual intrusion below the mesh.

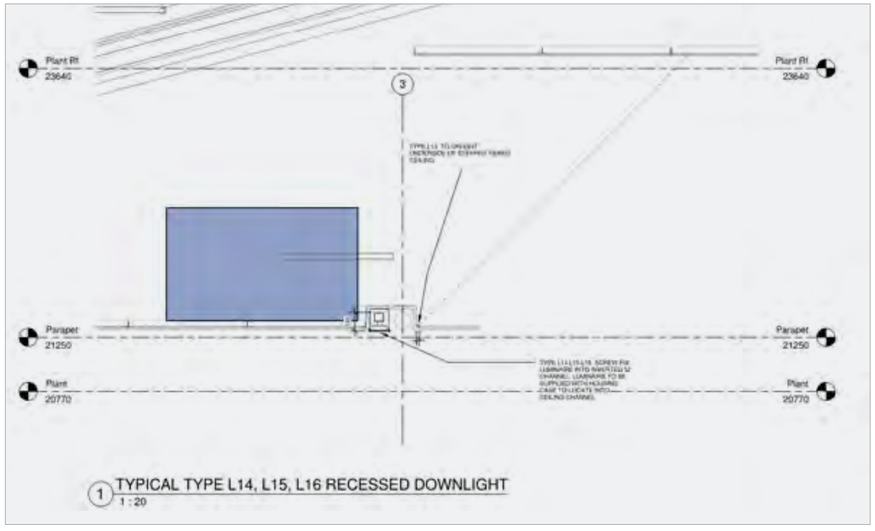
Opposite, top: One of the mark-ups for the revision of the theatrical performance lighting location layout, indicating panels and cut-out locations. Original locations reflected lighting simulation results and further refined with fittings moved away from the walls to broaden the beam angles as a result of onsite testing. Performance fittings were focused to provide a balance between lux level requirements and beam angle to provide uniform lighting to display walls from the varying luminaire set-outs.

Centre: Tender downlighting and uplighting section – uplighting was later removed, and downlights were replaced with alternative track lighting.

Below, left: Mesh removed for aiming. Once the fittings had been aimed and focused, the mesh panels could e relocated to conceal mounting and fittings as much as possible.

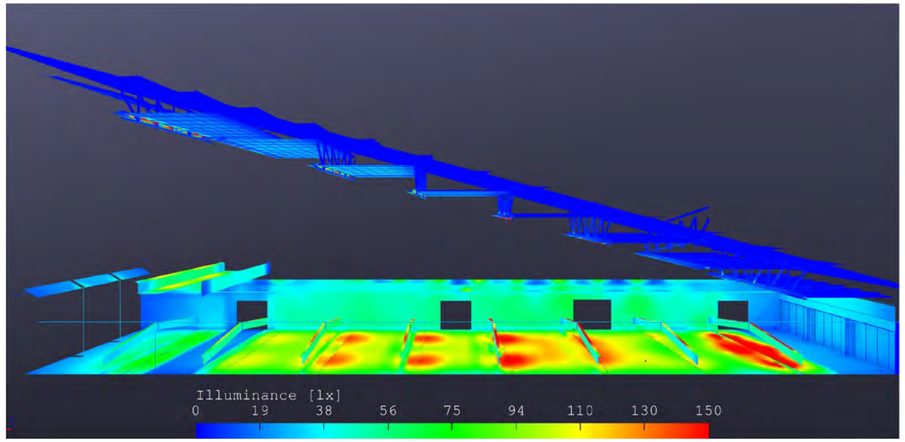
Below, right: Mesh with lighting installed. The mesh panels are removable and enabled refinement of performance fitting locations. At this stage the downlights had not been located as designed and were later relocated.

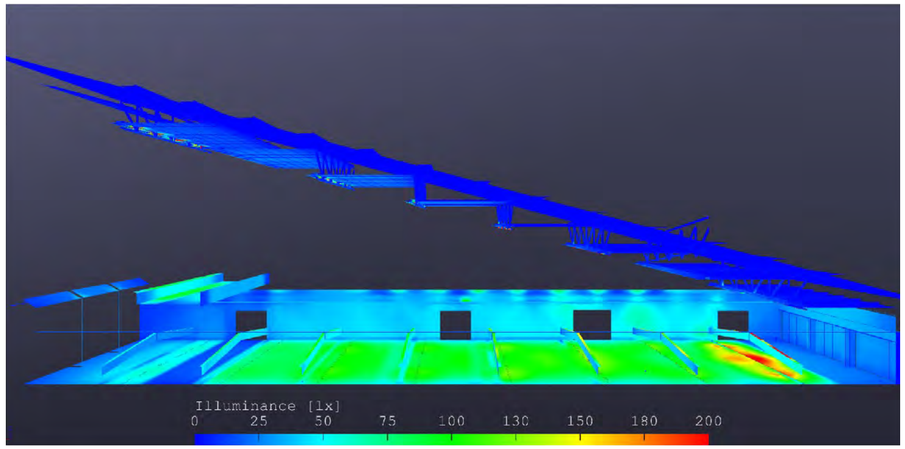


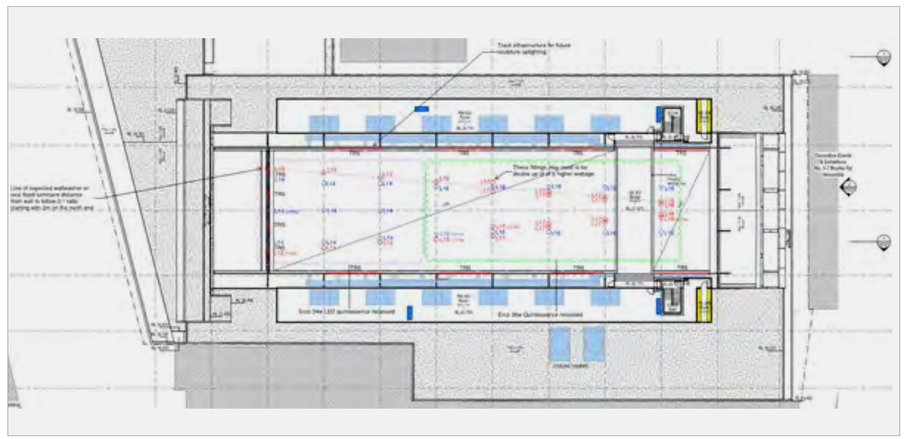












Opposite, top: Great Hall floor lighting uniformity simulation in ElumTools – first test. Fittings in this simulation are all located uniformly across the space with the same light distribution (beam angle) for all fittings. Note the bright hot spots of light depicted as red regions indicating a low uniformty of light across the floor.

Centre: Great Hall floor lighting uniformity simulation in ElumTools – second test with corrected lighting. Adjustment of fitting locations and beam angles resulted in a very high uniformity of the floor lighting with no bright hot spots of light other than at the low end of the building where it could be removed by dimming a single row of fittings, resulting in high uniformity and approximately 100 lux across the entire floor.

Below: Original downlighting replaced with alternative track mounted fittings and relocated with varied lensed beam angles to provide required uniformity.

This innovative approach was a leap forward from the original concept and, although its design was considered developed enough for costing, it required further design finalisation that could not be completed prior to tender. Not only was its mounting location critical for an optimum lighting result but utilisation of a theatrical DMX control system required additional commissioning and programming skills that are not often part of the usual contractor repertoire.

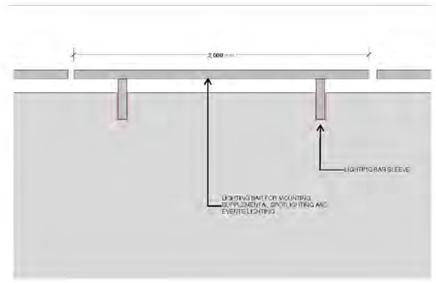
As this was a building of significant scale, one of the challenges was the limited practical opportunities for mock-ups. To refine locations and quantities for all lighting and confirm the feasibility of the performance wall-washing concept, lighting calculations were carried out in two calculation programs, ElumTools and AGi32, utilising IES photometric files provided by the performance lighting manufacturer and assumed reflective qualities of the interior finishes as provided by the architect. These simulations allowed Steensen Varming to confirm the absolute minimum quantities of fixtures required to fit within the tightening budget which allowed no room for contingency or error.

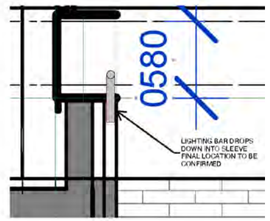
The lighting aimed at the Great Hall floor was also mounted at varying heights. Lighting simulations carried out in the early stages of lighting design to ensure a uniform light across the floor of the space included the stepped ceiling to inform the design and identify a variety of lens accessories required. As each ceiling section stepped up in height, a new lens beam angle maintained uniformity, also delivering higher illuminance levels from narrow beam angles at the greater heights. The appropriate spare lenses were specified, from extra wide flood at the Re-Drawing Room entry end to narrow spot at the highest point of the space. However, at the time of writing, the extra wide beam lenses had still not been installed with spots of light clearly evident at the Great Hall's entry.

During the later design stages, the Great Hall bridge had been deleted from the design and therefore its impact on the lighting of the display walls and the floors was no longer taken into consideration. By the time the bridge had been reintroduced to service the connection between the other floors, it was too late to introduce an integrated solution within the available budget. The resulting shadowing on the display walls is not the optimal outcome and may reduce the flexibility of display in the future; however, it is not considered to be a significant issue, and an alternative solution of a lighting track surface mounted below the bridge at each end is expected to provide additional lighting flexibility when required. After confirmation that the lighting would deliver the requisite light levels, a mock-up of the lighting effect was staged and the outcome approved by the design team.

In lieu of the completed roofing structure design, an 'as close as possible' set-out and location of the performance lights was drawn up in the Revit model. Clear advice on the lighting rigging infrastructure flexibility requirements for further refinement during installation and aiming was provided, and then left to be progressed by the D&C contractor once access to the ceiling could be gained and the roof truss design had been completed. Further refinement of mesh cut-outs and locations was co-ordinated between the lighting consultant and the architect once the ceiling structure was progressed far enough and detailed for the contractor to complete.

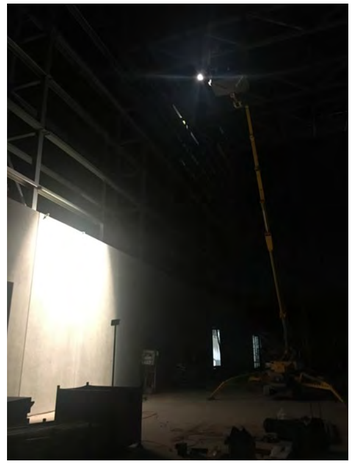
The large scale of art objects as viewed from the floor of the Great Hall necessitated an infrastructure for the spotlighting of individual artworks. This infrastructure would be provided by track lighting mounted in a channel running across the gallery at each level of mesh, and a supplemental lighting track located along the top of each wall to service lighting from above and below larger sculptural objects in the centre of the space. This wall location is also shared by a removable stage lighting bar that would provide mounting locations for special events lighting equipment and double as a hanging rig for artworks to hang in front of the display wall.





This page: Removable lighting bars elevation and section views. A removable lighting bar was proposed to provide supplemental spotlighting on artworks and mounting locations for hired-in events lighting. Spotlights and hired-in AV lighting would be mounted to the lighting bar, which could be removed when not required in order to not visually intrude on the architecture.







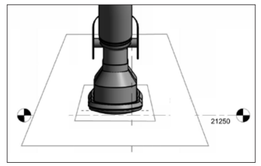


This page, top: Great Hall display wall lighting simulation in AGi32 to test the use of performance fittings as a wall-washing strategy.

Centre, left: Great Hall night-time mock-up to confirm simulations of the use of performance fittings as a wall-washing strategy. Theatrical lighting mounted to spider boom lift to represent simulated height and set-out.

Centre, right: Great Hall night-time mock-up illuminance testing of various downlighting beam widths.

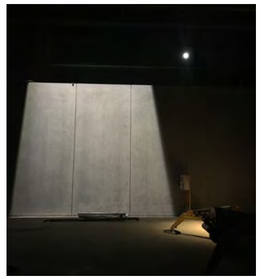
Below: Focusing of theatrical luminaires to light concrete panels and provide uniform wall-washing, and programming to enable full colour changing scenes.



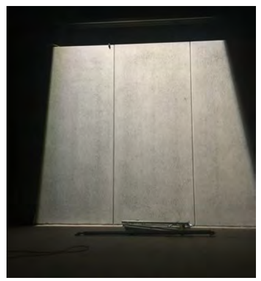
Early BIM graphic of theatrical luminaire mounted behind mesh to understand the impact of aiming angle on mesh cut-out size.



Theatrical luminaire mounted behind mesh ceiling and aimed to provide optimal wall-washing.







Onsite mock-up to refine aiming and adjustment of beam angle verified that the design intent of a uniform wall-wash could be achieved.

The strategy of adapting a stage lighting to a museum-style environment had the additional advantage in being able to deliver a DMX-controlled state-of-the-art theatrical colour-changing system of exceptional quality without added cost. It was anticipated that this system could be also used to support hired-in events lighting for specific events or festivals and also be utilised by artists in the creation of site-specific artworks in the future. This did, however, add one level of complexity to the lighting controls in that it had to interface with the entire Dangrove lighting control system while still being simple to operate. This required a complex behind-the-scenes controls interface between differing control protocols designed for flexible daily operational use, programming by Dangrove staff and access by external events teams as required.

After being novated to the contractor, it became clear through the review of contractor simulations and the alternative product selection that the design intent and the complex nature of the building functionality were not fully understood. Reviewing contractor calculations was the first step in understanding the direction in which the design was going, and providing the necessary advice became crucial to getting the design intent understood and back on track.

Without the necessary specialist experience, the design could not be finalised by the builder, who had raised concerns about the design being 'unbuildable'. Alternative luminaires were also being proposed and it was at this point Tzannes requested Steensen Varming be engaged to finalise the design. Dedicated to seeing the important aesthetics of the lighting preserved and the delivery of the central design innovation, Steensen Varming assisted the builder by reviewing contractor simulations, alternative lighting products, and finalisation of the Great Hall specialist lighting. This helped reduce risk to the project by circumventing the installation of less suitable alternatives and being able to refine the original design intent to help reduce costs while still delivering the best and most suitable lighting for the task.

This engagement did not extend to the commissioning and programming, leaving it open to further risk during the translation from design to a fully operational system, with possible consequences of reduced functionality and additional contractor costs. This became apparent after programming had been started during site observations.

Due to the fast pace of the project and limited access during commissioning, the only indication of a successful commissioning during site investigations was a basic on/off functionality, which is acceptable for standard lighting applications, but not satisfactory for projects utilising complex DMX control systems interfaced with the rest of the building's DALI control system. During the programming stage it is understood the programming agent had limited engagement and all fittings were found to be operating as required prior to handover. It is possible that a full testing of the system may not have been carried out, which consequently led to underlying issues not being discovered until the client had begun to investigate the full functionality of the system. At that point, complete access to all cabling and connections was not straightforward due to deletion of the maintenance platforms and removal of construction scaffold.

During Steensen Varming's site investigations, a number of observations were made. These included:

- Installation of the mounting system. The mounting system of the performance lighting was not installed as designed with respect to full adjustability. This had an impact on adjustments required during final aiming. It is not anticipated that this will affect future aiming, as this is designed to be a fixed solution. However, should there be an unforeseen requirement in the future, this flexibility is no longer available.

- Insufficient light distribution coverage of the northern display wall section. Beam angles were insufficient for the lower section, and the lowest level of fittings needed to be moved back from the wall to increase the coverage of the wall. In order to minimise costs related to the performance lighting of the Great Hall, an alternative, more cost-effective product had to be sought and specified by Steensen Varming, and quantities minimised while still mounting them in locations that harmonised with locations of the mesh ceiling panels. While this was not an impossible task, it did compromise design tolerances and remove any contingency for unknown disparities in light distribution between the simulations carried out and the actual real-life distribution. Consequently, near the end of the project, when these performance wall-washing fittings were installed, one section was not providing the distribution expected from the locations indicated as optimal from the simulations undertaken. The relocation was not difficult, but it is important to highlight this to be clear about the value of mock-ups for design verification as well as following specified mounting design flexibility to minimise any potential impact of costs related to additional work needed to be carried out on site to resolve these kinds of issues.

- Incorrect interpretation of design intent. Aiming and focusing was not interpreted correctly. Through no fault of their own, the programming agent who focused and framed each fitting on an individual section of concrete did not fully understand the design intent of lighting several sections of concrete with each fitting. This reduced the efficiency and total light output, and caused an unexpected halation of light at the edges of the framed beam. The original intent of bleeding the light softly across the display walls was designed to eliminate any hard edges of each luminaire's light distribution, with the added benefit of increasing illuminance on the walls through the bleed of light from each source, allowing the quantity of luminaires and intrusions into the ceiling mesh to be minimised during design development while also ensuring a uniform maximum of 300lux without additional spotlighting of artworks.

  The contingency safeguard against this had been lost during value engineering when the number of fittings had been reduced to the barest minimum but had been deemed acceptable if the beams of the fittings contributed to each other.

  Although this is not an optimal outcome, it is not critical for Dangrove. During the day there is enough daylight to provide the majority of light, and only requires a low level of supplemental electric lighting. The night time illuminance levels of 200lux are perfectly acceptable for wall-washing during night viewing, and given the nature of Dangrove's use, this is usually overridden by event lighting. The lighting of each pane has been endorsed by the client; however, it did create additional cost, with a second round of aiming, programming and additional filtering accessories to soften the beam edges.

- Indication of control system, luminaire failure or incorrect programming. There were indications of control system instability, possible programming errors or cabling faults. Some performance lights were not turning on, or were not the correct colour, and control panels were not operating the entire system as designed. This was noted in site observation reports, but by this stage, access to the mounting locations was no longer available for the investigation of cabling connections. This aspect was left to the contractor to identify and resolve any commissioning issues.

  The programmer was brought back in to reprogram and the issue seemed to be resolved, but over time, it began to plague the client again. Since then a new programming and commissioning agent has been engaged, and found that the DMX control cards of certain fittings had failed. The reason for this failure could not be identified, but the possible causes were either electrical power spikes, induced voltage on the cable (possibly caused by poor cabling) or poor performance of the control cards themselves. Inspections found that some of the proprietary cabling had been substituted with cabling presumably assembled with non-proprietary parts by the contractor. The possibility of external power spikes was eliminated by Steensen Varming's electrical engineers. Small fluctuations in power are also usually managed by integrated optical isolators within performance fittings of this type, but is unclear if this was also a failure in the product.

  It is almost impossible to confirm the cause of the performance lighting failures. Ordinarily, control failures would be captured during commissioning, but as they were not, the unfortunate outcome is that the costs of repair to a significant number (approximately 50 per cent) of fittings was passed to the client and, for a time, the lead time of repairs affected the functionality and aesthetics of the space.

Conclusion

Despite the complex challenges and the time taken to resolve certain issues, the design intent was preserved and the outcome a great success. Projects of this nature pose challenges seen and unforeseen. Steensen Varming was delighted to be part of such an ambitious and innovative project and to be able to work closely with Tzannes, Infinity and Judith Neilson to realise her vision for Dangrove.

Practice profile

Steensen Varming, founded in Denmark in 1933, are practitioners in mechanical and electrical engineering, lighting and sustainable designs that enhance spatial design. The practice provides unrivalled expertise in cultural projects, in particular museums and galleries, and has long-term relationships with many institutions internationally. It provides advice to the Museums & Galleries of NSW in the preparation of their published guidance documentation, and is a member of the Museums Association, which represents the people and institutions consulting some of the most significant international museums and galleries. Steensen Varming has studios in Copenhagen, London, Sydney, Hong Kong and New York.

Key people

Simm Steel, associate lighting designer
Mirjam Roos, associate director

Great Hall installation, with Alice Giles and Seven Harp Ensemble, utilising performance lighting, creating coloured wall-washing, and track spotlights on performers.



16

Hydraulic Engineering

Warren Smith & Partners

The roof drainage challenges

Dangrove was always going to be a challenge for roof drainage. The various uses of the building all require a durable, guaranteed waterproof envelope and highly effective rainwater discharge solution. There was no provision for external eaves gutters and downpipes on the perimeter, as the building is built from side boundary to side boundary. Rainwater could only be discharged to the front at Mandible Street and to the rear into the Sydney Water stormwater canal through an onsite detention tank.

Roof rainwater discharge to the kerb and gutter at Mandible Street was limited to 10 per cent of the total site discharge by City of Sydney Council public domain standards.

To reduce the potable water demand, rainwater harvesting and reuse needed to be included to provide a long-term sustainable water supply system for the cooling towers, toilet flushing, cleaning and irrigation on the terrace.

The main stormwater drainage system

The design of the main stormwater drainage system consists of the smaller front roof, the larger rear roof and the roof terrace.

All landscaping in front of the property has deep soil planting and did not require drainage.

The property has a total site area of 5350 square metres. The roofs and terrace cover 5218 square metres, or 97 per cent, of the site.

The City of Sydney and Sydney Water are the consent authorities for the storm and rainwater system discharge, and prescribe the maximum discharge of rainwater to kerb and gutter and to the Sydney Water canal at the rear of the property.

Sydney Water owns the stormwater canal at the rear, and most of the roof rainwater had to drain through this canal. The discharge had to be controlled through onsite detention (OSD).

In addition to controlled discharge, the City of Sydney Development Control Plan (DCP) and Botany Bay Water Quality Improvement Plan (BBWQIP) requirements for the adequate treatment of stormwater runoff had to be addressed.

We used software called MUSIC (Model for Urban Stormwater Improvement Conceptualisation), which helped us predict the performance of proposed stormwater quality management systems.

Warren Smith & Partners designed a treatment system to remove suspended solids and nutrients prior to being discharged to the Sydney Water canal and the City of Sydney kerb and gutter stormwater system.

This incorporated a rainwater tank into the OSD tank to improve the stormwater runoff quality as well as reduce the potable water demand, and two StormFilter™ units with rechargeable, self-cleaning, media-filled cartridges to absorb and retain pollutants from stormwater runoff. The pollutants include total suspended solids, hydrocarbons, nutrients and soluble heavy metals.

The 200,000-litre rainwater tank was sized initially to provide water to a traditional cooling tower. The cooling tower was replaced with wetted curtain air cooled condensing units during the detailed design. This allowed for a reduction in rainwater storage to 75,000 litres.

Satisfying the requirements of the two consent authorities added an extra layer of complexity to the design; developing a stormwater drainage solution proved harder than the actual engineering.

The front roof

Stormwater to the City of Sydney kerb and gutter was limited to 25 litres per second discharge, which is the equivalent surface area of 350 square metres. This would only allow for the stormwater discharge from the terrace.

The front roof was lower than the rear roofs and there was no opportunity to have a natural surface flow from roof to roof.

We explored several options to discharge the front roof to the kerb and gutter, including the addition of OSD to the kerb and gutter discharge. The resulting OSD tank would need to be above ground to gravity flow to the kerb and gutter and, in the end, proved to be too large to fit into the available space in front of the car park.

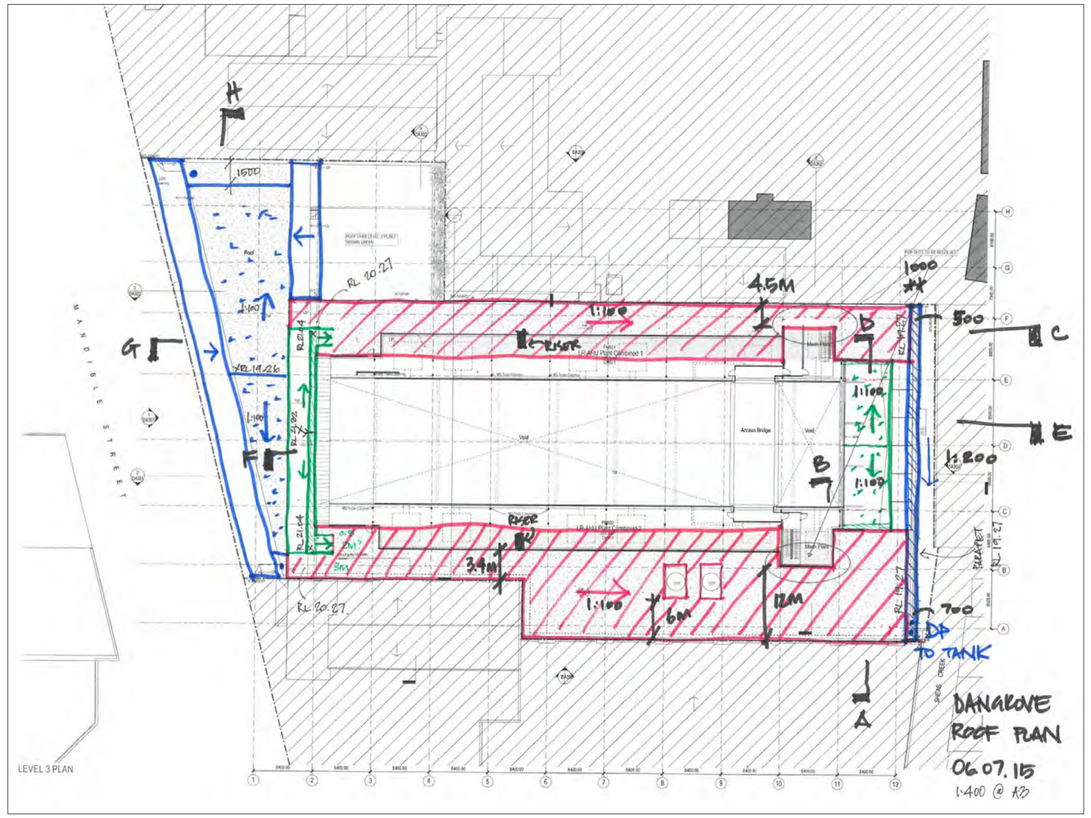
Because it was not possible to fit a tank there, a siphonic drainage system discharging to the rear rainwater and OSD tank was the only option to meet the strict kerb and gutter discharge limits – only the terrace could discharge to Mandible Street without exceeding the maximum kerb and gutter discharge.

Two siphonic drainage outlets were provided and joined to a single pipe, installed in the service passage outside the art storage and display area, and connected to the rainwater tank.

Challenges with the rear of the building

Stormwater management from the rear roofs, consisting of the steep Great Hall roof, two flatter lower concrete roofs and the plant room roofs, was the second challenge. Most of the rainwater from the rear of the building needed to be captured and directed to the Sydney Water stormwater canal.

The two flatter lower concrete roofs cover around 1300 square metres and we proposed that this would grade at 1 per cent to the rear of the property to a large concrete box gutter, located over the plant room and therefore outside the art storage areas.

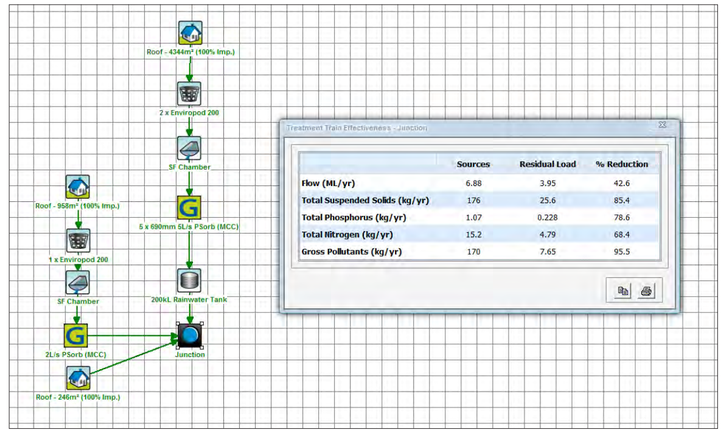


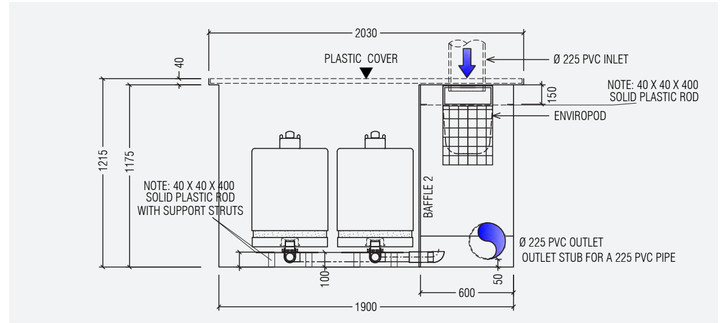
Roof catchment mark-up. The striking nature of the roof design presented challenges for getting large amounts of water to the rear of the site. The different colours in the sketch outline the different zones and flow directions to the front and rear of the site. With the roof profile directing water to the front, it had to be turned back towards the rear (shown in red).

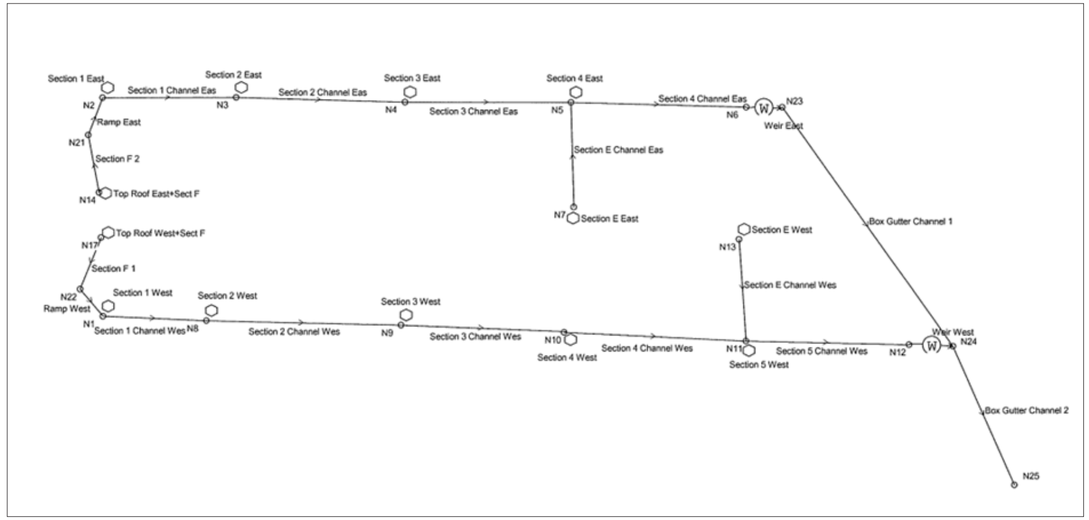
This page, top: DRAINS model calculation nodes.

Centre: MUSIC water quality model flow schematic.

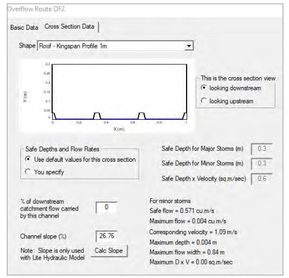
Below: Rainwater tank StormFilter section.



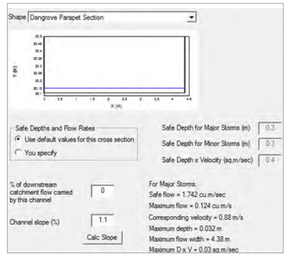




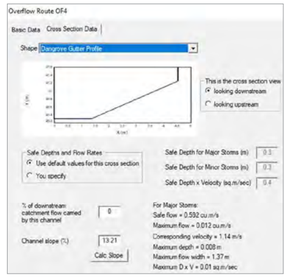




Great Hall Kingspan roof runoff calculations. Each section of roof gutter had to be modelled separately using specialist software to ensure that the system would easily handle the most violent storms.



Rear flat roof area flow depth.



DRAINS model rear channel gutter calculation.

The two plant rooms at about 400 square metres are covered in metal roofing and are provided with concealed external eaves, gutters and downpipes that drain onto the lower concrete roofs.

The Great Hall roof has a steep fall to the narrow end with a catchment of 1715 square metres, resulting in about 130 litres per second flow. We considered the high runoff velocity in excess of 1 metre per second and calculated a traditional box gutter with multiple outlets and a generous safety margin at 1 metre wide and 0.7 metre deep.

We explored several options for drainage from the box gutter to the rear of the property, including siphonic and gravity pipe system. Siphonic drainage proved to result in no smaller pipe sizes due to the length and limited vertical drop in the pipe system.

The pipe had to be mounted on the roof so that there were no penetrations for downpipes or outlets into the building. Any penetration would have posed a risk of potential future failure and subsequent water leakage into the building interior. Mounting the pipe on the roof provided a technically workable solution; however, it was deemed rather ugly by the architect.

The roof as a tanked waterproof deck

Designing a large box gutter with multiple outlets and maintaining access for service was another challenge that did not return very satisfactory outcomes, as it would result in multiple roof penetrations, waterproofing issues and large pipe work.

In the end, the architects suggested a large concrete channel, discharging at each end of the concrete roof, removing the need for gutter and downpipes.

The concrete roof was covered in a Wolfin waterproofing sheet membrane with an additional wearing membrane for protection of the waterproofing layer. We could now consider the concrete roof as a tanked waterproof deck that could withstand hydrostatic pressure at peak flows.

Our civil engineers ran a DRAINS hydrological model to establish the flow pattern and water depth across the roof, allowing the architects to set the height above the roofing deck for roof penetrations, plant room floor levels, door thresholds and the turn-up of the Wolfin membrane.

Further channel flow calculations were carried out on the rear roof drainage channel to ensure sufficient depth of water to the two 450 mm high density polyethylene channel downpipe outlets.

The channel was also designed with a lower front edge, which allows overflow to discharge down the external wall into the stormwater canal without causing damage to the building. In addition, multiple overflow pipes through the vertical wall of the channel, above the highest operational water level, were provided to allow for an early relief of rainwater in case of a blockage.

The result presents a completely sealed waterproof roof where rainwater follows a natural flow path like a ground surface runoff condition, ending up in a fail-safe elevated drainage channel.

There are no multiple downpipes, sumps and complicated flashing details, each of which could present a potential water ingress risk.

Conclusion

Dangrove has been provided with a unique rainwater collection and discharge system that ensures waterproof integrity and low maintenance over the life of the building. This was possible through a highly collaborative design process between the architects and the engineering team.

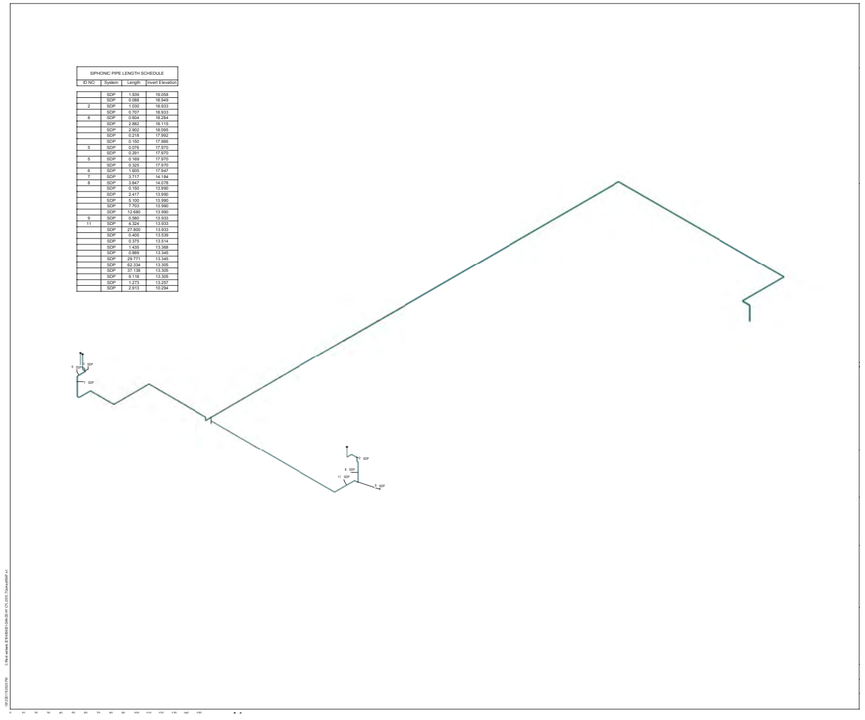
Practice profile

Warren Smith & Partners (now Warren Smith Consulting Engineers WSCE) has been providing industry leading engineering design solutions in hydraulic, fire and civil and Sydney Water co-ordinator services since 1981.

The business operates in NSW and Victoria with a total of 70 staff, and has successfully completed more than 7000 projects in the areas of commercial, educational, entertainment, arts, heritage, health and research development.

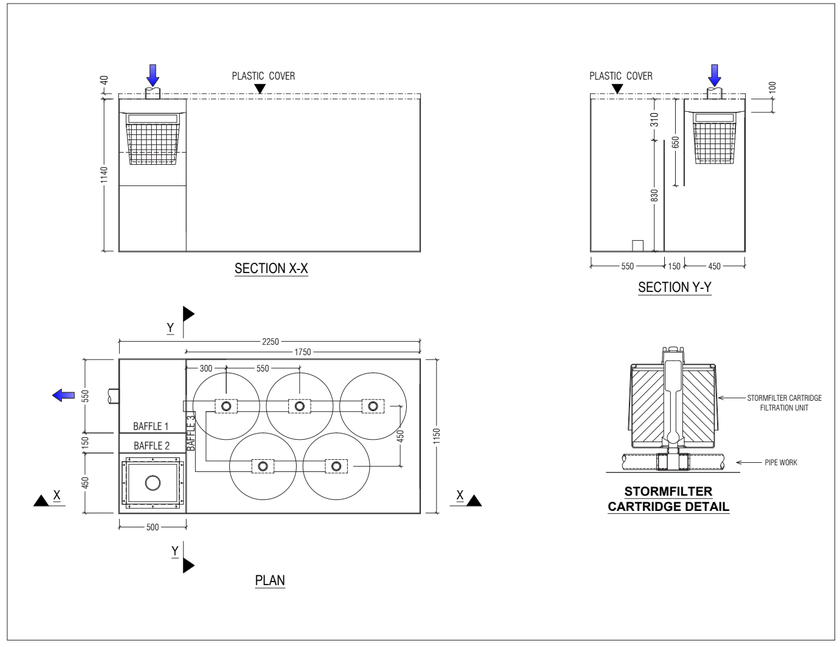
Key people

Andreas Heintze



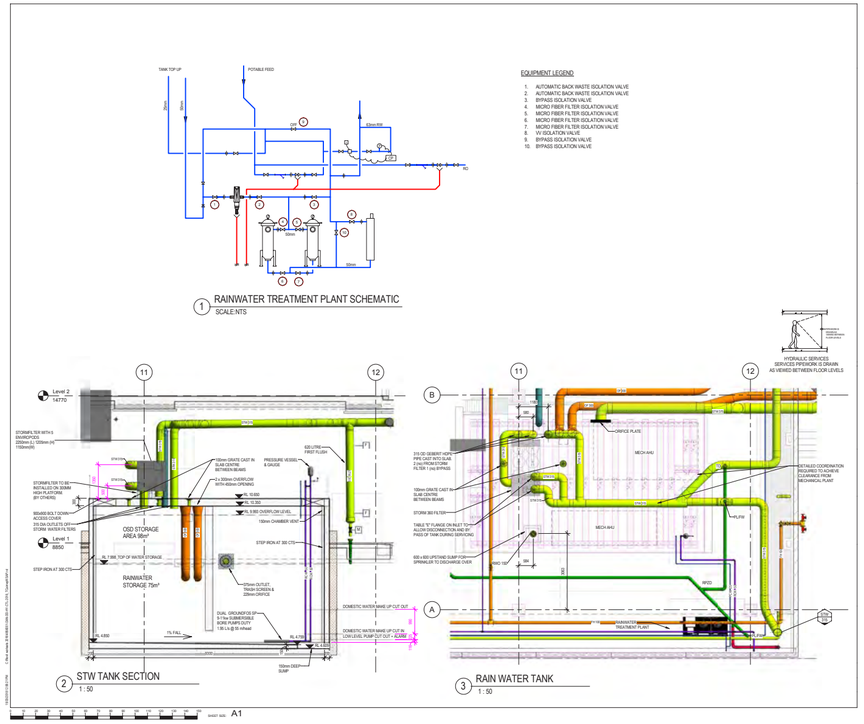
This page, above: Siphonic drainage isometric of the front roof drainage system, which is the only roof that required a longer downpipe network. At the time of the project it was rare for the plumbing system to be completely modelled in 3-D. The decision was made early on so that the system could be more easily co-ordinated and the installation team had certainty in the co-ordination.

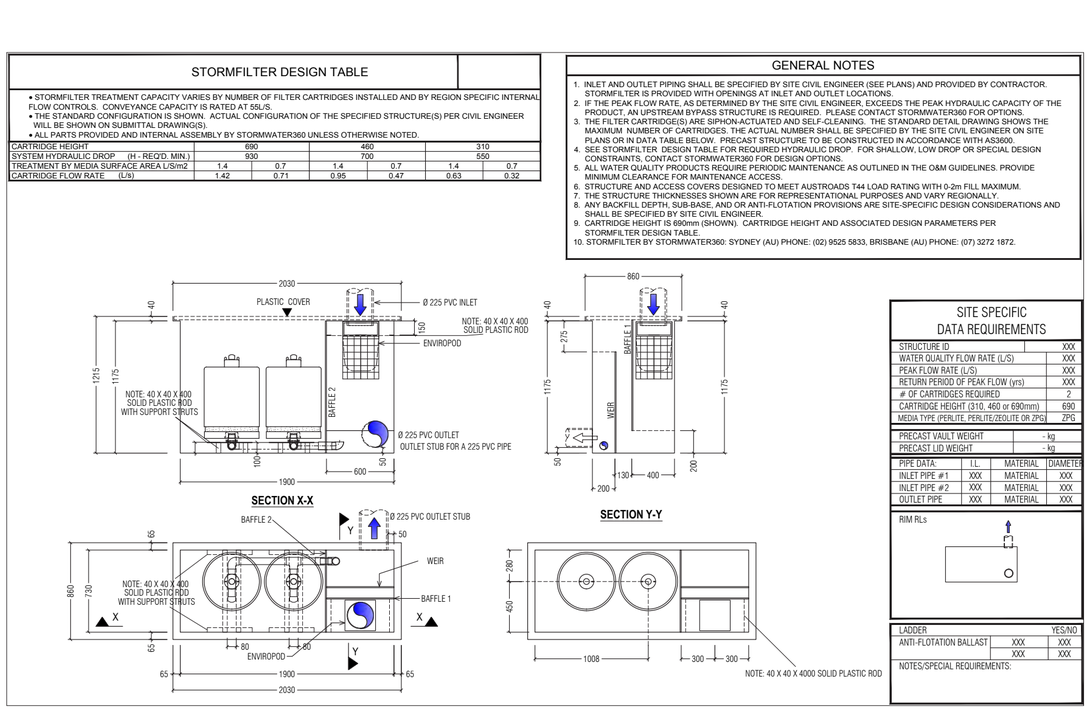
Below: Detail of the final rainwater tank and filtration.



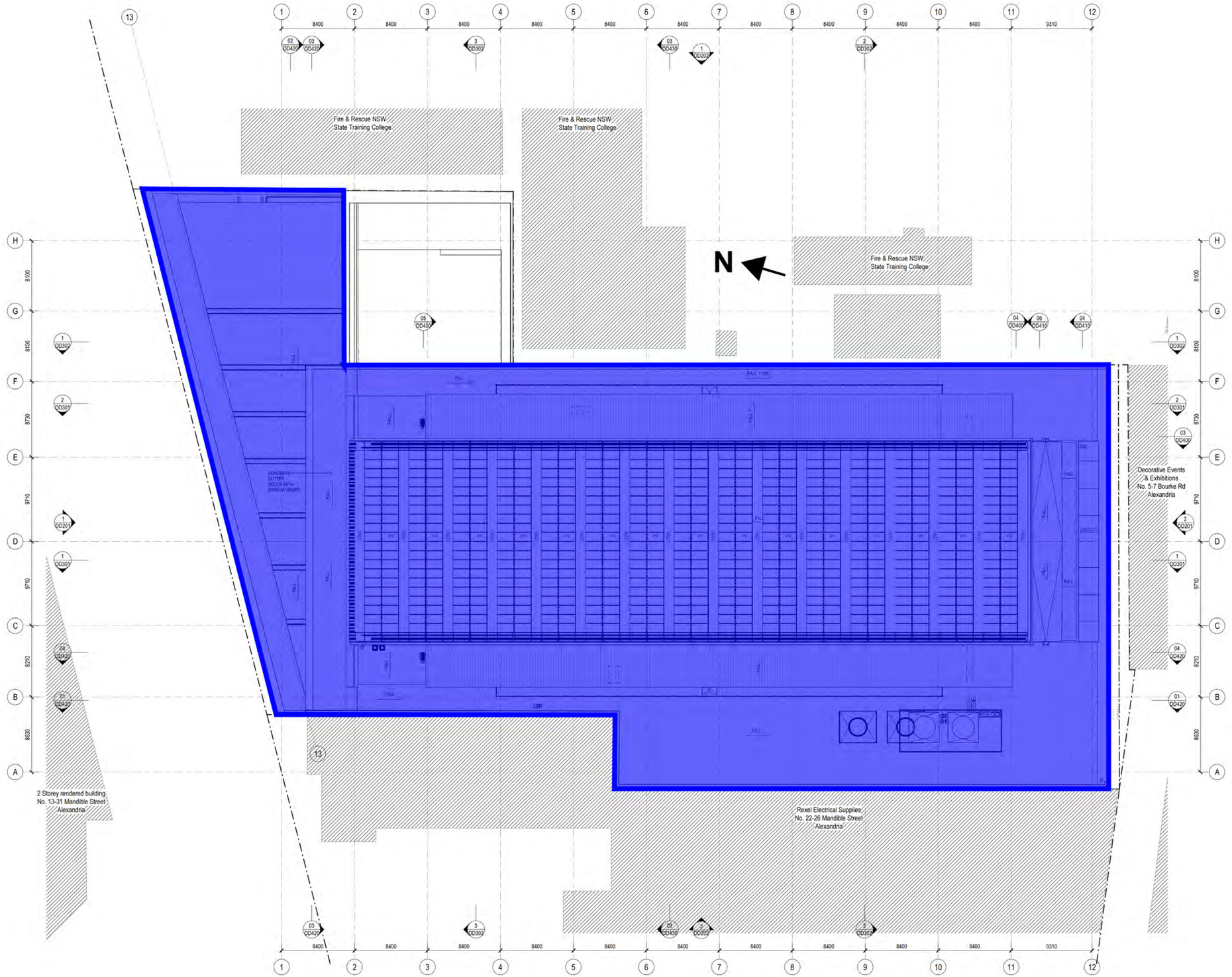
This page, above: Technical drawings of the filtration systems for the front and rear discharge.

Below: Various suppliers were consulted early in the design to ensure that Council's water quality requirements could be met. The selected system from Stormwater 360 incorporates two filter cartridges and an EnviroPod module.





The total roof area measures approximately 5220 square metres. The roof concept remained consistent from the early stage sketches through to the construction-ready documentation shown here. This enabled the hydraulic roof drainage to be co-ordinated in detail through the building design process, ensuring the design is as risk-free as possible.



17

Electrical Services

Steensen Varming

An overview of the brief

Dangrove is a purpose-built art storage facility, consisting of receiving and processing areas, art storage spaces, workshops, administration offices, multipurpose area and a central art exhibition space. The electrical services designed by Steensen Varming for Dangrove consists of the power, communications, lighting, vertical transport and security systems. This formed one part of Steensen Varming's scope, which also included the mechanical services, specialist lighting design and environmentally sustainable design (ESD) advice. We were involved on the project from a very early stage of design right through to the end of the construction.

The electrical services design principles included careful consideration and intelligent integration of the systems into the design solutions for the building. Innovation and technology were to be appropriate, tested and robust. The systems were required to present safe and reliable solutions that considered intuitive user controllability, with adequate provision for scalability, adaptability and ease of maintenance. They also had to be cutting edge and environmentally friendly.

From the outset, the electrical services at Dangrove needed to achieve two clear goals. The building had to be designed to safely store and display artwork but, at the same time, the client wanted it to be designed in such a way that it was simple and easy to use. Typically, these two goals do not go hand in hand – in our opinion, the design managed to achieve an acceptable balance between the two.

The components of the electrical services

The electrical power services for Dangrove can be likened to its arteries and veins, providing power and energy for all its elements. The communications systems are its nervous system, sending signals of data and monitoring conditions, ensuring security. All are critical to the smooth operation of the building. As long as they function properly, these systems are usually taken for granted, but their complexity is increasing at the same startling rate as technology is developing. The electrical lifelines range from power generation, supply and infrastructure reticulation to communication networks, security systems and vertical transportation.

Their design and delivery require patience and perseverance; liaison with supply authorities, strategic advice on cost and space planning, clear and concise briefings and precise documentation detailing every system powering the building, running the air conditioning and controlling the lighting.

The most outstanding feature of the electrical system at Dangrove is the very large photovoltaic solar panel system, spanning the majority of the building's roof space, supporting the energy requirements and delivering a key sustainable element in its successful environmental performance. The solar system incorporates 500-plus panels (560 panels during the design stage), each of which is in the order of 300 W, for a total solar system in the order of 160 kW.

In terms of the design and installation of the power and communications systems, strict codes needed to be adhered to. Fortunately, the interface with these systems is at a very low level – wall-mounted outlets for the plugging in of equipment. This means that while the system itself, which operates in the background, is quite complex, it is very simple for the user. The same can be said for the lighting control system; it's very complex behind the scenes, but with easy-to-use switches and control panels.

For the high-tech security system, a similar balance was achieved through the incorporation of an electronic access control system to manage door and garage access throughout the building as well as a CCTV system covering sensitive spaces. The design is not unnecessarily complex and, again, is quite easy to use. Once installed, the security system was essentially 'set and forget', requiring very minimal user interaction, limited to the use of access cards. As with the lighting control system, this perceived simplicity is achieved through the intelligent programming of the security system. By consulting with Dangrove users to understand how the building would be used, we were able to ensure that the design of the security system would not be over the top. We did not implement complex CCTV analytics, which are intelligent programs that report the movement of items, as they were not deemed to be necessary – Judith Neilson has a fully secure environment in which every item is tracked and positioned in the facility with full curatorial level details.

The main challenges

The overall strategy for the electrical design is for it to work seamlessly in the background without much fuss. For this reason, electrical equipment is generally located in the back-of-house areas to ensure it doesn't get in the way of the building's main goal of being a world-class art storage facility. If the building achieves this goal, the electrical installation is a successful one.

Various challenges were faced while completing the electrical services design. The main ones included working through the arrangement of the electrical services plantrooms within Dangrove in conjunction with Tzannes; the design and specification of the systems and equipment required within Dangrove to meet the requirements of both Judith Neilson and the building users; and ensuring that, through the design and construct (D&C) procurement of the project, the quality of the installation and requirements of the building were maintained and not lost or compromised through the contractor's finalised design and, ultimately, installation.

Addressing the electrical services' issues in the context of the overall architectural design was essential, especially with regards to the efficiencies of an integrated approach and multi-functionalism, which required a commitment to teamwork with the various stakeholders.

Fortunately, these challenges can be overcome when working within a team willing to collaborate and meet to discuss and work through a building's design – this was a quality possessed by the Dangrove team. It is not always the case on projects; challenges can occur for contractual or financial reasons.

The scope of work

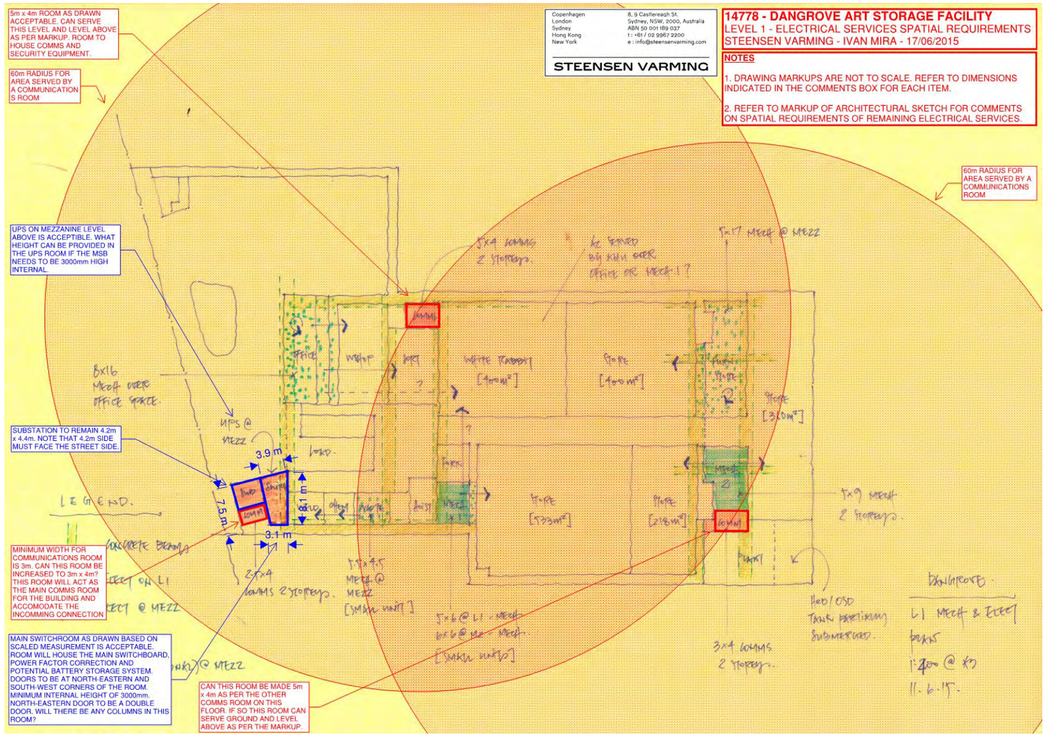
Given the D&C nature of the project, the most important goal the documentation needs to achieve is that it must outline the full scope of services required within the building, but not necessarily provide all the details of each system. In other words, the design will not be fully detailed or fully completed by the consultant, but must fully outline/describe the required scope to a level which allows the contractor to finish the design, and include for everything required of the brief.

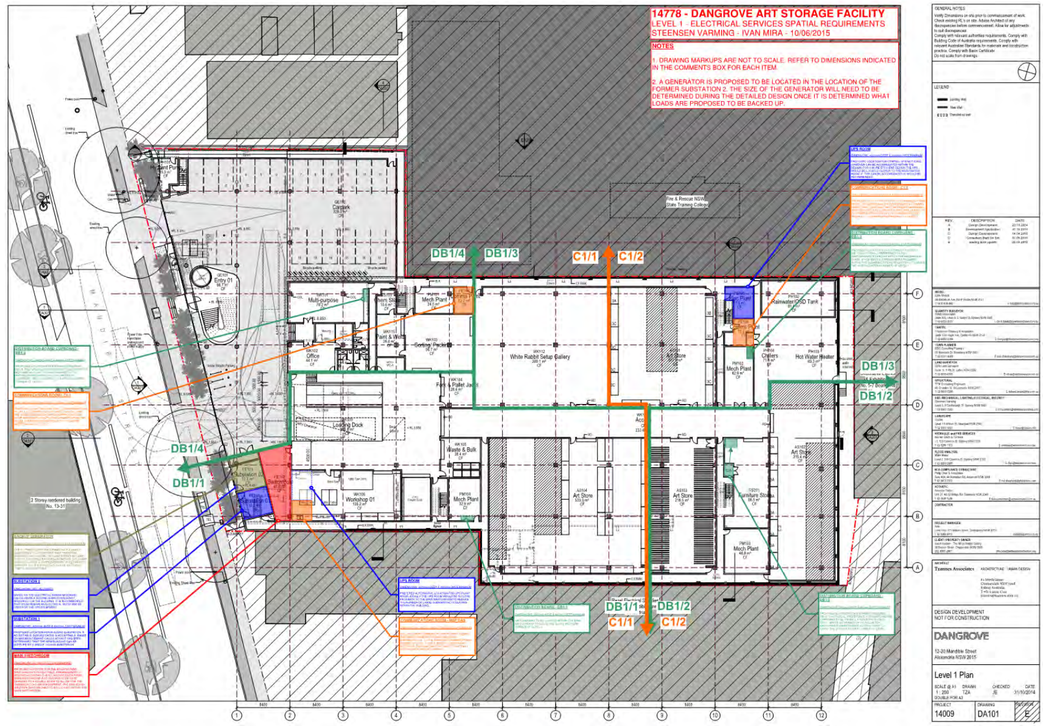
Steensen Varming ensured that all spaces were provided for within the architectural design for the electrical services systems, but did not select the systems. This allowed the contractor to implement knowledge and experience they had in terms of system selection and arrangement. From a risk perspective, this method of procurement typically reduces the client's risk as it places the onus on the builder/contractor to deliver a building that has not fully been designed, but provides them with the opportunity to suggest and modify the design to suit their construction methodology. It also allows the chance to gain a cost advantage over a fully designed project by utilising existing relationships with preferred suppliers rather than being instructed on the systems to be used.

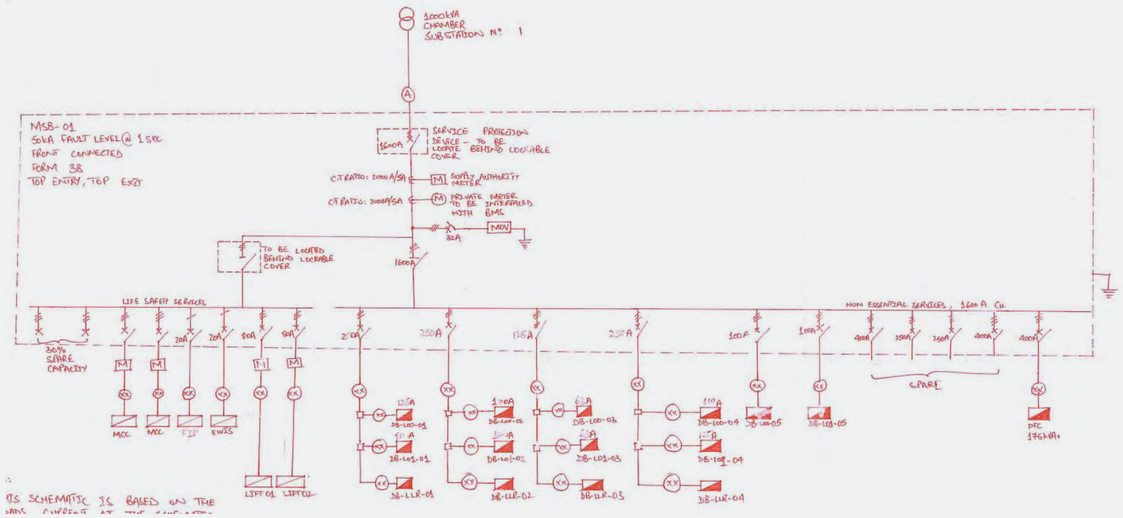
In addition to the detail of documentation required, it was crucial that the design documentation aligned with Tzannes' and Judith Neilson's vision for the building as well as the requirements of Judith and her team. This was achieved through undertaking a design briefing process, involving Steensen Varming first putting together concept design sketches along with a report identifying what we believe the building required. These documents then went through a detailed review along with face-to-face meetings to get an understanding of the needs and wants of the project stakeholders.

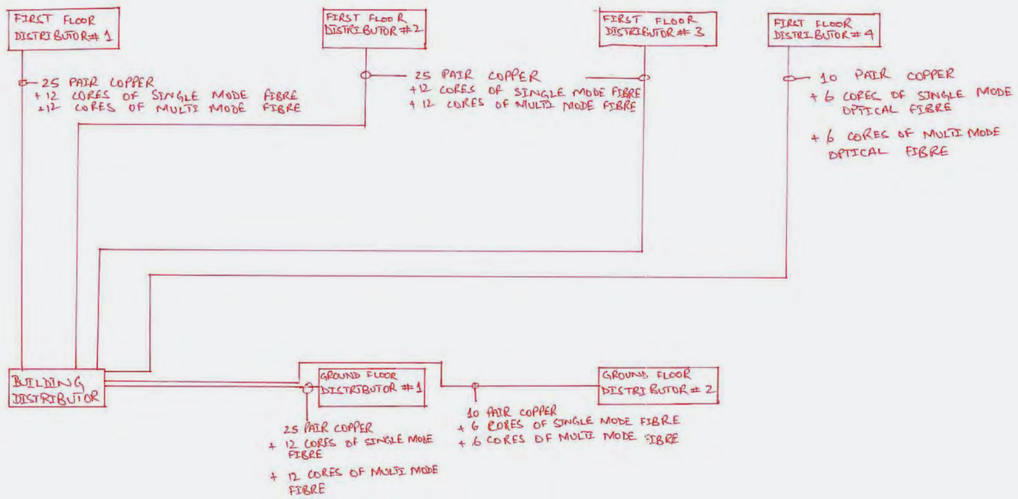
Above: Overlaid on a floorplan sketch is an indication of the spaces required and the electrical services needed.

Below: Overlaid on a floorplan sketch is an indication of the spaces required and the electrical services needed. The green and orange lines depict which rooms service particular areas of the building from a power and communications perspective.









Above: SK4 – electrical single line diagram. Prior to it being drawn in CAD, this diagram illustrates the design of the main switchboard, which supplies all electrical loads within the building. It indicates the specifications of the main switchboard, the equipment required within it – including circuit breakers, power meters and busbars – and connections from the main switchboard to all switchboards in the building.

Below: SK5 – communications single line diagram. Prior to it being drawn in CAD, this illustrates a high-level drawing of the communications system for the building. It shows the communications rooms and the communications cable links between each of them.

The electrical services documentation completed by Steensen Varming captured the following subsystems:

- Power and communications system. All plantroom and back-of-house spaces established and co-ordinated with Tzannes' architectural design, considering the necessary equipment and clearances required for the building to operate. Layout drawings of all spaces indicating the locations of transformers, switchboards, solar panel system, communications racks, power and communications outlets and miscellaneous power supplies. In addition to drawings, a performance specification explaining and detailing the compliance requirements of all systems was completed to allow the contractor to price and ultimately construct the works.

- Lighting and lighting control. Layout drawings indicating locations of all light fittings laid out and selected in consultation with Tzannes. Lighting control functionality detailed in specification. For further detail, see the lighting section, page 197.

- Vertical transportation. Lift selections and performance specification detailing all compliance and technical requirements of the lifts.

- Security systems. Layout drawings indicating the locations of all agreed security equipment such as card access readers, CCTV cameras, equipment racks and sensors. Performance specification outlining the compliance and technical requirements of the system.

The main tasks

For the electrical services design, two main tasks were completed at the beginning of the project; the review and confirmation of incoming services connections for power and communications to the new building, and the allocation of plantrooms within the proposed building design to accommodate the electrical equipment required for the building to function. This involved the sizing of the substation, main switchroom, distribution board cupboards, solar panel system, communications rooms and establishing preliminary cable pathways.

Preliminary applications for both power and communications services were submitted to Ausgrid and Telstra, both of which confirmed sufficient capacity in the network to accommodate the new building. Given the extent of the building, it was determined from our maximum demand calculation that a new substation needed to be established within Dangrove to support its anticipated electrical load which formed an input into the development of the electrical space requirements of the building.

Developing and co-ordinating the electrical services' space requirements with the architect in the initial stages of the building design are critical to the successful delivery of a project. Steensen Varming completed several iterations for the building, typically done through mark-ups and sketches, as well as attending various meetings to discuss and work through the requirements. Initially, the requirements were provided to Tzannes in the form of a table outlining the areas required, detailed requirements for the rooms, such as fire rating and images of sample equipment, to give Tzannes more context behind why the spaces were required. Tzannes took this information and did a first pass of integrating the elements into the architectural design.

In addition to the rooms required to house the electrical equipment for operating the building, various lifts were also essential for the operation of the building. This included a front-of-house lift, a very large goods lift and a dock leveller. Steensen Varming worked closely and collaborated with various vertical transport suppliers to determine the requirements of each lift to ensure the building was appropriately serviced. The D&C contract allowed the builder to approach other lift suppliers they had pre-existing relationships with, rather than having to deal with those who provided advice during the design stage. It was essential that selected lifts fit within the design parameters and meet the specified performance requirements. By the completion of the project, only the supplier of the front-of-house lift was changed, with the goods lift and dock levellers being provided by the suppliers consulted during the design stage.

Following the first pass of the integration of the spatial requirements by Tzannes, Steensen Varming reviewed the architectural design and provided comments and further information to further finesse the requirements into the architecture. Comments were generally limited to the sizes of rooms and the locations of rooms. Meetings were also held to discuss and work through the arrangement. After various back and forth iterations, the architectural design incorporated all required electrical services rooms required to serve

Dangrove, laid out and designed in such a way that each space was fully utilised with minimal wastage of space. Cable pathways were also considered to ensure the proposed arrangement was going to be acceptable. This was mainly from a capacity perspective, but also from an access and maintenance perspective to allow sufficient space in case additional services were required in the future, or existing services needed modification.

With all the plantrooms required by the electrical design established and incorporated into the architecture, Steensen Varming moved on to documenting the services essential to the operation of the building. During this process, Steensen Varming met and discussed the building requirements with the client herself, building users/employees and selected service providers. This involved the team going through the building, room by room, to establish exactly what services needed to be incorporated in the design for each space. The information gathered was transferred into a set of PDF mark-ups and submitted to the team for their review and approval to ensure all requirements had been captured. Once accepted, the details were incorporated into our Revit model and design documentation.

In addition to layout drawings for each of the subsystems in the electrical design, single line diagrams were produced to show the overall design of each system and how it all linked together. SK4 and SK5 on page 228 show early examples of the single line diagrams for the power system. SK4 shows all the switchboards and sub-main cables connecting them; SK5, the communications single line diagram, indicates the location of each communications room and the cable links between each of them.

Once the final locations of equipment were known, the arrangement and routes of all major cable trays and proposed final sub-circuit routes could be developed. These trays would be used to reticulate all the required sub-main cabling, sub-circuit cabling and communications cabling throughout the building. Designing the reticulation systems involved modelling the proposed cable trays within the Revit model, to ensure that cabling originating at all the distribution boards and communications rooms could be reticulated to the final locations of equipment, co-ordinating their routes with the architecture and other services equipment. Given the arrangement of the building, the size and configuration of the Great Hall, the other services that needed to be co-ordinated with and restrictions as to where exposed services could be installed, this proved a challenging task. Tzannes required all services to be easily accessible. By working in a 3-D model and co-ordinating closely with the other team members, namely Tzannes and the Steensen Varming mechanical engineers, we reached a solution which met all the objectives of the building.

In addition to the design drawings noted above, detailed specifications were also written to enable the documents to be issued for tender. Specifications were written for the electrical services and vertical transport systems. Given it was a D&C construct, these were written in a format that stipulated the performance required rather than the specific equipment.

Once a builder was appointed along with the respective subcontractors, Steensen Varming's role in the project became a monitoring and review role on behalf of the client. This involved the review of the contractor's finalised design, workshop drawings, calculations and commissioning data to ensure that the contractor's design, and ultimately the installation, met the requirements of the design put together by Steensen Varming. Generally, the electrical contractor did not deviate from the Steensen Varming design in terms of scope and provision of services; however, alternative equipment was proposed in some instances. Steensen Varming reviewed this for quality and technical requirements to ensure the same standard of equipment was being achieved.

In addition to the review of the contractor's design and documentation, the review role also involved Steensen Varming undertaking site inspections through the construction period. While the responsibility to ensure the installation was in accordance with the requirements of the design and Australian standards lay with the contractor and builder, Steensen Varming's inspections were more focused on the quality of the installation by the contractors to ensure the work was completed to an appropriate level of quality. Site inspection reports were completed following each inspection with any items of concern. However, these were generally of a minor nature as the contractor's installation was to the expected level of quality and finish.

Post-construction

With the construction completed, we believe the design and construction of the electrical services has been a successful one. Personally, I consider a job to be successful if there are no issues to be resolved post-construction. Our understanding is that, electrically, the building has been problem-free since completion. The pride and joy of the electrical installation for Dangrove is no doubt the solar panel system which, based on discussion with the building managers, has been working tirelessly in generating electricity for the building and is going some way to producing enough power to support the needs of the whole building. We understand all electrical systems are operating as expected, quietly in the background where they belong, as I believe the building itself, especially a building as grand as Dangrove, should take centre stage.

The sketch illustrates results of discussions during the early part of the design stage into proposed security services. A workshop was held with the client and Tzannes to determine which doors needed to be secured by card readers, where intercoms were required and which areas had to be monitered by CCTV.



Practice profile

Steensen Varming, founded in Denmark in 1933, are practitioners in mechanical and electrical engineering, lighting and sustainable designs that enhance spatial design. The practice provides unrivalled expertise in cultural projects, in particular museums and galleries, and has long-term relationships with many institutions internationally. It provides advice to the Museums & Galleries of NSW in the preparation of their published guidance documentation, and is a member of the Museums Association, which represents the people and institutions consulting some of the most significant international museums and galleries. Steensen Varming has studios in Copenhagen, London, Sydney, Hong Kong and New York.

Key People

Ivan Mira
Michael Harrold

18

Acoustic Engineering

Acoustic Studio

The challenges

On the face of it, a storage facility in an industrial zoned area doesn't sound like much of an acoustic engineering design challenge. But there were challenges. The facility requires 24/7 operation of mechanical equipment to maintain suitable conditions for art storage. Much of this equipment is located at roof level, and the noise emissions must comply with stringent limits required by the planning approval.

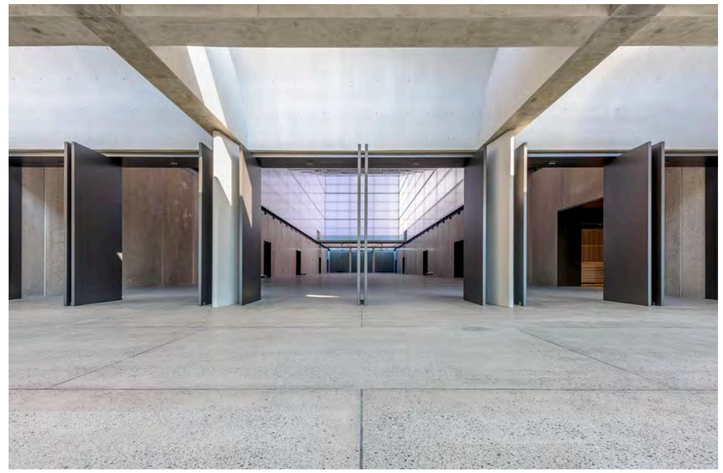
Determining the design brief for the internal acoustics of the facility also required considerable thought. Internal acoustic requirements for this type of facility are not defined in codes or standards, and therefore it was necessary to consult with the client and design team at some length to understand the intended use. This would then be used as a basis to recommend acoustic criteria.

Successful acoustic environments are always underpinned by an understanding of how the occupants will use the spaces – the way they need and prefer to engage with the spaces, and the acoustic stimuli that inhibit or enhance their activities.

The acoustic design brief also highlighted another challenge: to deliver good internal acoustics with a 'light touch' (or, to put it another way, to avoid unsightly acoustic treatments that detract from the beautiful interiors, such as those shown here).

Noise emission

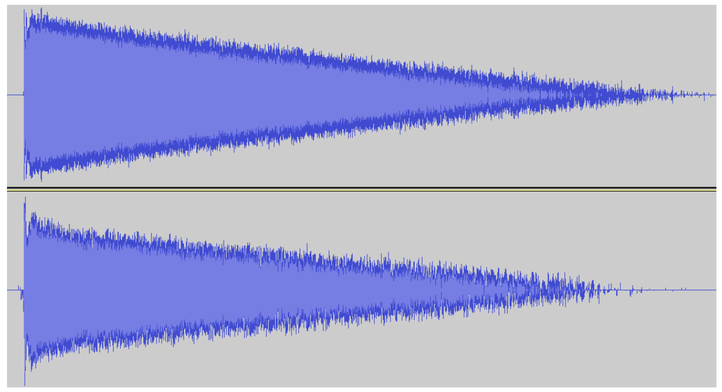
Although the site is in an industrial area, there were a number of nearby noise-sensitive receivers that needed to be addressed at the design stage. The adjacent Fire and Rescue NSW site includes a training facility adjacent to the boundary with Dangrove, as well as sleeping quarters for fire crews and state emergency control centre staff, located near Wyndham Street. At the design stage, the eight-storey apartment block at 2–6 Mandible Street also had direct line-of-sight to all of the future rooftop plant at Dangrove. This is not the case



The interiors are unspoilt by unsightly acoustic treatment.







This page, top: Site plan showing surrounding noise-sensitive receivers.

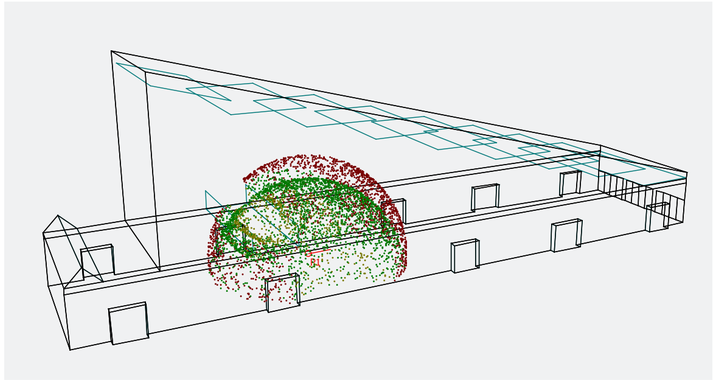
Centre: View from the rooftop plant area, towards the Fire and Rescue training facility.

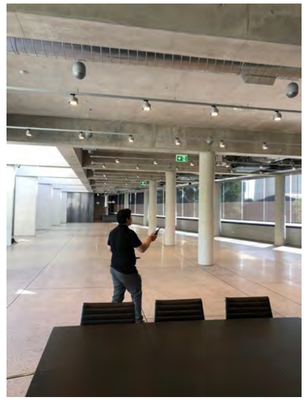
Below: Predicted (upper plot) and measured (lower plot) sound decay from an impulse, showing sound energy (vertical axis) decaying over time (horizontal axis). The measurement was carried out with a number of artworks and associated items in the Great Hall, which may explain the slightly shorter reverberation than predicted.

This page, top: A still image from an animation in the ODEON acoustic model of the Great Hall, showing sound radiation from a test source. The red dots illustrate direct sound radiating from the test source and the green dots show the first reflections from sound interacting with the room surfaces.

Centre: Anthony Cano checking noise levels in the function space. The air conditioning system can be operated at reduced duty at key stages during a function to reduce noise levels if required. This approach avoided the need for bulky sound attenuation in the space.

Below: The office spaces include visually unobtrusive (black polyester fibre insulation) sound absorption on the soffit to ensure comfortable and functional acoustics.







now, following the construction of the new Rail Operations Centre, but was an important consideration in the design. These issues needed to be addressed in the development application acoustic report submitted to the City of Sydney at the design stage.

Noise controls, such as attenuators and internal duct linings, were incorporated in the design and then checked during construction. Noise measurements were carried out on completion to confirm compliance. This was documented in a verification report to support the project Occupation Certificate.

Internal acoustics: the Great Hall

The Great Hall was a key focus for internal acoustic design, given its large volume. The user requirements for the space also evolved during the design.

The acoustic design solution was to include sound absorption above the ceiling to moderate reverberation a little and to incorporate noise control in the ventilation system to ensure appropriate noise levels.

The large volume of the space naturally results in a long reverberation time, around 6 seconds at mid-frequencies. This provides ‘cathedral-like’ acoustics which enhance the sense of scale. And, although not designed for performance, the acoustics also lend themselves to certain types of music and sonic art. Temporary acoustic panels can be implemented, if required, to further moderate the acoustics for performances; to date, this hasn’t been necessary. In any case, the space is often filled with numerous large works of art and the associated storage cases etc; this adds diffusion to the space, which breaks up the acoustic reflections a little.

Internal acoustics: other spaces

The air conditioning system serving the function space can be operated at reduced duty during key stages of a function, such as speeches, so as to reduce noise levels, if required. This approach avoided the need to add bulky sound attenuation.

Conclusion

It was a pleasure to work on this project. Acoustics was not at the forefront of the client’s requirements but we are delighted that our acoustic design input has achieved a successful outcome without detracting from the beautiful architecture. The Great Hall is acoustically reverberant, as expected, but rather than being a problem, this has actually added to the functionality of the space during performances.

Practice profile

Acoustic Studio, founded in 2003 in Sydney, is an acoustic consultancy that specialises in building acoustics and transportation noise and vibration. Its expertise – a merger of acoustics, engineering and design – covers many different development types, including auditoria and theatres, industrial, residential, commercial, educational and transportation.

Key People

Dave Anderson, director
Anthony Cano, senior acoustic engineer

The Great Hall has been used for a number of music performances. The long reverberation time provides a very rich, warm and blended sound. This is suited to certain types of music and sonic art, but not to music with rapid notes, which tend to blend together.

19

Landscape Architecture

OCULUS

The role of the landscape architect
As landscape architects and urban designers, we strive to create projects in the public and private domain that are challenging, contemporary and multi-dimensional; ones that encourage engagement with landscape and spark conversations between the people who occupy them. The Dangrove art storage facility project offered an exciting opportunity to explore these interests in a truly collaborative way, and with the support of a very sophisticated client in Judith Neilson.

The notion of progression
Working closely with Tzannes, we developed a strong narrative which was based around the notion of progression through space, both landscape and architecture. It was almost like a procession, starting from the front door and seamlessly flowing throughout the building and the various landscape spaces. The streetscape interface with the building is a physical manifestation in simplicity in form and function and the landscape reinforces this linear form with the main pedestrian entry centrally located and slightly elevated. Flanked by linear planted gardens, the loading dock is located on one side and the vehicular entry to the internal car park is mirrored on the other. The facade of the building is grounded in the landscape, and along the Mandible Street setback we introduced a row of *Acer palmatum* 'Sango Kaku' (coral bark maples) – a tree with brilliant coral bark and bright green foliage – which both accentuates the linear, wedge form of the building while punctuating it with vivid colours. The deciduous nature of the maples also means the visual experience will change through the seasons. Low shrubs, native grasses and ground cover plants introduced striking green foliage and blue-purple flowers while providing screening as well as articulation of the building entries.

As part of the strong sequence of entry to the building, the existing aerial powerlines in the street were placed underground so that new street trees could be planted to enframe and enhance the streetscape. Given its high expense, considerable thought was given to other options; however, the client agreed that the cost was worth the visual improvement to the streetscape and the building's setting. The new street trees consisted of regular spacing of evergreen native *Eucalyptus eximia* (yellow bloodwood), which complement the architectural rhythm of the building. The street trees form an integral part of the City of Sydney's street tree master plan for the area to increase biodiversity and the urban tree canopy.

Entering the building, the space opens up to to reveal state-of-the-art facilities for core operations, including a welcoming entry foyer and reception, restoration and curation spaces, workshops and specialised storage areas and secure parking. These are all accessed from Mandible Street, which is treated as part of the overall composition of the landscape canvas for Dangrove.

Moving up through the building, the main staircase intentionally switches back on itself; on arrival at the first floor, the view opens up to a large sun-filled 'picture' window framing the view of the courtyard garden terrace. Sitting almost monumentally in the centre of the terrace is artist Angus Taylor's sculpture of an oversized reclining figure, distorting all sense of scale. There is an immediate connection between the outside and the inside of the building, allowing light to pour in from the courtyard space. This has provided a serendipitous moment where the landscape and artworks complement each other, and allow each to be viewed and engaged with from different vantage points in the building. The view into the courtyard at the top of the stairs is directed straight at the artworks, with the planting behind acting as a green 'foil'. The view from the library into the courtyard

Overleaf: Mandible Street frontage with coral bark maples and low-flowering ground cover plants.





through the leaves of the vegetation in the garden is filtered and intimate, and offers glimpses of the artwork. In contrast, the view of the courtyard from the main entertaining area is expansive, emphasising the connection between outside and inside spaces, and between landscape, art and architecture.

The trees are complemented with low-growing ground cover plants in lime greens and purples to provide a carpet around the base of the bosque. The low planting also emphasises the horizontal planes that define the terrace space, while allowing the trees to become a strong vertical element in the landscape.

The large precast concrete courtyard wall hosts climbing plants with fragrant flowers on a tensile stainless steel 'green wall' mesh system which screens the concrete walls as well as the walls of the neighbouring property. Despite a number of different expressions, the planting forms a cohesive palette with similar colour themes while still allowing enough variability for the space to be read differently as you move through it.

The courtyard

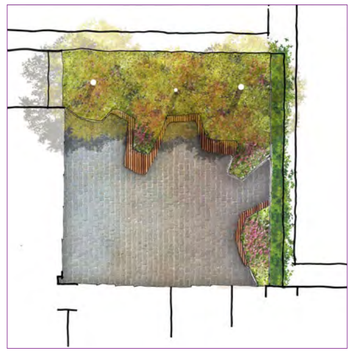
The courtyard was intentionally designed as an exterior landscape room with finely crafted detailing of the various landscape elements. Large precast concrete paving planks were carefully installed on adjustable paving pedestals that allow drainage between the joints. These eliminate the need for surface drainage pits or trench grates, which would visually disrupt the the continuity of the monolithic paved ground surface. The paving slabs were specifically aligned to be perpendicular to a large precast concrete seat that continues the linear theme reflected in the architecture of the building. The stack bond paving pattern reflects the precast concrete materiality and form of the interior architecture so that the lines between inside and outside seamlessly connect, especially when looking out of the building through large windows to the courtyard. The effect is similar to viewing the scene through a camera lens.

The concrete materiality reinforces the industrial nature of the building; a large linear planter combines with the precast linear seat on the north-eastern side of the courtyard terrace. The planter introduces a bosque of *Lagerstroemia indica* 'Tuscarora' (crepe myrtle) specifically chosen to add vibrancy in the space in summer with brilliant crimson flowers. Selection of the most appropriate tree was not a random process but more a consideration of shape, form, texture and seasonal colour. Numerous trees were considered and, after careful thought, this particular species of crepe myrtle was agreed upon among the design team and client.

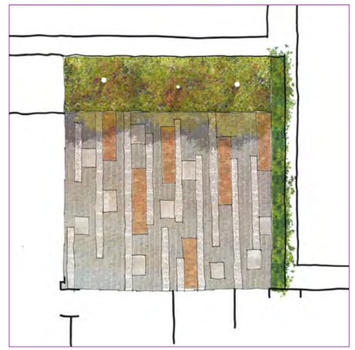
This page: Landscape plan of the Mandible Street frontage. The aerial power cables were placed underground; all new native street trees were to be planted in the verge with a background of deciduous, colourfully accented coral bark maples.

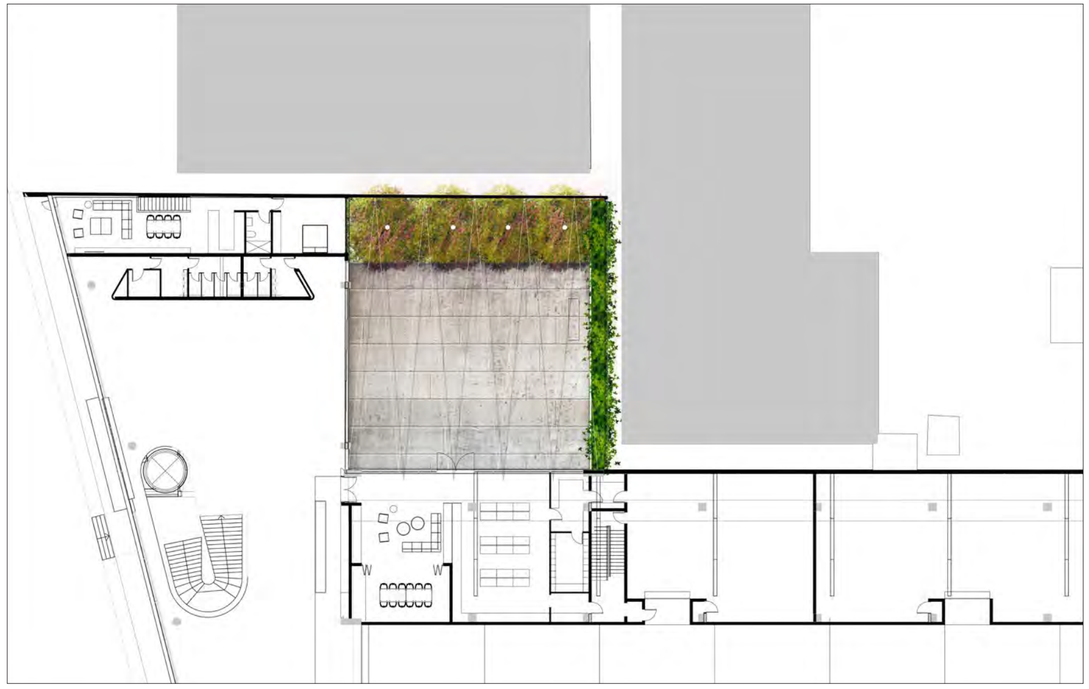
Opposite, above: A number of design options for the courtyard were tested, with many being discounted as overly fussy. There was a preference for simplicity and flexibility, and the need for a space where large artworks could be exhibited.

Below: The final design for the courtyard references the simplicity of the architecture with monumental paving slabs, a 'green planted background' with a long seating bench and vine-covered trellis. This allows the artwork to be the focus of the space.



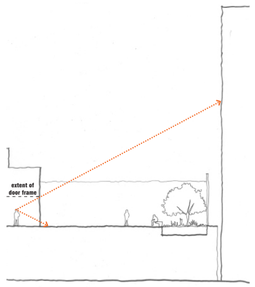






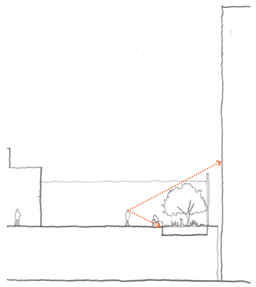
DANGROVE VIEWS

VIEWS FROM INSIDE



KEY OBSERVATIONS
- Large expanse or ROC wall visible from office spaces
- Distance from ROC wall increases the visual mass
- Door frame height can dictate how much of the ROC wall is seen

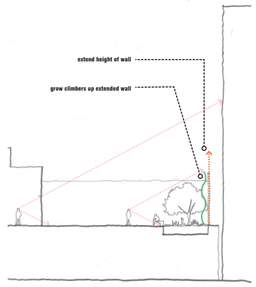
VIEWS FROM OUTSIDE



KEY OBSERVATIONS
- Smaller expanse or ROC wall visible when looking ahead from the terrace
- Trees and planting screen the direct view but not the views up

DANGROVE SCREENING OPTIONS

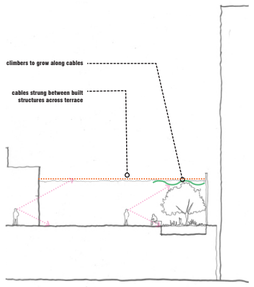
ADDITIONAL WALL HEIGHT AND CLIMBERS ✓



OPPORTUNITIES
- Extending the height of the wall and growing climbers up will add green screening while trees and plants establish.
- The green wall will soften the large concrete walls

CONSTRAINTS
- The climbers and planting will take time to establish
- A structural engineer will have to assess the height limitations of the wall

CABLES WITH CLIMBERS ✗



OPPORTUNITIES
- Cables with climbers provide a roof to the terrace with restricted views to ROC wall

CONSTRAINTS
- Climbers will take time to establish and require frequent maintenance to encourage their growth in the correct location
- The terrace is wide and cables will sag in the middle when fixed to either side. Climbers wil not span the entire terrace
- Most importantly the development celebrates large industrial spaces and their vast expanses beautifully. Adding cables overhead will encourage the opposite effect in the terrace space. The space will feel confined and insular. As the only space with view to the sky we feel this shouldn't be restricted.

OCULUS DANGROVE ART STORAGE FACILITY 12-20 MANDIBLE STREET ALEXANDRIA
ROC WALL SCREENING OPTIONS

SHADE TOLERANT PLANTING

GROUND COVERS AND FEATURE PLANTING

PLANTS TO REPLACE

Dichondra repens	Kidney Weed
Liriope muscari	Lily Turf
Lomandra longifolia 'Lime Wave'	Lomandra Lime wave

SHADE TOLERANT SPECIES

Hosta balcyon	Hosta
Pachysandra terminalis	Japanese Spurge
Rhoeo spathacea	Moses in the Cradle



Hosta balcyo



Pachysandra terminalis



Rhoeo spathacea

TREE REPLACEMENT OPTIONS

Lagerstroemia indica requires more sunlight than is available. Below are some alternate tree options.



POTENTIAL REPLACEMENT TREE
Stenocarpus sinuatus **Firewheel Tree**

Mature Height: 6-10m
Mature Spread: 2-3m

Key features
- beautiful red flower (summer-autumn)
- tall and columnar (will need to increase quantity of trees)
- shade tolerant (rainforest species)
- evergreen tree



POTENTIAL REPLACEMENT TREE
Hymenosporum flavum **Native Frangipani**

Mature Height: 4-10m
Mature Spread: 2-6m

Key features
- yellow flowers (spring)
- flowers are strongly scented
- shade tolerant (rainforest species)
- evergreen tree
- fast growing



POTENTIAL REPLACEMENT TREE
Waterhousea floribunda **Weeping Lily Pilly (previously Syzygium floribundum)**

Mature Height: 10-15m
Mature Spread: 7-10m

Key features
- white flowers (spring-mid summer)
- larger tree (good for screening)
- shade tolerant (rainforest species)
- evergreen tree

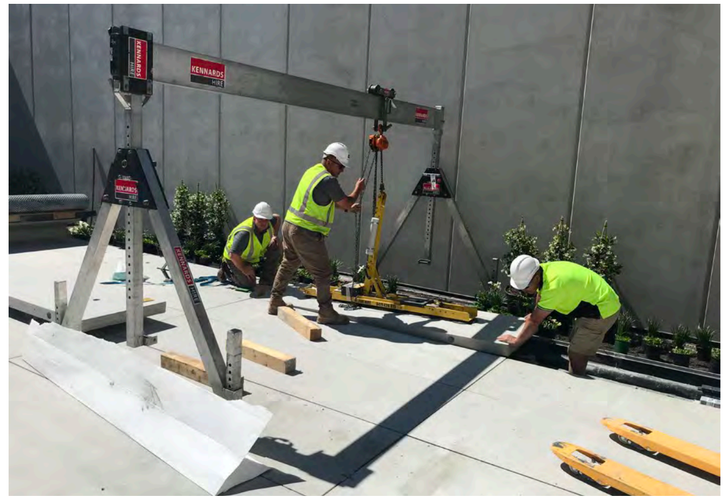
OCULUS DANGROVE ART STORAGE FACILITY 12-20 MANDIBLE STREET ALEXANDRIA
ROC WALL SCREENING OPTIONS

This page, top: Sightline analysis of internal views from the building and external views from the courtyard.

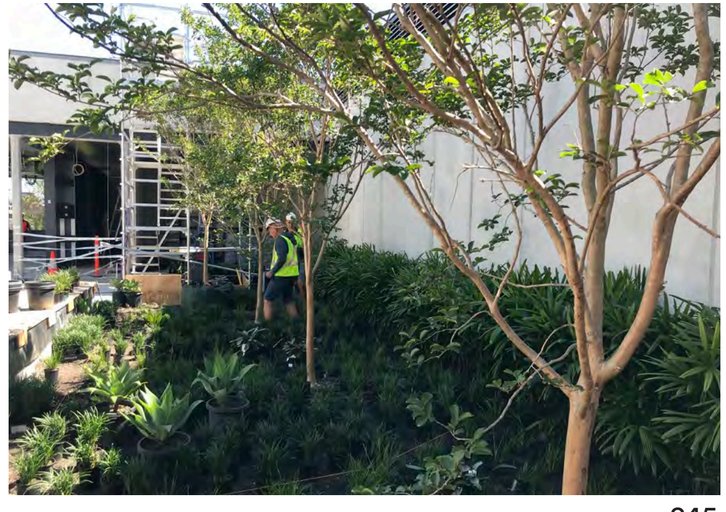
Centre: Various green screening options were considered to reduce the visual scale and bulk of the adjacent building.

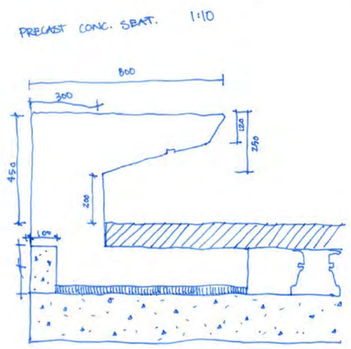
Below: The landscape planting options featuring a selection of shade-tolerant species.

This page: Construction photos during paving and planting installation.





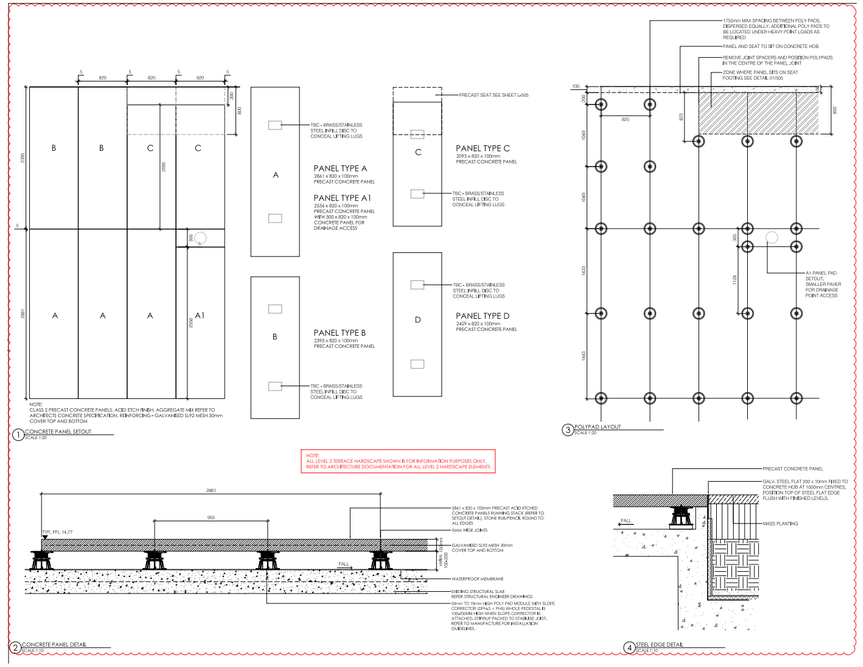


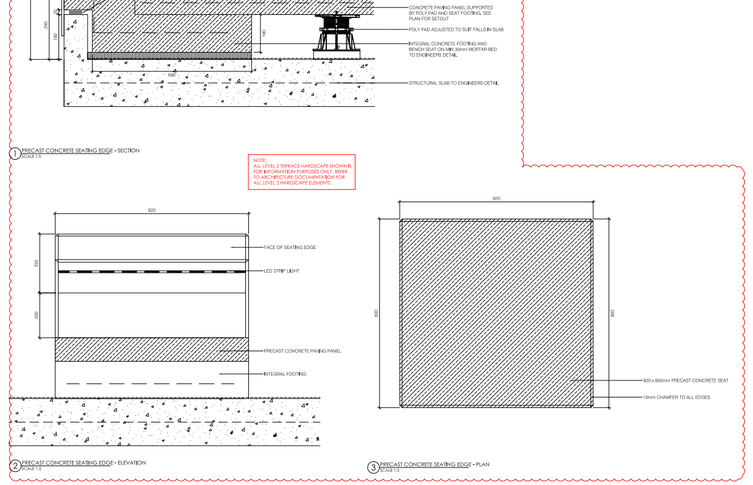


Left: The courtyard, featuring monumental paving, vine-covered trellis and built-in seating. Artwork is by Angus Taylor.

Above: Sketch of custom precast concrete seating concept.



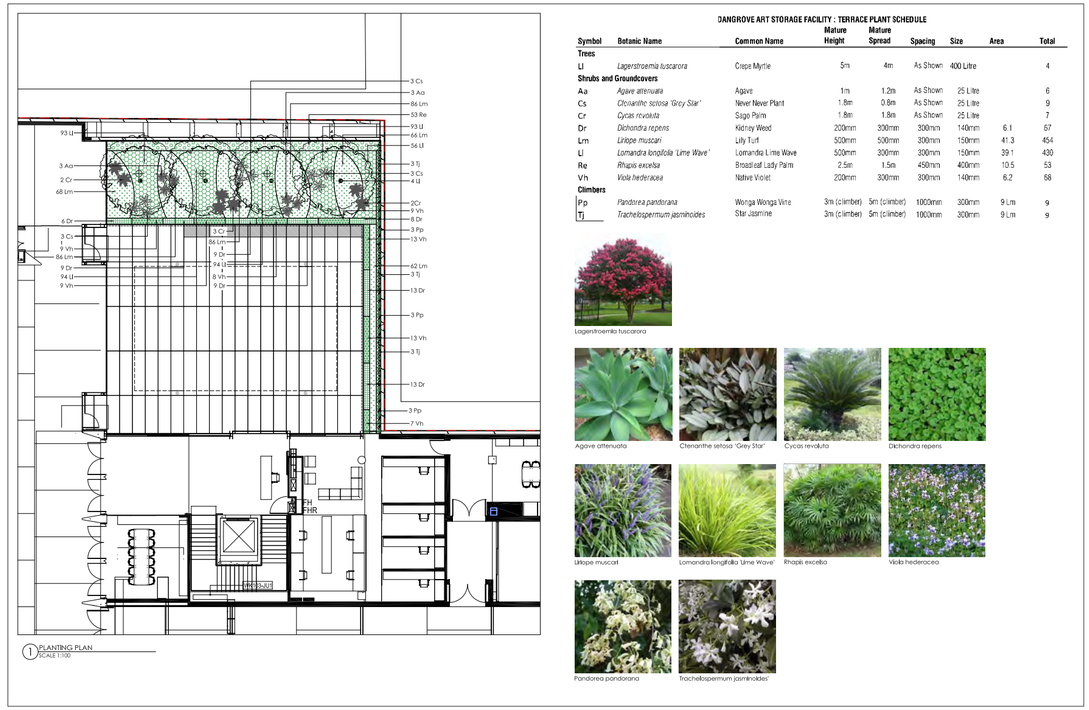




Opposite: Courtyard planting of Tuscarora crepe myrtles with climbing star jasmine–covered trellis structure.

This page, top: Precast concrete paving slab detail with structural supports.

Above: Final precast concrete seating detailed design.



DANGROVE ART STORAGE FACILITY : TERRACE PLANT SCHEDULE

Symbol	Botanic Name	Common Name	Mature Height	Mature Spread	Spacing	Size	Area	Total
Trees								
Ll	*Lagerstroemia tuscarora*	Crape Myrtle	5m	4m	As Shown	400 Litre		4
Shrubs and Groundcovers								
Aa	*Agave attenuata*	Agave	1m	1.2m	As Shown	25 Litre		6
Cs	*Ctenanthe setosa 'Grey Star'*	Never Never Plant	1.8m	0.8m	As Shown	25 Litre		9
Cr	*Cycas revoluta*	Sago Palm	1.8m	1.8m	As Shown	25 Litre		7
Dr	*Dichondra repens*	Kidney Weed	200mm	300mm	300m/m	140mm	6.1	67
Lm	*Liriope muscari*	Lilly Turf	500mm	500mm	300mm	150mm	41.3	454
Ll	*Lomandra longifolia 'Lime Wave'*	Lomandra Lime Wave	500mm	300mm	300mm	150mm	39.1	430
Re	*Rhapis excelsa*	Broadleaf Lady Palm	2.5m	1.5m	450mm	400mm	10.5	53
Vh	*Viola hederacea*	Native Violet	200mm	300mm	300mm	140mm	6.2	68
Climbers								
Pp	*Pandorea pandorana*	Wonga Wonga Vine	3m (climber)	5m (climber)	1000mm	300mm	9 Lm	9
Tj	*Trachelospermum jasminoides*	Star Jasmine	3m (climber)	5m (climber)	1000mm	300mm	9 Lm	9

Lagerstroemia tuscarora

Agave attenuata

Ctenanthe setosa 'Grey Star'

Cycas revoluta

Dichondra repens

Liriope muscari

Lomandra longifolia 'Lime Wave'

Rhapis excelsa

Viola hederacea

Pandorea pandorana

Trachelospermum jasminoides'



Opposite, above: Final courtyard planting plan and plant schedule.

Below: The courtyard.

Conclusion

The OCULUS design team provided landscape architectural services from early concept stage through design development, documentation and construction services to completion of the project. This included challenging detailing of the large paving slabs, which were designed to be structurally capable of taking heavy loads, especially large-scale sculptural elements such as the ‘Reclining Man’ sculpture. All the materials for the terrace were craned over the building and assembled piece by piece, including the precast concrete seat, paving slabs and advanced trees and soil. The garden areas also contain landscape lighting to accentuate the trees and the seat at night.

Water management includes the capture of stormwater from the building roofs which is stored in large underground tanks in the car park. Both the terrace and the street setback landscape are irrigated with a fully automatic irrigation system with soil moisture sensors using harvested rainwater from the storage tanks.

The landscape design approach closely aligns to Tzannes’ architectural intent, drawing on materiality to create seamless transitions from internal to external spaces. On reflection, collaboration between the architects, landscape architects and an informed and engaged client was central to the design process and has resulted in a highly resolved and detailed project that spans the intersection between art, landscape and architecture. The various landscape spaces are flexible, considered and well mannered – places that people can occupy formally or informally and interact closely with artworks. The landscape canvas is intended to function as an extension of the building, with a seamless interface between interior and exterior space maintaining its architectural language.

It is a testament to Judith’s passion for art, architecture and landscape that has led to the project being a resounding success and a thoroughly enjoyable and rewarding process for all.

Practice Profile

OCULUS is a cross-disciplinary design studio committed to connecting people with their environment and each other.

Our projects contribute to public life, combining high levels of amenity with ecological sustainability. We work across all scales, from the design of parks, gardens, streets and mixed-used precincts, to rooftops, terraces, architectural structures, furniture, green facades and breathable interiors.

Our multidisciplinary team has expertise in urban design, landscape architecture, architecture, industrial design and horticulture. We have an open studio approach and encourage all staff to be creatively involved in all stages and processes of the design.

As designers concerned with public space, our work addresses the conditions that contribute to the ongoing success of a place: whether they be social, cultural, economic or environmental. Our work is as much about the way people inhabit space and engage with each other as it is about physical and environmental qualities.

Key people
Roger Jasprizza
Jessica Hodge
Louise Mould

20

Construction

Infinity

Infinity's interest in the project

When Alec Tzannes contacted Infinity to enquire if we would be interested in providing a tender submission for the project, we were immediately attracted to the prospect of becoming an integral part of the project delivery team for a building that, we believed, would become iconic.

The design concept placed before us was not just unique in its bespoke nature, end use and high performance, it also offered an opportunity for us to implement decades of our expertise into the built form to ensure the project had a serviceable life exceeding 100 years.

At the time, we weren't familiar with Judith Neilson, a visionary client passionate about art, and prepared to invest a substantial amount of time and money so that it can be enjoyed now and by future generations. We soon came to understand the depth of her overall passion to create excellence.

Dangrove presented as a dramatic and voluminous structure with a high level of building performance and a unique interior. The Infinity team embraced the challenge of collaborating with the architect to finalise the design and construct the facility to meet the client's expectations. We needed to prepare a tender bid that would convince Judith and her advisers that Infinity was the best option for the job.

Winning the tender bid

In order to convince Judith that Infinity should be selected as the preferred contractor we needed to understand and carefully consider a number of issues, some of which would have a direct bearing on our construction methodology and sequencing:

- The form and function of the proposed building.
- Design intent of the architecture and environmental intention of the enclosed space.
- The proposed geotechnical and structural solution.
- Physical site constraints associated with the address, along with implications of construction parameters that would be set by City of Sydney, Sydney Water and Ausgrid.
- Construction obstacles caused by the stormwater canal at the rear of the property and the overhead powerlines across the front of the site.
- Contaminated ground conditions and the high natural water table which, in order to minimise environmental impacts, would have an impact on construction methods.
- Restrictions on vehicle size and movements permitted around the site, along with restrictions of entering and exiting the site with vehicles, imposed by the City of Sydney. These would impact on the construction methodology and even the structural solutions required.
- Restrictions of proposed onsite production and fabrication lengths in the existing design. These would pose construction challenges that we felt could not be achieved.
- The time frame to construct the project along with the limited access from adjoining properties.
- The challenging construction loads imposed on the permanent structure during the course of the works based on the design proposal. We proposed they be reconsidered, in order to minimise the amount of temporary support structures that would hinder progression of the fit-out works.

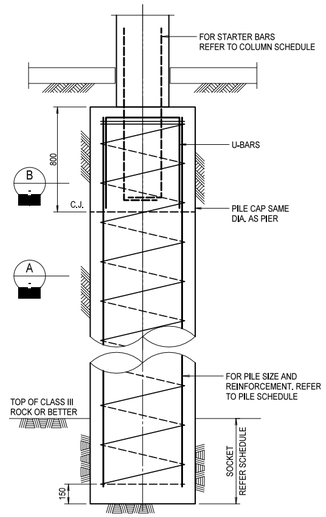
- Availability of proposed materials and specialised trades in a booming market.
- Risks associated with working at extreme heights due to the nature of the design.

After identifying the challenges and construction parameters that we would encounter, we had to determine how we could value-add our expertise to deliver the expectation, and remain competitive against a market of well-known contractors who were all determined to win the project.

It became abundantly clear to us that we had to develop several alternatives to the structure, fabric, services and civil works to enable the brief to be met and to maintain a competitive position on cost and time. We identified key areas to target with an alternative proposal:

- The volume of contaminated material that was potentially required to be removed from the site under the proposed excavation.
- The proposed size of the piles. These would produce a significant volume of contaminated material that would be required to be treated and removed offsite.
- The ground slab design, in order to reduce the extent of material needed to be removed from the site.
- The concrete structure, modifying it to utilise as many offsite prefabricated elements as possible. This would then minimise construction and production onsite and reduce the amount of temporary support framework that would otherwise hinder the progress of the fit-out of the works.
- Hazards associated with conventional formwork for extremely high strutting heights for suspended concrete slabs.
- Risks from inadvertent damage to the proposed internal concrete block walls caused by the extent of materials handling in constructing them. There was also risk associated with having high block walls within spaces where these walls could be subjected to impact from forklifts.
- The proposed roofing system would need to be changed to one with better long-term maintenance. Replacement to be undertaken from above of grommets, which have a very limited life span, and the roofing material itself.
- The proposed roofing system required additional structure to house the specified thermal insulation within the secondary framing grid, suspended below the roof sheeting preventing access to the underside of the roof sheet. This would create challenges for the long-term maintenance required to replace the roofing grommets, attached to bolted connections that held the roof sheeting down.
- The roof membrane system would need to provide a better warranty and a greater resistance to impact damage by eliminating the compressible layers of the proposed system.
- The polycarbonate facade skin. Arcowall had been specified because they were the only company at the time that met the functional requirements and were willing to give a project-specific extended warranty. After construction started, various alternative options were reviewed by Tzannes and Infinity, with the client making the final decision to choose Rodeca, based on recommendations by the architect and builder.
- The external steel elements. These contained surfaces that could not be maintained for the 100-year life cycle as they were not easily accessible. Using structural grade aluminium would eliminate this problem, only requiring maintenance of the paint that was accessible without removing other building fabric.
- Window steel material that came into contact with ground slabs changed to structural grade aluminium to avoid long-term embedded corrosion of the steel that could not be maintained without removing the elements.
- The type of chillers. By avoiding the use of cooling towers, the extent of load on the roof slabs would be reduced, and long-term maintenance issues and risk of Legionnaire's disease eliminated.
- Inground hydraulic services. Rationalising these would reduce the extent of excavation and contaminated material.
- Glass panels. Due to the limitations with local suppliers, importation would reduce the amount of jointing in the facade to meet the architectural brief.

The extract shows the original extent of pile reinforcement.



TYPICAL PILE DETAIL
SCALE 1:20

- The use of precast column and slab elements. This would reduce the amount of materials handling and support framing, enabling clearer access in a shorter period to conduct construction activities below the newly produced structure.
- Develop fire-engineered solutions in consultation with the services design to enable the long fire egress paths to be achieved.
- Light fitting selection, availability and suitability for use with museum quality artwork. We needed to verify with the suppliers and manufacturers of the lighting the effectiveness of the fittings to produce suitable lux levels on the artwork from the heights the fittings would be located.
- Review constructability and detailing of the architectural components that were to be installed at significant heights with particular consideration of working at heights and improved maintenance and replacement of these items during the serviceability period of the life cycle of the building.

Design and construction

Success in the design development and delivery of a building of this scale and performance is largely contingent on the ability of the team to collaborate in an open way with a view to developing the best solution for building elements in the context of function, maintenance, cost and time. The culture of the design team led by Infinity embraced this collaborative ideal and delivered well-resolved design and construction solutions.

There was an extremely close and collaborative process between Infinity, Tzannes and Aver. This is critical to a successful D&C contract. Every single part of the design was questioned, interrogated, debated, reviewed, workshopped, proofed and settled on. Some things stayed the same, others were improved for construction, but the intent stayed the same.

A definite measure of success for such a facility is the life cycle cost management and maintenance initiatives created through thoroughly researched design and construction techniques coupled with material availability and compatibility.

Our charter was to create spaces to satisfy the brief while minimising long-term maintenance issues and access issues for maintenance personnel due to height and scale of the project.

The operational cost and safety in design of a building of this calibre must be considered by the design and construct contractor. In developing the construction techniques, we were cognisant of the future performance and ease of maintenance measures that could be adopted for the building.

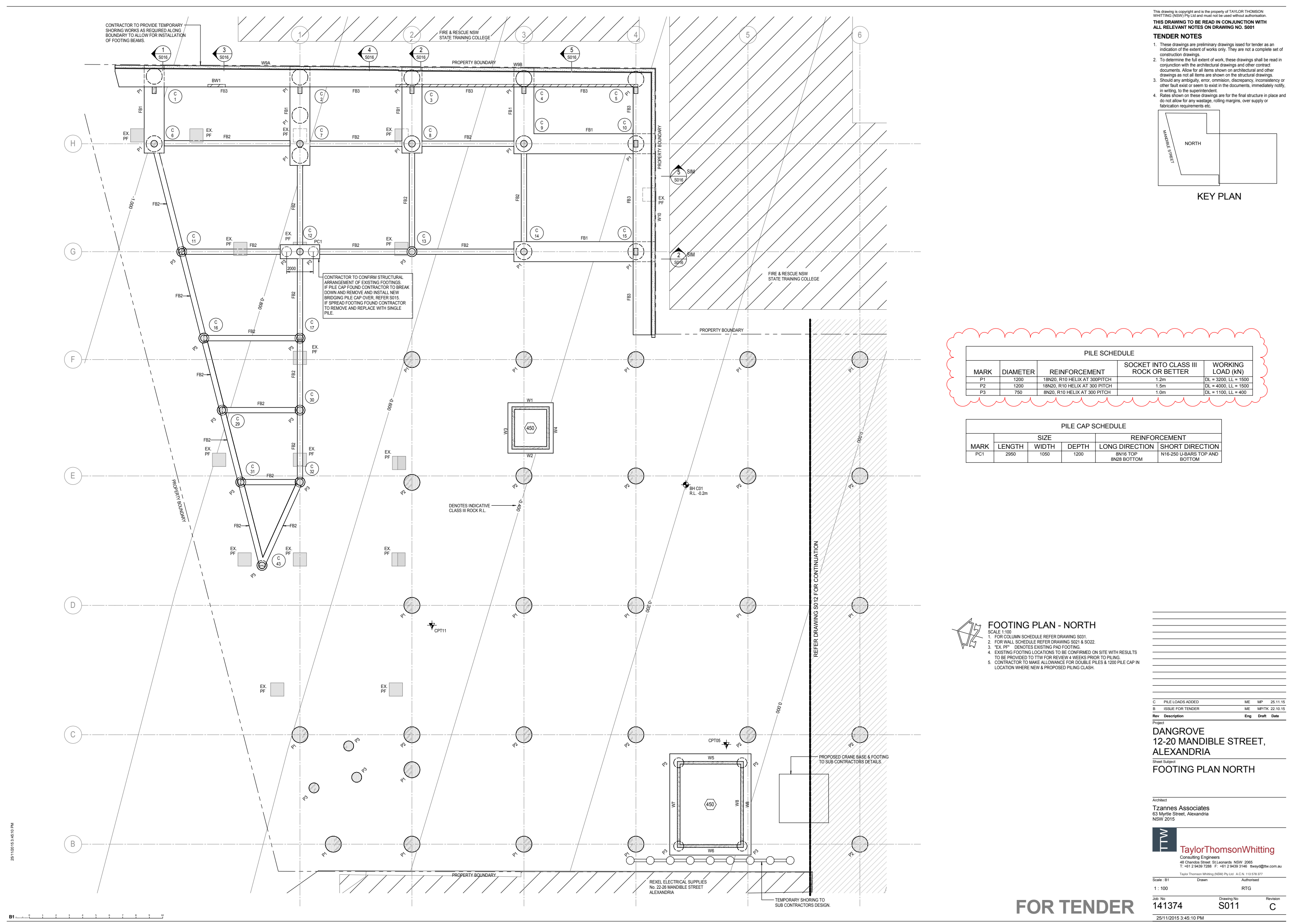
In this unique building there is a collection of spaces that are not usually seen under one roof. The spaces also have diverse functions that had to be carefully considered in the selection of materials and development of construction detailing.

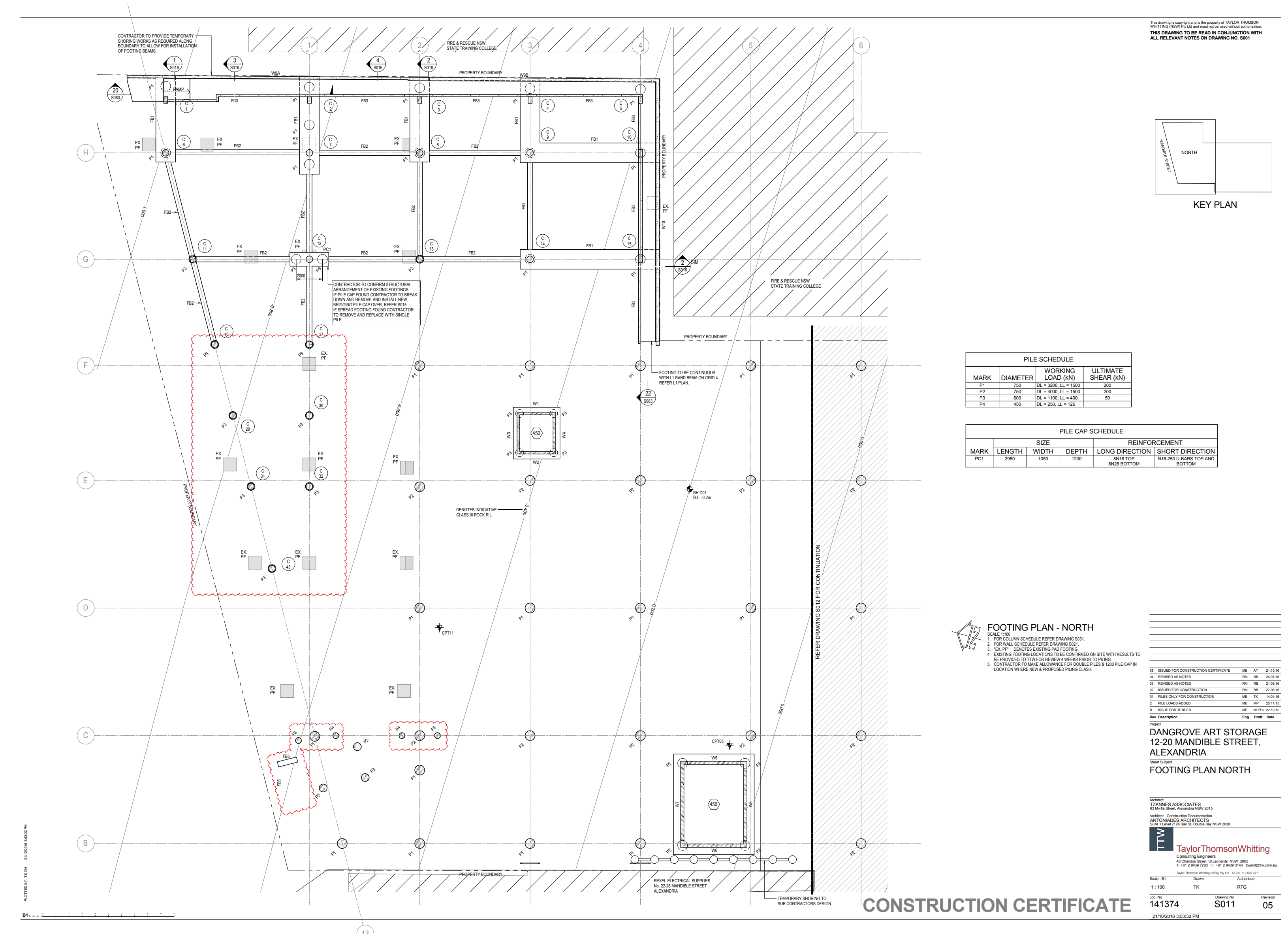
Geotechnical issues

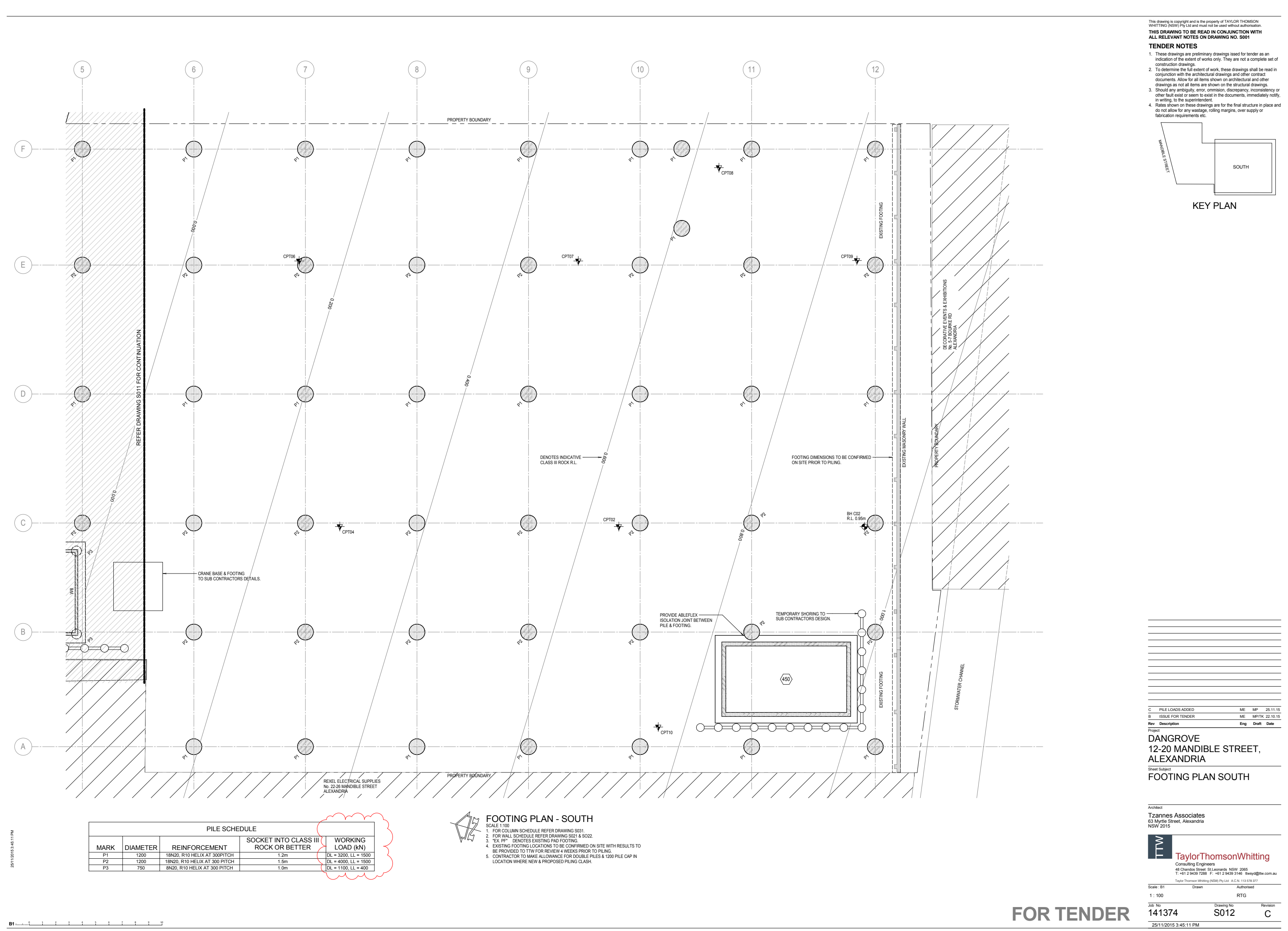
The challenging ground conditions limited the type of footing system able to be used. In addition, the poor ground conditions and water charging typical for the geographical location created design challenges and buildability constraints. There were areas of contaminated fill and, in addition, with the water table only 1 metre below the working surface, it was expected that any excavated fill, including the pile overburden, would potentially be acid sulphate soils.

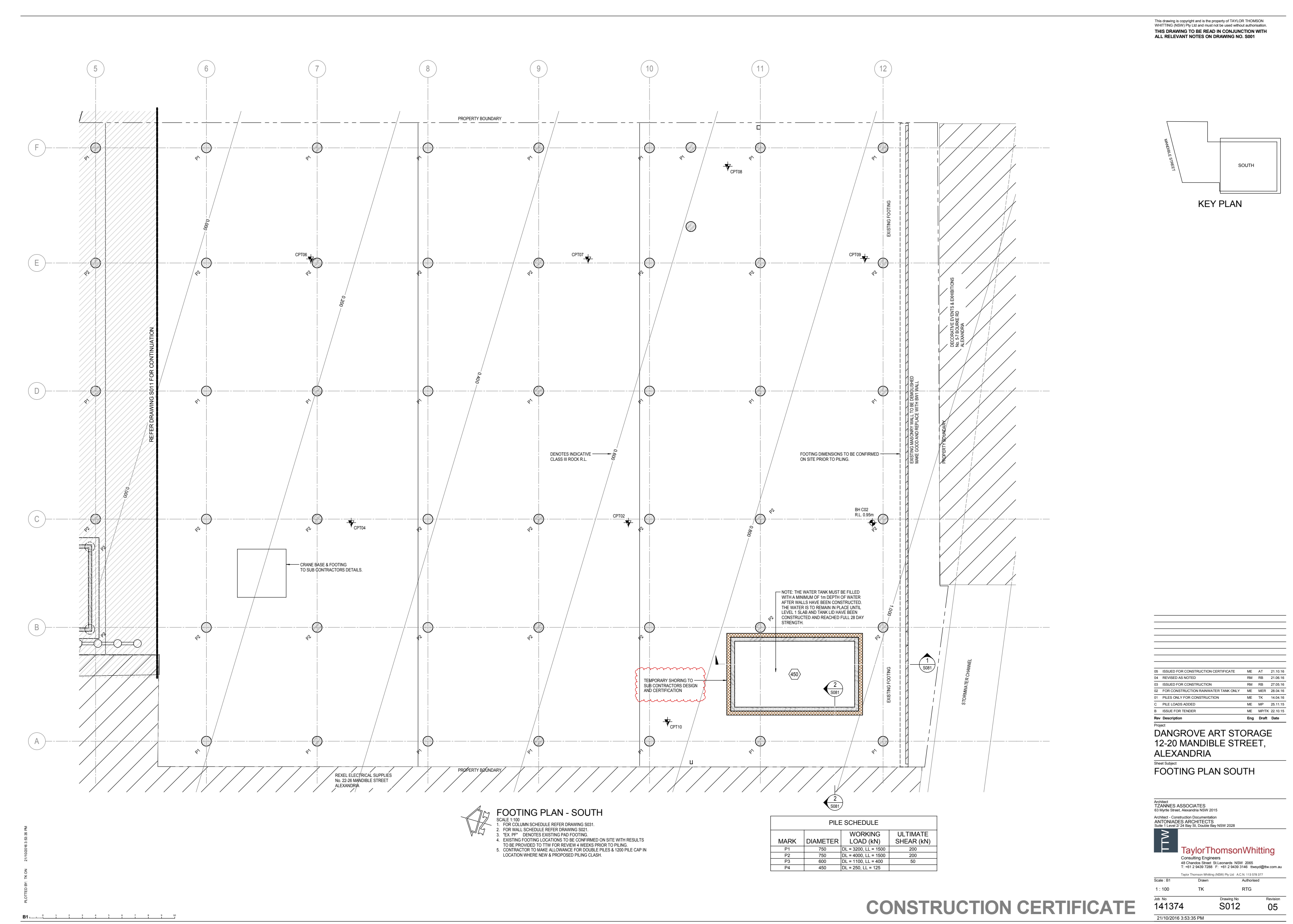
The proposed design had 1200 mm diameter end bearing piles with a medium amount of reinforcement. In collaboration with the client's structural engineer, TTW, we investigated the use of longer/deeper 750 mm diameter piles socketed well into the rock stratum. We utilised the rock stratum and extra reinforcement to provide the lateral stability required for such a tall structure. This proposal almost halved the quantity of volatile overburden from the piles. The existing ground slab was to be retained and built over.

The proposed level 1 (ground floor) slab was to be constructed using a series of ground beams over the piles and existing slab. The new slab construction, designed to be a suspended slab, required either engineered fill to be brought in over the top of the existing slab, for the proposed slab to bear as lost formwork, or void formers to be laid over the top of the existing slab to create the same suspended slab.



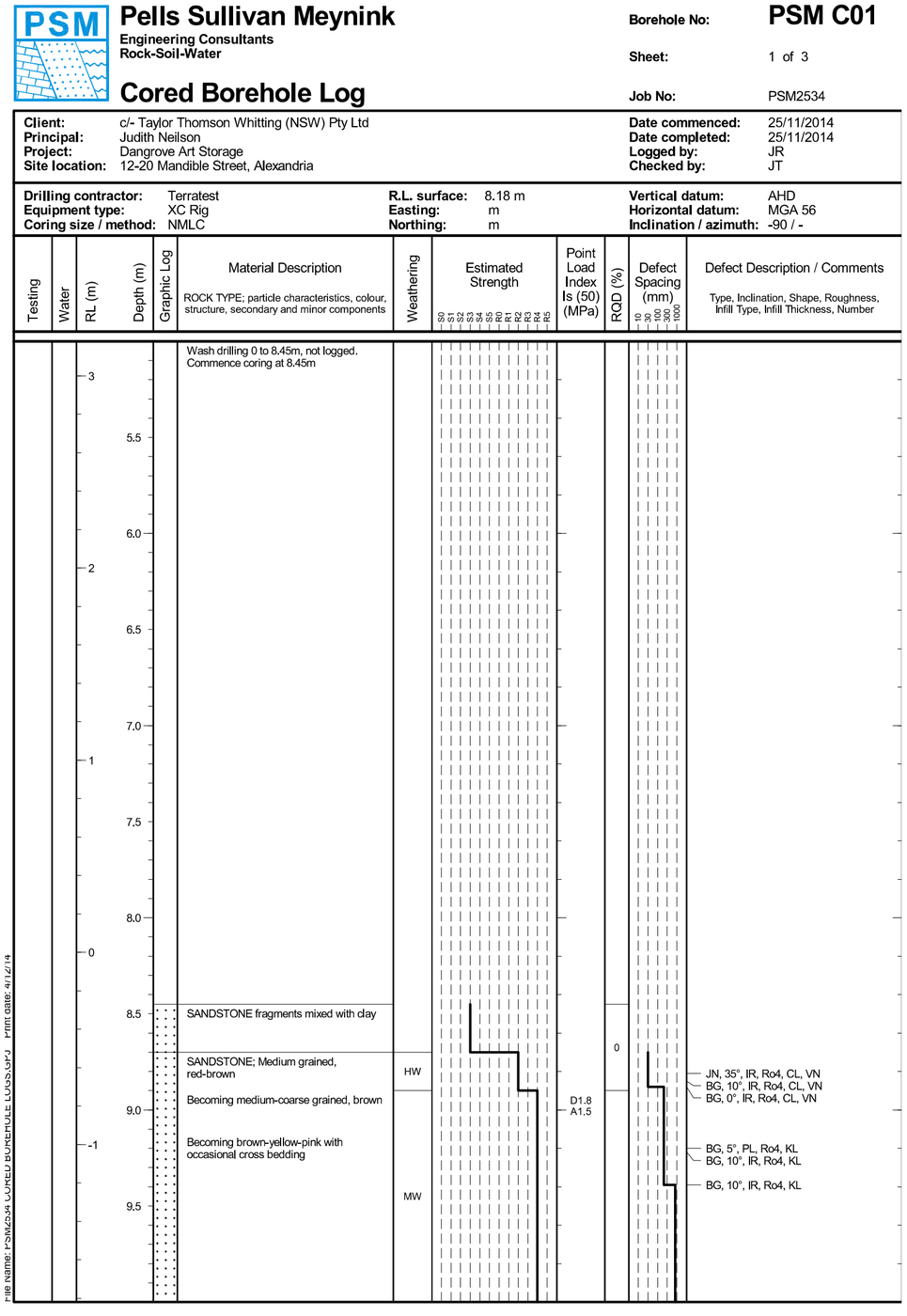


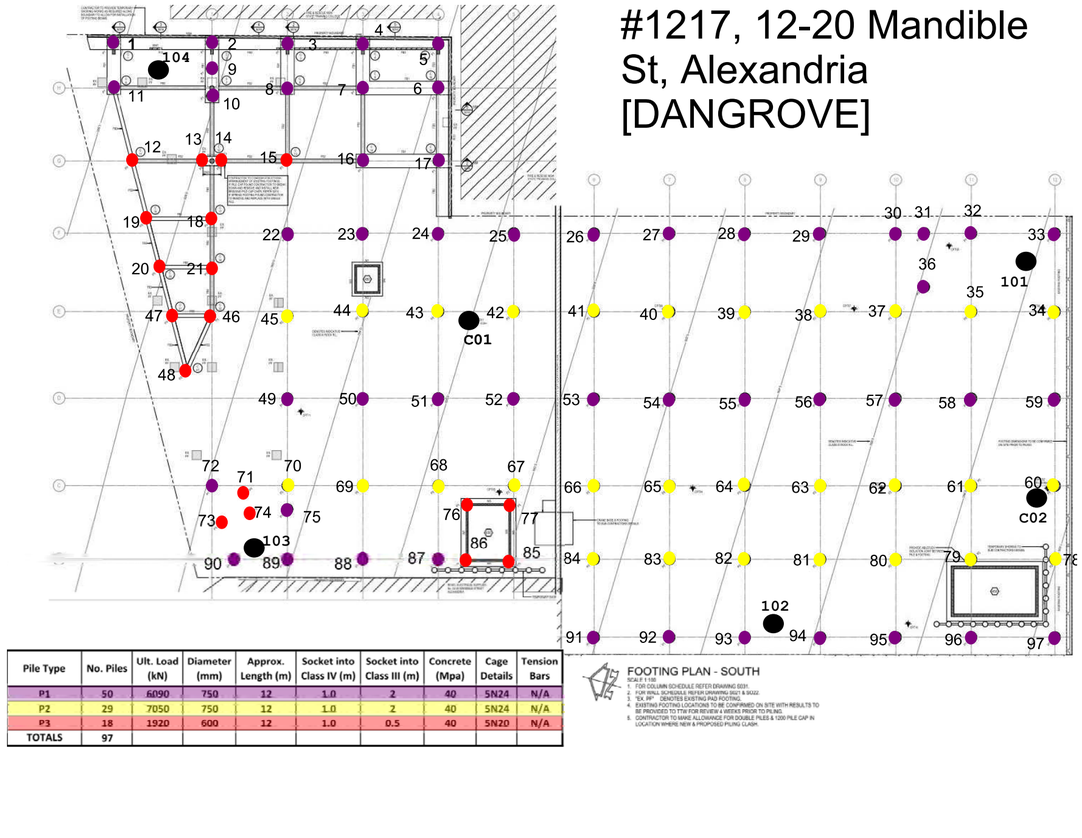




This page: The original design for the layout of the piles.

Opposite: These construction drawings show the refined pile layout that was used.





Pile Type	No. Piles	Ult. Load (kN)	Diameter (mm)	Approx. Length (m)	Socket into Class IV (m)	Socket into Class III (m)	Concrete (Mpa)	Cage Details	Tension Bars
P1	50	6090	750	12	1.0	2	40	SN24	N/A
P2	29	7050	750	12	1.0	2	40	SN24	N/A
P3	18	1920	600	12	1.0	0.5	40	SN20	N/A
TOTALS	97								

Opposite: The final geotechnical bore information.

This page: The layout of the final pile design, including the reinforcement.

This would effectively mean that all the excavated material and overburden from the piles would need to be removed from the site.

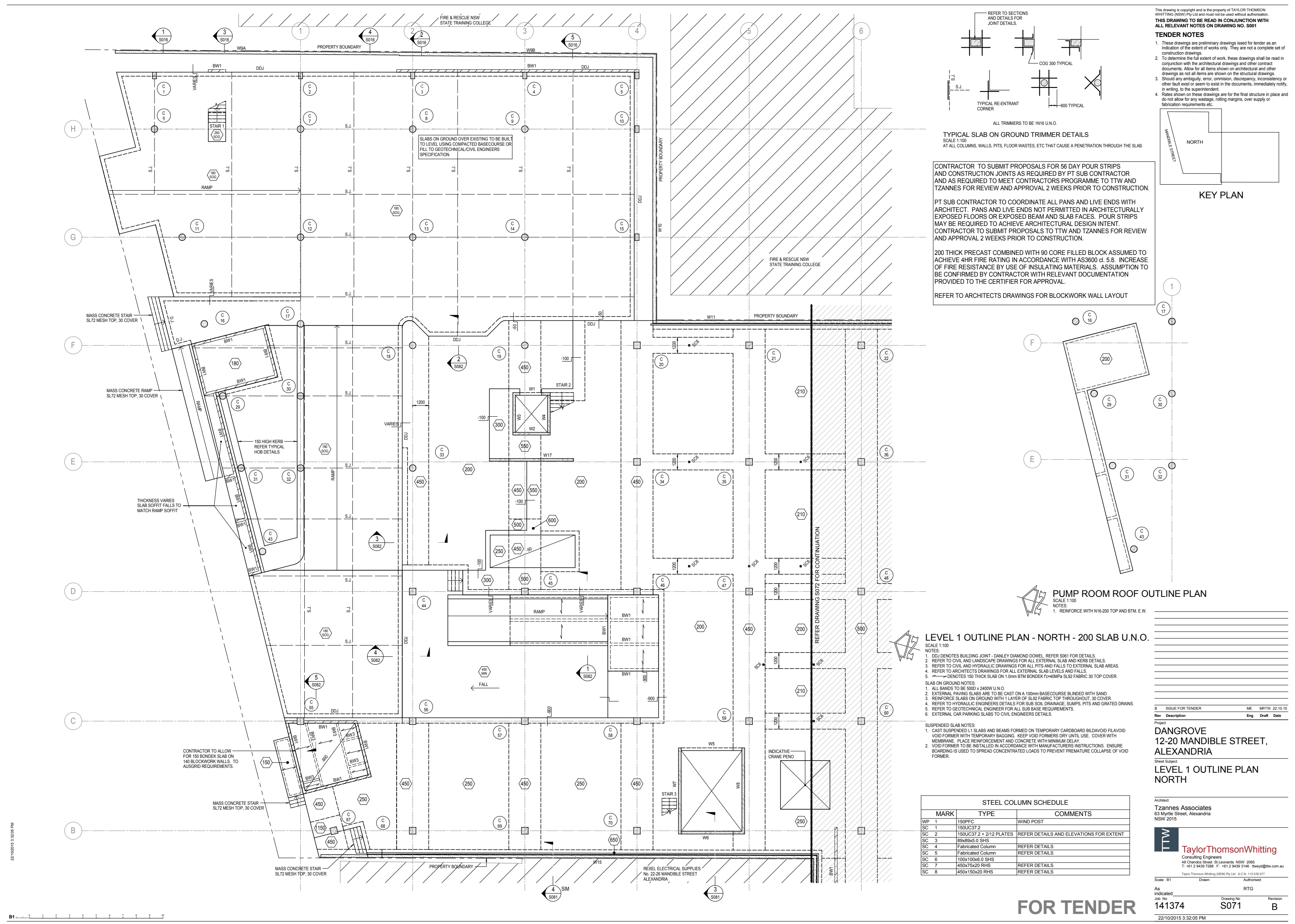
In consultation with Ultrafloor, we developed a suspended slab solution that did not require void formers or engineered fill. We utilised this permanent formwork system, essentially made from using precast beams closely placed together with a topping slab. The beams would bear on the footing beams, resulting in voids between the two slabs. These were all approved by TTW.

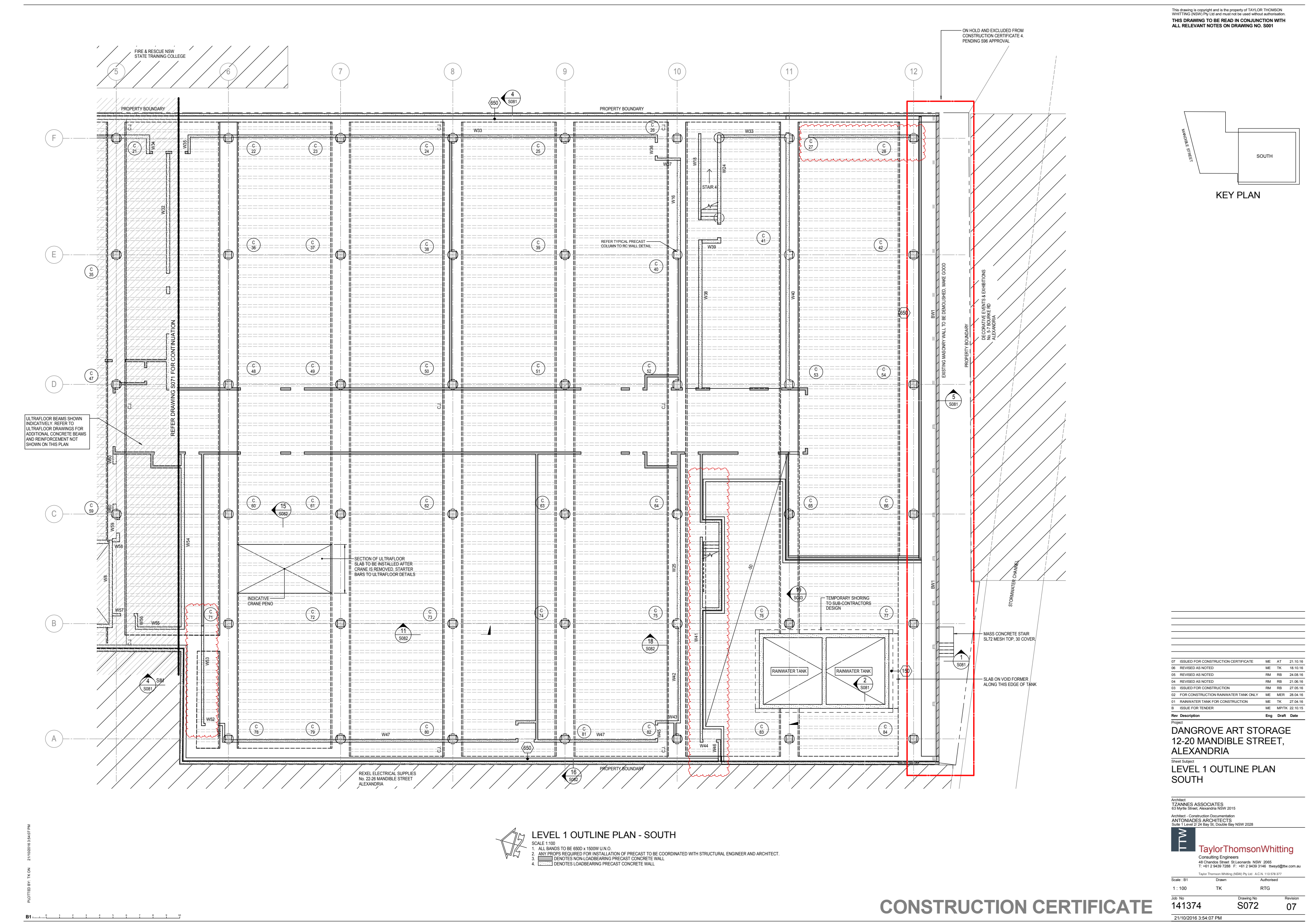
We treated the potential acid sulphate soils from the pile overburden with agricultural lime, which stabilised the material, and enabled us to place it in the void between the two slabs, eliminating the need to dispose of it offsite. As well as avoiding the need to bring void formers or engineered fill to the site, this initiative also removed the risk of water penetration through the ground slab and ultimately saved time, money and the risk of environmental issues associated with removing contamination.

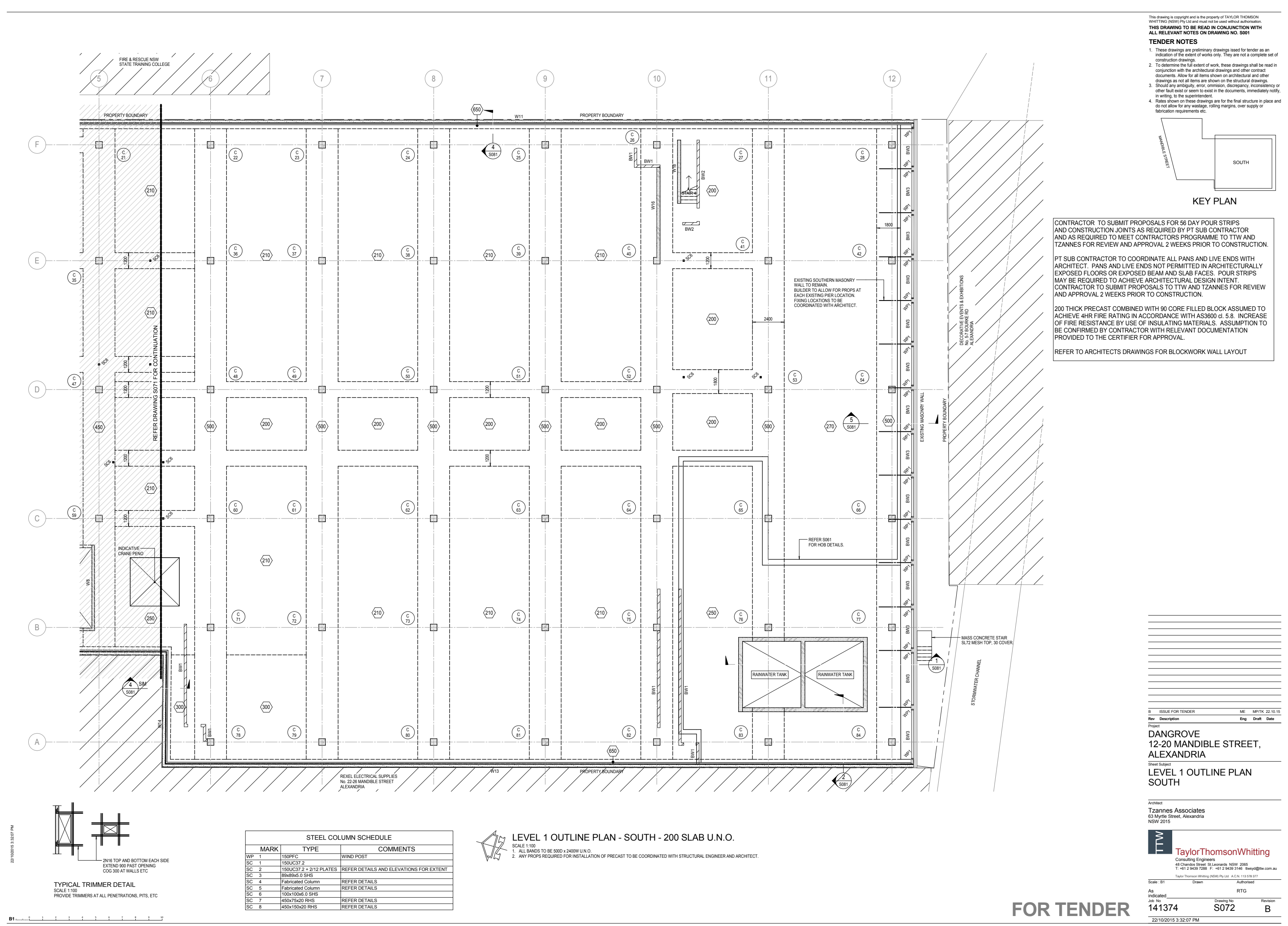
The structure

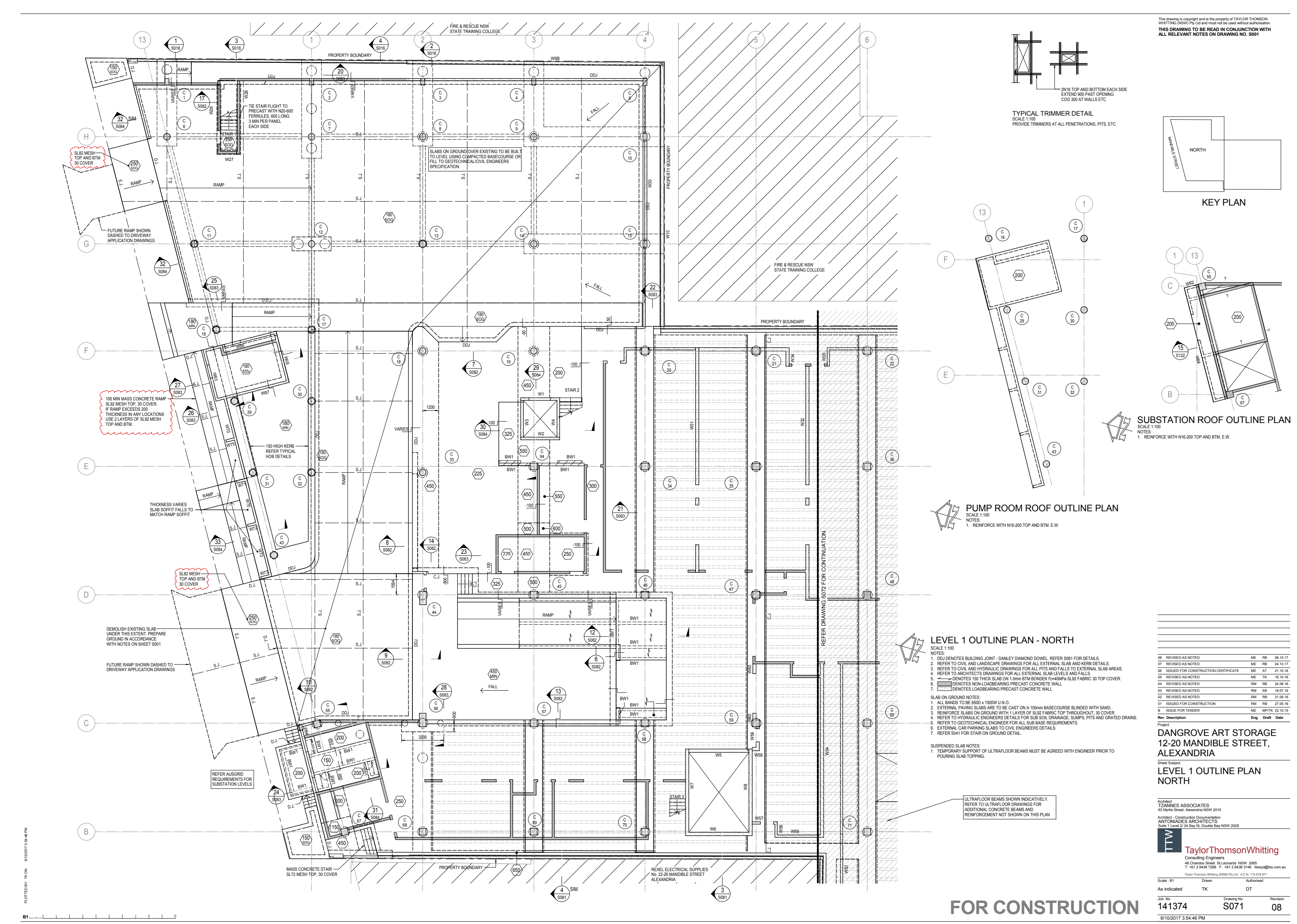
The site presented numerous challenges. Many required design solutions to maintain relative ease of construction. The design and construction issues faced were identified prior to commencement of construction, or very early in the construction program. To ensure all challenges were captured, the materials handling and access issues were resolved concurrently with the structural design changes.

Due to the depth of the site and its odd shape, materials handling and general access for construction had to be carefully considered. The crane solution was critical for the wholesale design changes we proposed for the structure. The original concrete frame and masonry infill design was augmented in favour of a precast panel solution for columns









This page: The original plan of the ground floor. Opposite: The Ultrafloor slab design that enabled the encapsulation of the excavated soils.

and walls, and more Ultrafloor for suspended slabs. This gave the project speed and significantly contributed to the overall performance of the spaces. Solid concrete walls replaced blockwork walls which increased the thermal mass of the building. The number of construction workers required to erect the structure on the site over the same period of time was at least halved.

The proposed structure was essentially a traditional concrete-framed building. The upper perimeter walls were to be a cavity construction, utilising non-load-bearing precast wall panels as the outside skin, with a cavity of 50 mm plus insulation, then architectural concrete blocks.

The sequencing for the construction of these walls would be difficult to achieve. The precast panels would need to be installed first. Keeping in mind that the blocks also needed to be tied off the precast wall panels to obtain stiffness in the wall, an adequate method of installing the insulation away from the precast wall could not be determined.

We were concerned that the materials handling of the individual blocks for the walls would be very difficult; the walls were at least 5 metres high and the blocks would need to be put on scaffold platforms at 1 metre increments. As the blocks would need to be handled multiple times after leaving a pallet, there was the risk of damage to their corners. The extent of scaffolding required to be transported into each room, and then erected and dismantled, would be a significant task. We raised these concerns with the architects and project managers.

Using the proposed blocks, we constructed a sample wall. This demonstrated that even with virtually no materials handling from pallet to the wall, chips in corners of the blocks were evident. Part of the brief for the walls was that they would need to have some impact resistance as the storerooms would be racked for artwork that would be moved around by forklift. Impact of a forklift on the block walls could cause severe damage to the wall but also to people and property.

Our alternative proposal needed to:

- Eliminate the risk of water ingress into the building if the external precast panels' joints failed.
- Reduce the amount of materials handling for the walls.
- Reduce the extent of materials handling associated with scaffolding.
- Achieve a thermally insulated wall.
- Achieve a wall that had a reasonable amount of impact resistance.

In order to finalise the building framework, the team needed to resolve the wall system. Infinity initially proposed a conventional precast panel with caulking for the upper perimeter, but this was rejected as it would have been impossible to inspect it for failure. Working collaboratively with the architect to develop the details, the proposal was for the use of precast wall panels in lieu of block walls on the upper perimeter, using a double-skinned precast panel with inbuilt drainage cell and thermal insulation all in the one wall panel on the upper levels. The prototype for this was built and tested. We believe this is the first time this design has been used in the local market.

On the lower levels, the architect introduced a drain against the exterior panels on the inside of the perimeter that would capture any water ingress from failure of the precast joints. This also meant that the inside face of the wall was exposed so if there was failure of the joints, it could easily be seen in the service corridors and attended to. The system also included a low-pressure void created by the drainage cell and other details that Infinity and the architect discussed and agreed upon. We utilised a combined thermal insulation board lined with fibre cement to be applied to the corridor face of the precast walls of the storerooms.

The walls of the Great Hall were proposed to be block walls with exposed aggregate. We provided a sample panel of the wall in precast concrete that was received well by Judith Neilson, the architect and the Project Manager.

While a sample precast panel for the face of the Great Hall was approved in principle, there were challenges that needed to be considered during the production of the precast panels along with the construction of the concrete floor panels which were required to resemble the precast panels. Moisture in the mix and also the rate of drying of the concrete had slight effects on the colour tone of the concrete. There was also additional coloured aggregate added to the mix that needed to be broadcast across the wet concrete after it was screeded. Varying pressure applied on the screeded finish as the surface was trowel-finished created varying levels of exposure of the aggregates after the slabs were ground and polished. We were concerned at one stage that we could not achieve a perfect







A progression of excavated material being treated in piles, positioned in mounds in the existing slab, and then being covered by the Ultrafloor..

Above: Sample prepared showing double skin precast external wall with insulation and drainage.

Below: Visible here is the low level drain system should water ingress through the precast joints occur.













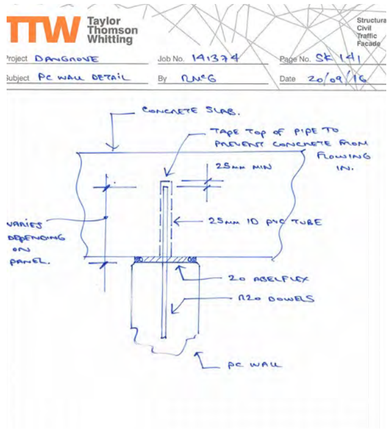
Top left: An upper floor beam with precast wall below. The white foam providing load isolation between the beam and the precast is visible. On the left, the Ultrafloor beam system can be seen.

Top right: Engineer's detail of the precast wall isolation. Expanded foam sheeting was used in place of the Abelflex noted to enable ease of installation of the dowels.

Centre: Detail showing foam isolation between the beam and precast walls below.

Below left: Precast panel – polished concrete sample.

Below right: Polished concrete sample for the floor slab panel.



Left and right: Precast marking plans showing art stores and external walls on both levels.

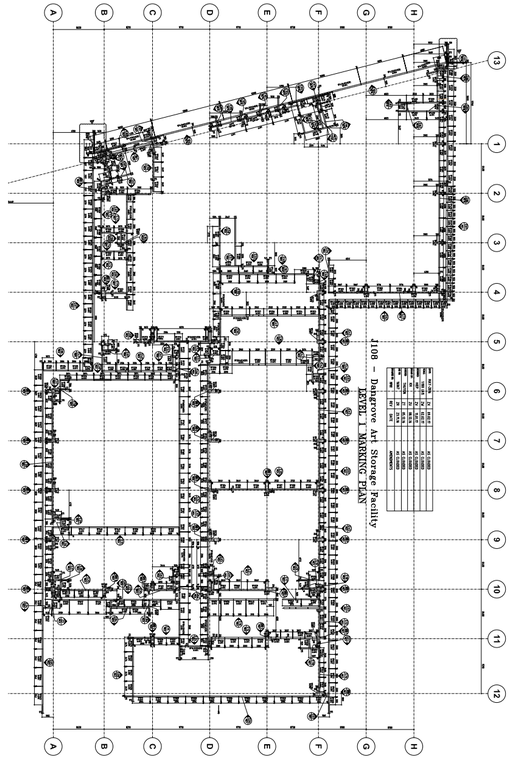
consistency of the exposed aggregates. After review with Tzannes of the various samples produced and consultation with Judith, the variations were preferred as the intent was not for the finish to be as consistent as a terrazzo.

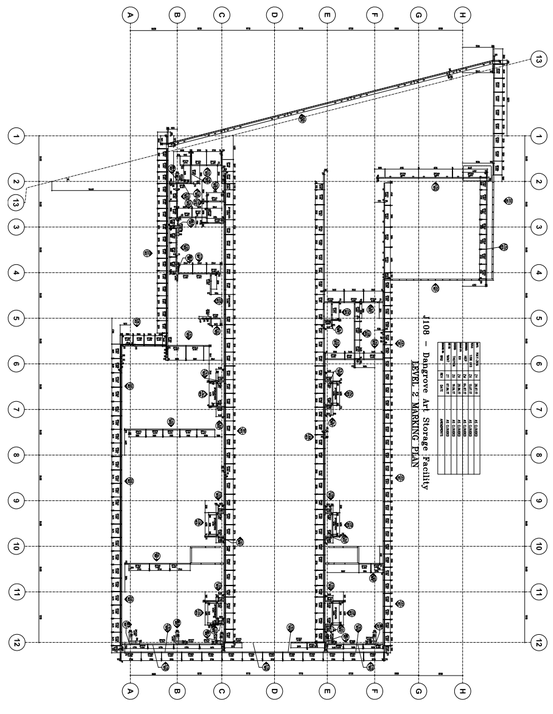
For consistency we proposed that the internal walls and dividing walls to rooms also be constructed in precast wall panels. This was discussed at length with the design group as we initially wanted these walls to be load-bearing elements to enable the columns around the rooms to be eliminated. The instruction was to provide a solution for long-term flexibility of the spaces, which meant that the internal precast walls had to be constructed with the structure to ensure they would not become load bearing. This would enable their removal if required in the future. The design intent of the proposed structural framework was not compromised.

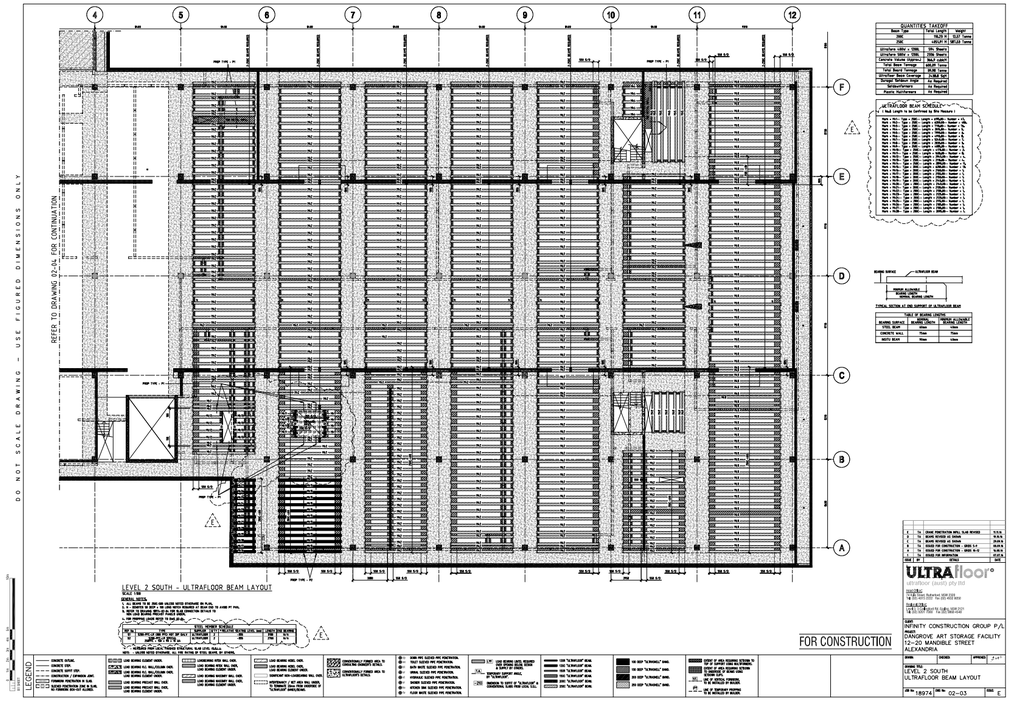
With an approved wall method determined, we could then complete the design of the concrete frame. We continued with our objective of utilising as many precast elements as possible.

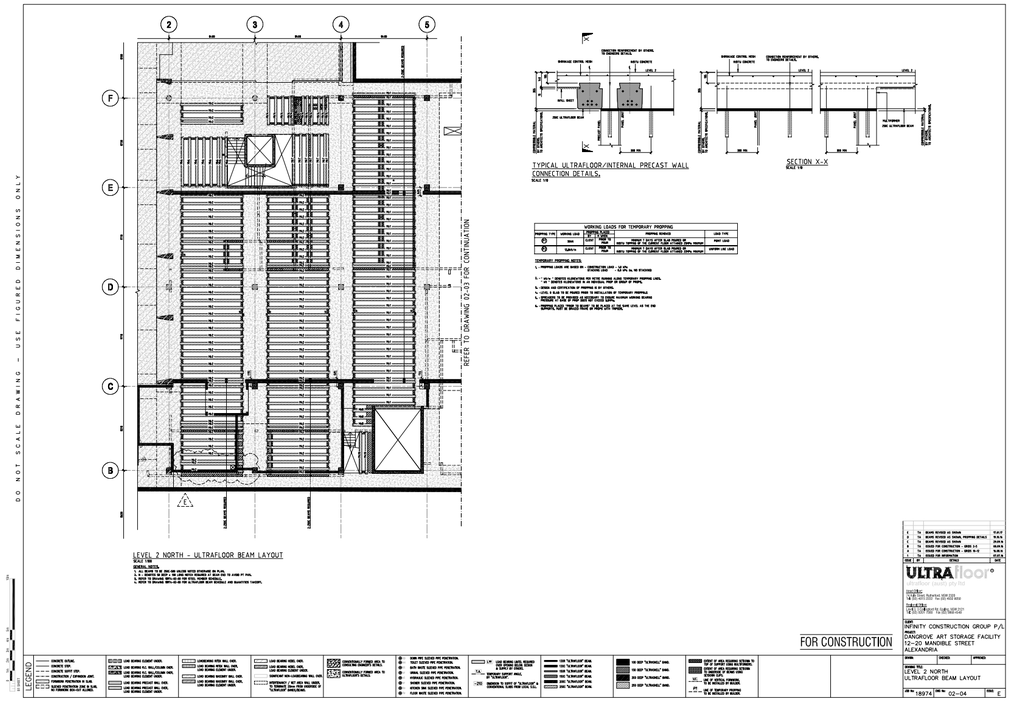
We introduced the use of precast columns within the storerooms wherever possible and also introduced an Ultrafloor system for the level 2 suspended slabs. The Ultrafloor system would:

- Significantly reduce the amount of materials handling required for full formwork decks.
- Reduce the amount of risk associated with workers forming up decks at 5.5 metre strutting heights.
- Decrease the amount of waste that would be generated on site.
- Decrease the amount of time to construct the slabs.









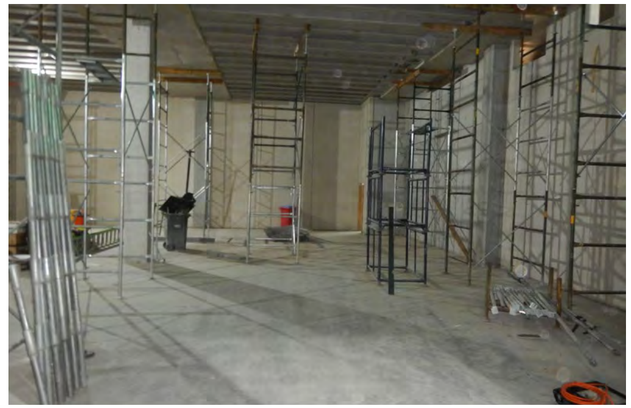
Above: Level 2 South Ultrafloor beam setout.

Below: Level 2 North Ultrafloor beam setout.

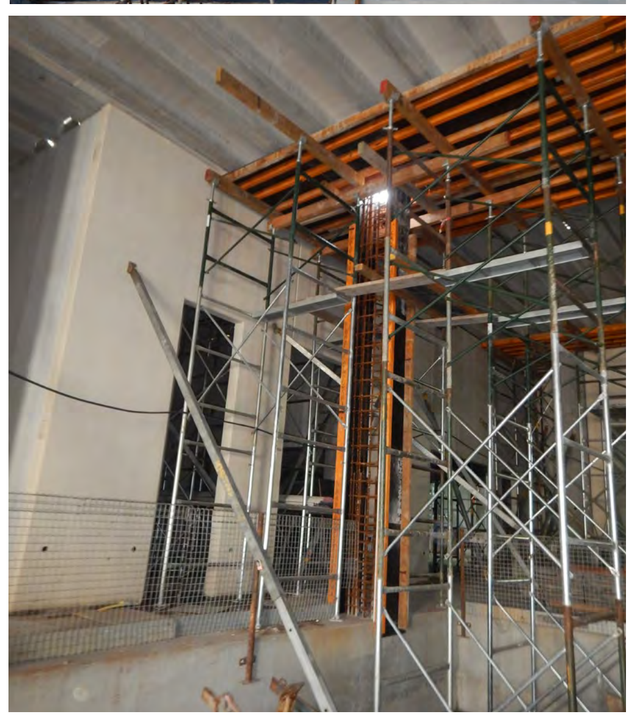
Top: Completed Ultrafloor structure with temporary propping.

Centre: Ultrafloor beams integrated into the form PT concrete beam.

Below: Ultrafloor beams temporarily supported from below.







The roof

We studied the original Aramax roof form and prototype in the context of performance and site installation. It was designed to be constructed in continuous length sheeting. The design intent of using a roofing system of this nature was to eliminate the means of ingress of water from the roof through joints in the material as they overlap along the length in the direction of water traversing down the roof. It had quite a deep profile, which provided the roofing system with much greater strength. This enabled it to span significant distances, ultimately reducing the amount of roof support steel such as purlins.

In order to use this system for the upper roof of this building, the roof sheet had to be rolled onsite. The area required for the onsite fabrication equipment was significant; there wasn't the space to undertake the process within the site itself unless one joint was introduced. An additional production bay would be required, which was only known once we met with the manufacturer. This information was not made available to the architect during their initial selection process. To continue down this path, the roofing would have to be constructed on the roadway, which would result in road closures over a period of time with no guarantee that council would permit the closure.

In addition, the proposed roofing system also required an integrated suspended framework to hold up thermal insulation required for the building. Prior to our involvement, a prototype was constructed, which we reviewed during a meeting with the consultants.

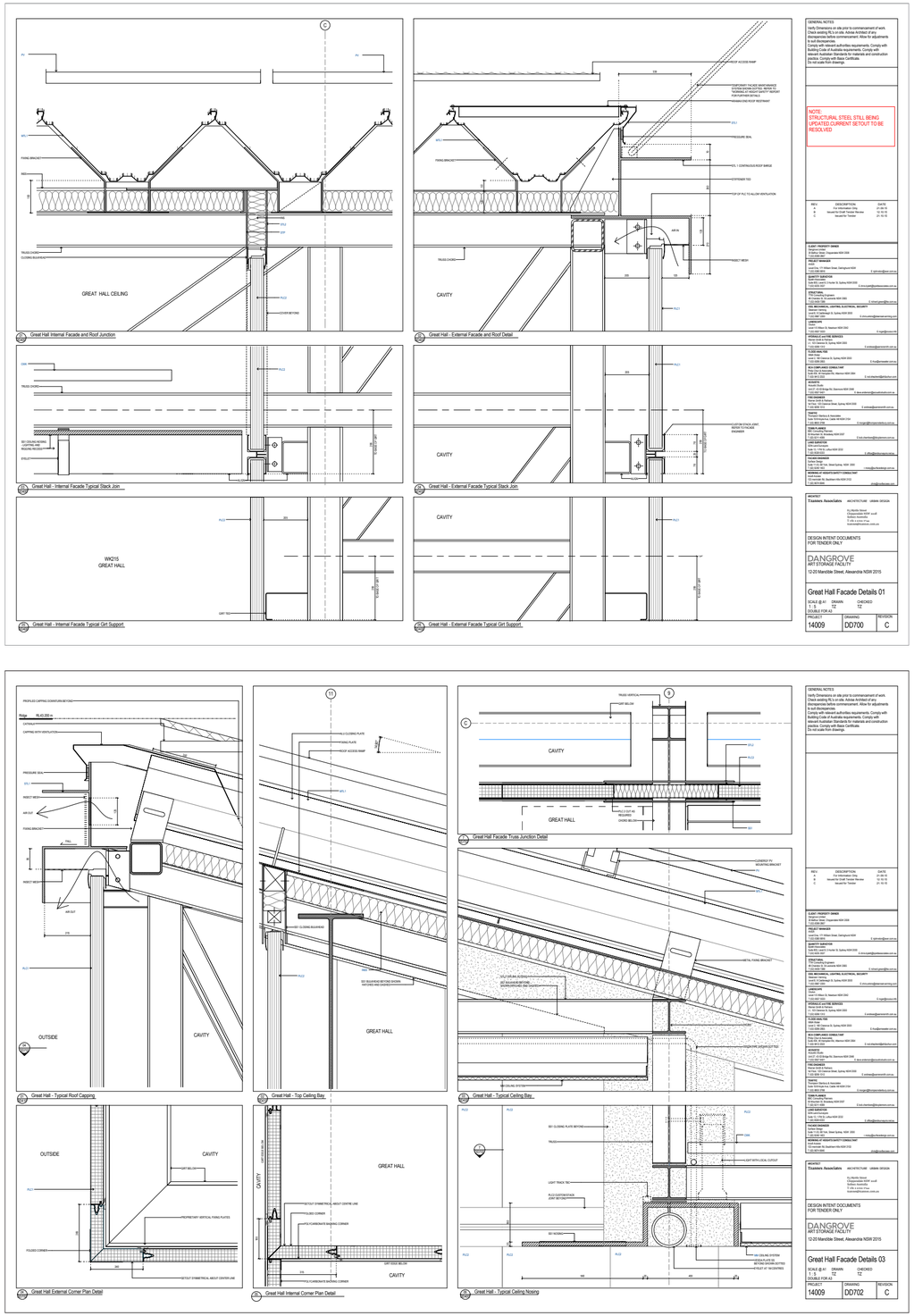
We noted several issues of concern:

- The roof sheeting required that it be bolted into the structure. Steel cleats taking the internal profile of the sheeting needed to be installed along the primary beams.
- The fixing of the bolts was through the side of the profile of the roofing materials. In order to create a seal between the bolt and the roof, neoprene washers were used, which had a life expectancy of less than 20 years.
- The life expectancy of the washers would be less than 20 years.
- Access from under the roof sheeting was required to replace the neoprene washers.
- An additional lightweight structural steel framework was required to be suspended underneath the roof to install thermal insulation in blanket form. The insulation would have a tendency to separate and sag over time.
- Access to service the roof from underneath, including replacing the bolts of the roof sheeting, could not be done without removing the thermal insulation.

With all the complications involved, we felt an alternative solution should be considered. After much investigation, we proposed to change the material to a proprietary product made by Kingspan for the following reasons:

- Although the Kingspan roof sheeting could not be produced in one length, it had a specified joint junction design to eliminate the ingress of water.
- The panels could be delivered to site in lengths of approximately 20 metres.
- Materials handling of the roofing was relatively simple, and panels were distributed over the roof by use of a proprietary suction clamp lifting mechanism.
- Each panel is 100 mm thick PIR insulation with metal sheeting on both faces. The thermal performance of the Kingspan panel was considerably greater than the proposed suspended insulation.
- The insulation does not require maintenance.
- The roof sheeting required a second level of support framework, which we would have powder coated black.
- The face of the roofing could be produced to provide a Zincalume finish.
- The underside of the roofing panel would be powder coated black.
- Access to replace neoprene washers was relatively simple and could be undertaken from above the roof sheeting.
- The installation time of the Kingspan system and support steel was significantly less than the proposed Aramax system and the proposed support network for the thermal insulation. It also required no access from below.
- The installation of access ways required on the roof would be far less complicated using a Kingspan roof than Aramax roofing.

The Aramax roof sheeting as proposed.









The prototype of the Aramax sample. From top: Identifying the sub-structure of the suspended insulation; identifying brackets and bolted connections shown beneath the roof sheeting; bolted connections shown above the roof sheeting.

Above: The required Kingspan overlap detail for roof sheeting.

Below: Proprietary lifting mechanism used to pick up Kingspan roof panels.

The polycarbonate facade

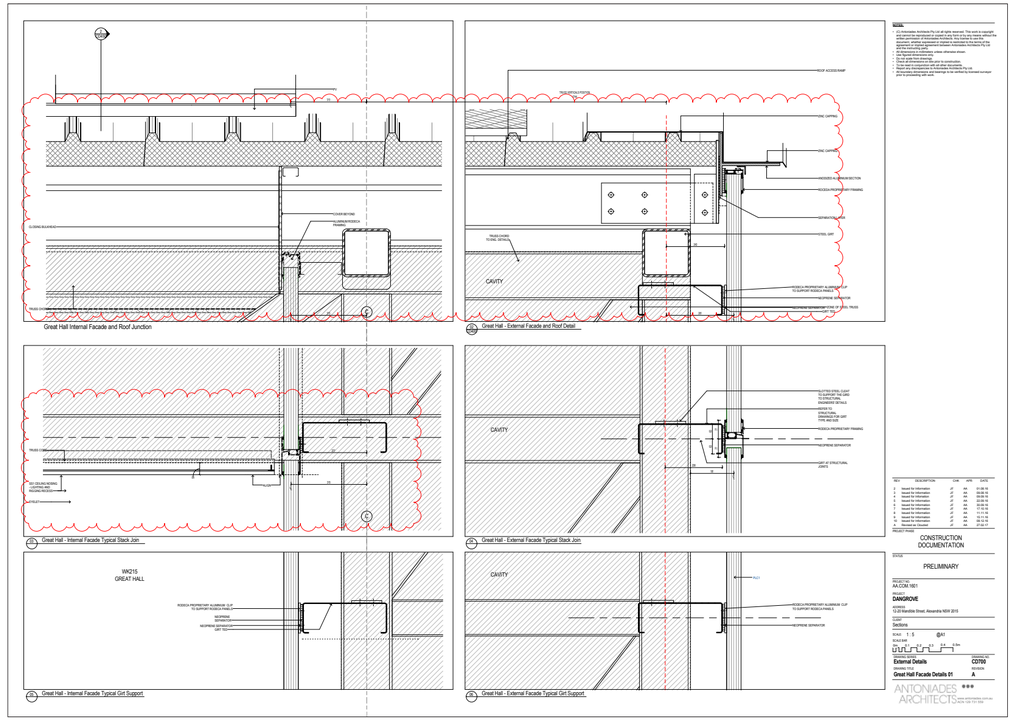
The proposed facade material was a multi-walled 60 mm thick polycarbonate panel by Arcowall manufactured in Italy.

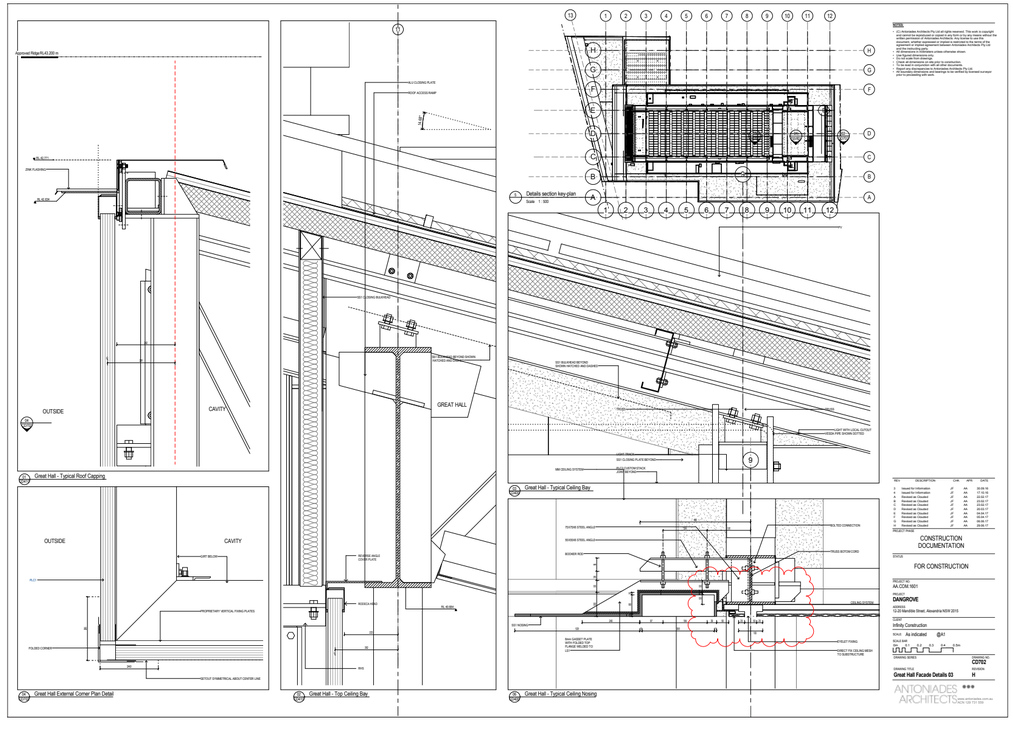
The design intent was to incorporate a translucent wall facade cladding onto the projecting prominent structure of the building envelope of the Great Hall to enable diffused natural light to enhance the environment of the internal space. The facade was also required to meet the thermal performance of the space, which was assisted by creating a cavity of 2.5 metre width around the upper perimeter of the Great Hall. The polycarbonate was to be used on the outside face of this void, which was the external skin of the building envelope and on the inside face of the void which was the architectural finish of the upper voluminous space of the Great Hall. The dual walls either side of the cavity not only increased the thermal performance of the space, it also provided a secondary layer of protection to the Great Hall. If any of the external perimeter walls require replacement, they can be replaced without affecting the internal conditioned space of the facility or disrupting the use of the facility.

This walling surrounded three reasonably large elevations. The southern elevation is approximately 24 metres wide and 21 metres high, and the triangular east and west elevations are 80 metres long and 21 metres high. Due to the extent of panelling, careful consideration in the construction detailing was required to accommodate buildability, site installation challenges and, importantly, weatherproofing and expansion and contraction of the product.

This type of facade walling system had not been widely used in Australia. As such, we struggled to obtain local expertise associated with the installation of the proposed product. Through research, a similar product manufactured by Rodeca in Germany was found. Tzannes had originally reviewed it, but at the time, their warranty and colour sample were rejected. The introduction of an alternative manufacturer enabled us to obtain better technical advice and construction detailing from both suppliers as they were both very keen to have their product showcased on such a prominent building.







The reduction in the profile of the Kingspan roof over the Aramax.

We prepared comparisons between both products and constructed large prototypes of each system. This enabled us to determine that there was a slight difference in colour between both manufacturers and enabled us to undertake a detailed investigation of the components and the way they were required to be assembled. As neither system had much history of any local installation, we needed to educate our local facade/roofing contractor teams on the installation procedures to develop time frames and cost of the installation.

A detailed performance comparison between the two manufacturers' products was prepared for the design team to consider. The performance of both was very similar as was the cost to purchase.

There were four variances in the performance comparison that stood out to us as being very important as we held the design obligations and liability under the head contract:

- The external skin of the external panel was proposed to be clear. There was a concern that, over time, it would develop a yellowish tinge due to the exposure of sun's ultraviolet light. Both manufacturers provided a 100 per cent replacement of their product for 15 years. Rodeca offered a further extended warranty of depreciating colour change for the following 5 years. The extended warranties were also offered because the application was not subject to typical industrial conditions, and the two skins provided increased levels of protection. Also, the maintenance of the facility improved conditions.
- Weather protection of the facility was crucial. Both manufacturers provided a 15-year replacement warranty on the external skin. Rodeca offered a further extended warranty of depreciating damage replacement for the following 5 years, which was negotiated by Tzannes.
- The replacement procedure of a damaged panel required careful consideration. Both products would require a working-at-height procedure, and both were a tongue and groove vertical edge installation (required to achieve watertightness of the vertical panels). We found that we could locally replace the Rodeca panels by removing the adjacent panel. The Arcowall, however, required all panels to be removed back to the edge of the building adjacent to the damaged panel, which would result in additional costs and time.
- The waterproofing detail and interlock between the panels of the Rodeca system was preferred.

While both performance specifications met the requirements under the contract, our preference was to use the Rodeca system for the reasons noted above. However, ultimately the decision was Judith's, based on recommendation from the architect and taking into account the builder's views and report. Her decision primarily came down to the difference in colour and diffused light between the products; she preferred the Rodeca. Each supplier provided a 1.2 by 2.4 metre sample with sills and joiners, which allowed for a better understanding of the systems.

Roofing membrane

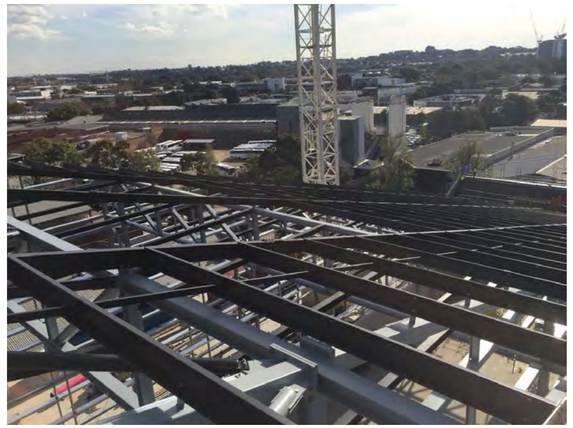
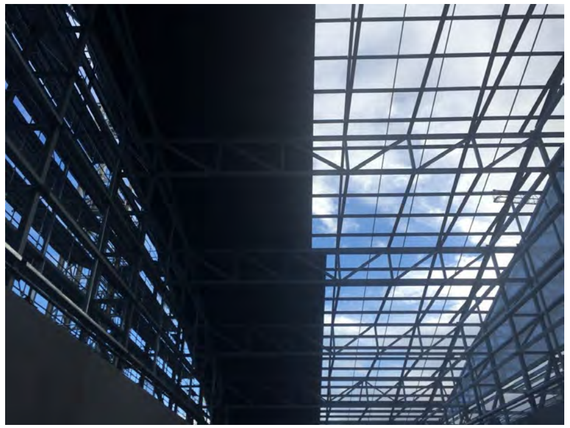
Protection of the artwork from external weather elements was paramount in the construction detailing and selection of membrane systems.

The concrete roof structure located directly above the upper level art stores is of post tensioned slabs which were constructed using low shrinkage concrete.

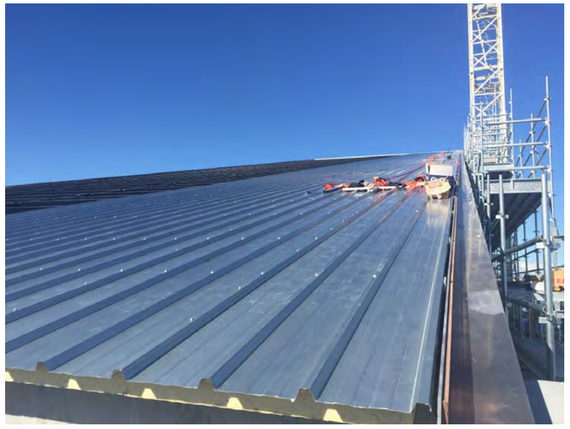
These slabs were constructed to fall towards the south over a length of approximately 90 metres. They were large pours, with construction joints required between pours that would be potential ingress paths of roof water into the art stores below. As part of the architectural aesthetic, the soffit of the slabs was exposed. As such, thermal insulation of the slabs needed to be thermally protected from above on the roof level.

The greatest challenge in the selection of the most appropriate membrane system was to find a system that, as well as providing a 20-year warranty, would also accommodate the expected movement of the slabs due to their length, incorporate an insulation layer, and be easy to repair if it was damaged during construction or after the building was occupied.

The proposed system was made up of two layers of membrane separated by an insulation board, with a high-density protection board over the top of the insulation material. While the manufacturer's technical data noted that the system could be glued down, we held reservation that, due to the extent of the membrane and the length of runs, fixings would be required through the layers. Over time, there was a risk that, with the expansion and contraction of the slabs, the insulation board and protection board would separate.





The progression of the roofing installation.

As originally specified the roofing membrane (MEM2) was one of two options, being either:

Membrane Type 2: MEM2
Product Description: WPM 615 – TPO Roofing sheet membrane
Application: Trafficable roofing slab membrane over Polyiso Insulation and HD Cover Board
Thickness: 1.5 mm
Supplier: Ardex
Colour: Grey
Note: Membrane(s) and insulation to act as a complete system

Or as an alternative:

Membrane Type 2A: MEM2
Product Description: Cosmofin FG
Application: Trafficable roofing slab membrane over Polyiso Insulation and HD Cover Board
Thickness: 1.5 mm
Supplier: Projex-Cosmofin
Colour: Grey
Note: Membrane(s) and insulation to act as a complete system

Through much research and discussion between Infinity, the Project Manager and the architect, we adopted a system that had the insulation board and high density board positively fixed into the slabs, with the primary membrane being a Wolfin membrane installed over the high density board.

In addition, the architect required that a layer of protective Cosmofin walkway membrane, produced by the same manufacturer, be installed over the top of the Wolfin membrane to protect it from damage, but also from ultraviolet light. Along the location of the construction joints, a band of Wolfin membrane was installed to the manufacturer's details, which involved a continuous welded layer of the membrane fixed to a compatible reglet cut into the surface of the concrete. This band also had tolerance to withstand any expected expansion and movement of the construction joint.

The net result would be that the insulation and protection board was positively held down with mechanical fixings, and the primary membrane was located above the other panels, in a location where rectification could be undertaken to repair any damage to the membrane if it occurred during construction or after handover.

Architectural steel glazing framework

Several areas of the facade contained large architectural steel elements on the exterior. We were concerned about the overall longevity of these members, as well as how they could be serviced and maintained without having to remove existing building fabric. The first member that we requested to be changed was the perimeter architectural steel fascia surrounding the upper metal roof structure known as EB1.

Once installed, this member would be mostly concealed with roof flashing. Although the protective coating specified to be applied on this member was of a high-quality industrial coating, the serviceable life cycle of 100 years would be difficult to achieve unless at some point it was removed and recoated.

Almost 200 lineal metres of this member was going to be installed. It would not only be concluded with roof flashings, but would also be used to connect the head members of the external polycarbonate walling system.

It immediately became obvious to us that the material for EB1 should be replaced with structural grade aluminium, which is far less resistant to corrosion than steel. In collaboration with Tzannes we developed a slightly amended profile to construct the member, using continuous welding at vulnerable joints.

We were also concerned about two other areas of architectural steel on the facade – the main entry and courtyard architectural steel glazing elements. Our primary concern was the steel material specified would have components embedded into the slabs that would come into contact with water. This would result in the steel plates being inaccessible for maintenance and recoating when required.

Engineering calculations were undertaken to determine the sizes of the plates required if they were substituted with structural grade aluminium. We determined that the substitution

of steel for structural grade aluminium would maintain the design intent while increasing the life expectancy and reducing the maintenance.

Internal architectural metalwork

A significant amount of architectural steel was to be incorporated into the interiors of the space, which was intended to provide architectural relief to an industrial form of construction.

The architectural design intent for the interior metalwork was quite clear in the original drawings. The design development of the items focused on availability of materials and co-ordination of structure and services, along with buildability and construction detailing required for the materials handling and installation of what would be very heavy elements.

The most significant design development related to the ceiling of the Great Hall, which consisted of a series of flat metal mesh ceilings stepping up to an overall height of almost 28 metres above the finished floor.

The ceiling was to be panelised into a grid of removable mesh panels which could provide serviceable access to structure and services within the ceiling cavity.

The graphic on page 282 shows how the ceiling panels effectively became a removable ceiling tile in a grid ceiling. Each tile, made of expanded metal framed by angles, can be individually removed to access services, and maintenance of the structure above. Light fittings are located above the ceiling panels. Penetrations of varying sizes were required to allow the light distribution to pass through the ceiling panel onto the Great Hall wall panels, creating a uniform wash of light over their surface. The varying dimensions of these penetrations were a factor of the varying heights of the ceiling panels above the Great Hall floor.

The tiered ceiling provided a challenge at the change of level interface. The designers wished to express the edge with a significant horizontal plane feature. Their concept design was carefully considered, and a solution was developed comprising a feature laser cut stainless steel section which provided a beautiful aesthetic as well as the structural performance needed to support the ceiling tiers and maintain a continuous level for the 19 metre span. This member was affectionately known as the LS1.

In the images on page 283, the LS1 can be seen at the leading edge of each ceiling alignment.

LS1 was under each of the roof trusses, cantilevering out 900 mm to provide an almost floating appearance. The trusses were approximately 8.4 metres apart. Profiles were to be cut out of the plate to assist in reducing the weight but also to provide transparency through its 900 mm width, lessening the amount of visible material and the bulky appearance of the member. The fixing of LS1 was to be discreet, with all connections concealed above the member. It would also contain a recess to house lighting.

While the design intent of LS1 was quite clear, facilitating the production was quite a challenge. There were eight runs of LS1, with six panels in each run. A total of 48 members had to be produced. The production of each panel had to be precise with very little tolerance for dimensional discrepancy.

Each LS1 unit was very heavy and had to be connected as a cantilevered unit suspended from the truss. LS1 was required to be constructed of plate steel welded to form the profile to house the lighting. We engineered profile cut cleats that provided stability to the cross-section of the member and were also used to suspend the LS1 from the truss.

The fabrication of LS1 required connection details that could be adjustable. As the load of LS1 was transferred onto the truss, we expected that there would be some deflection. Each length along the truss had to be installed consecutively. After the truss was loaded, each LS1 panel was then adjusted in height to cater for the deflection of the truss in order to achieve a flat level surface.

The material originally specified was stainless steel plate. Through the design development, it was determined that the weight would be too difficult to handle and the LS1 was fabricated from aluminium plate wrapped in mirror-finished stainless steel.

Design development commenced in November 2016 and continued up until mid-2017 with several prototypes developed before the final prototype was approved.

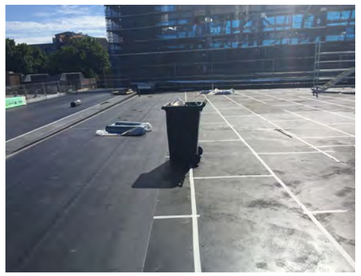
Hydraulic services

The hydraulic design prepared by others was mostly design developed and constructed. Due to the change in roof levels, the northern roof facing Mandible Street required its own drainage system. The original design had all the water from the northern part of the roof deposited into the council gutter through the kerb. A planning issue arose which would require the introduction to the scope of an underground piped council stormwater

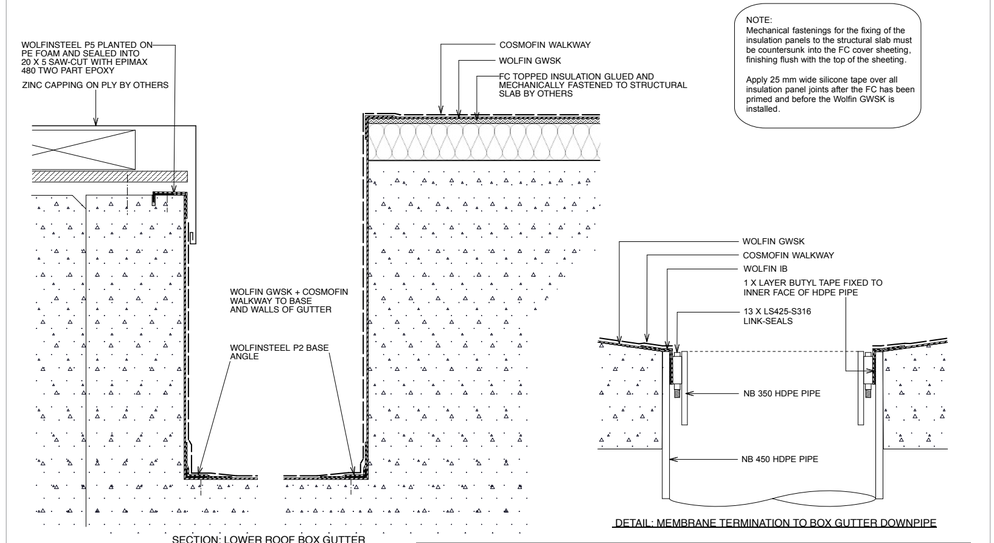


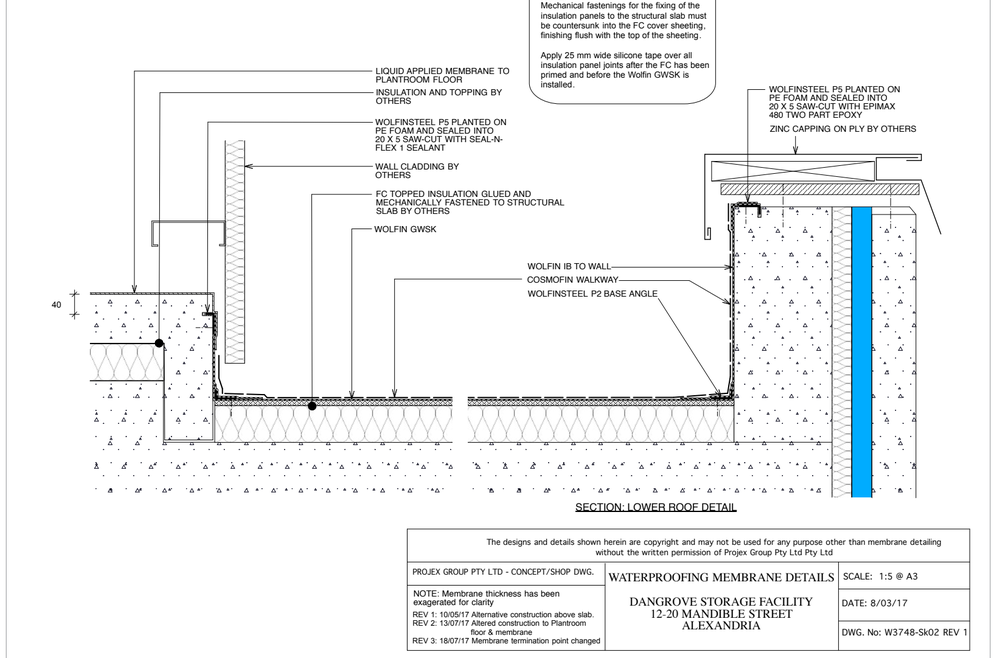




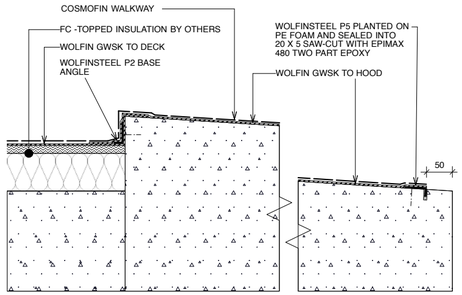


From top: Insulation board laid on roof concrete; high density board laid over visible insulation and positively attached with pins; Wolfin being laid over insulation board; Wolfin membrane laid over high density board and insulation.

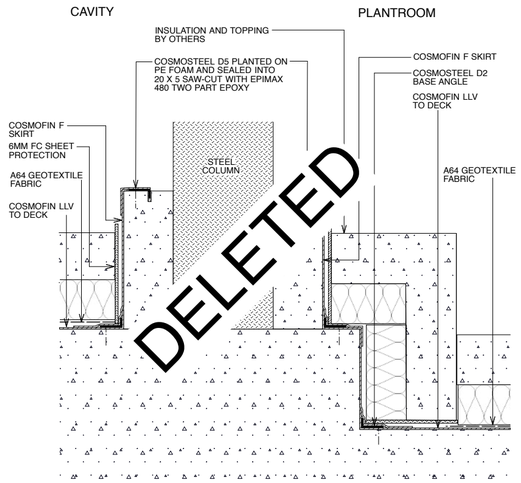




This page and overleaf, the design for approval and installation documents used for the roof membrane.



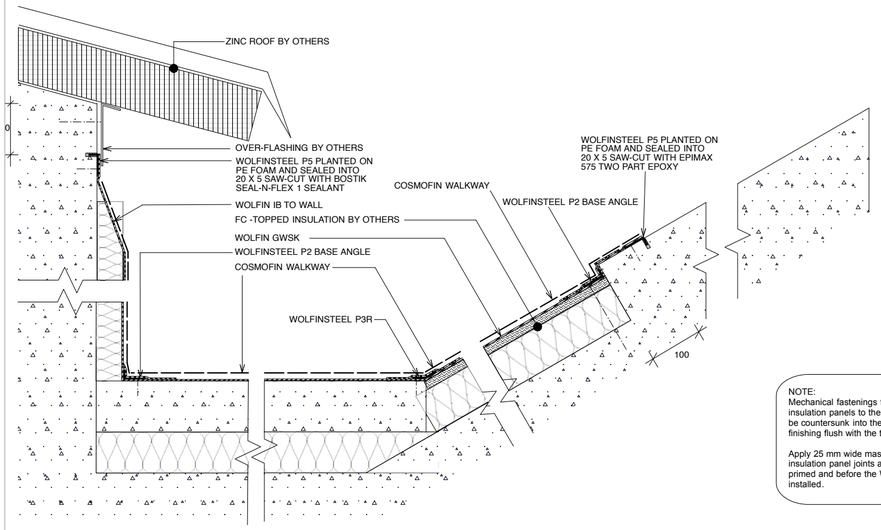
SECTION: LOWER ROOF, HOOD FACING MANDIBLE ST



DETAIL: LOWER ROOF, STEEL COLUMN & STEP GRIDS 2 - 3 SIMILAR

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PROJEX GROUP PTY LTD - CONCEPT/SHOP DWG.	WATERPROOFING MEMBRANE DETAILS	SCALE: 1:5 @ A3
NOTE: Membrane thickness has been exagerated for clarity REV 1: 10/05/17 Alternative construction above slab.	DANGROVE STORAGE FACILITY 12-20 MANDIBLE STREET ALEXANDRIA	DATE: 8/03/17
		DWG. No: W3748-Sk03 REV 1



SECTION: UPPER ROOF NORTH SKYLIGHT

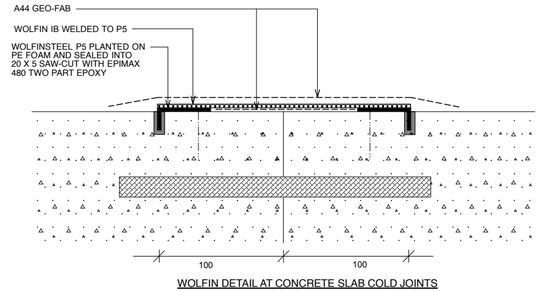
NOTE:
Mechanical fastenings for the fixing of the insulation panels to the structural slab must be countersunk into the FC cover sheeting, finishing flush with the top of the sheeting.

Apply 25 mm wide masking tape over all insulation panel joints after the FC has been primed and before the Wolfin GWSK is installed.

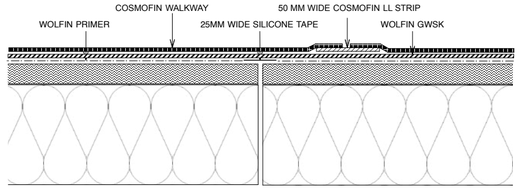
NOTE: Membrane thickness has been exagerated for clarity

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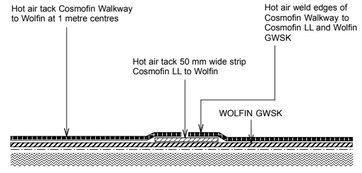
PROJEX GROUP PTY LTD - CONCEPT/SHOP DWG.	WATERPROOFING MEMBRANE DETAILS	SCALE: 1:5 @ A3
REV 1: 10/05/17 Alternative construction above slab. REV 2: 2/08/17 Top terminations altered	DANGROVE STORAGE FACILITY 12-20 MANDIBLE STREET ALEXANDRIA	DRAWN BY: MH
		DATE: 8/03/17
		DWG. No: W3748-Sk04 REV 2



WOLFIN DETAIL AT CONCRETE SLAB COLD JOINTS



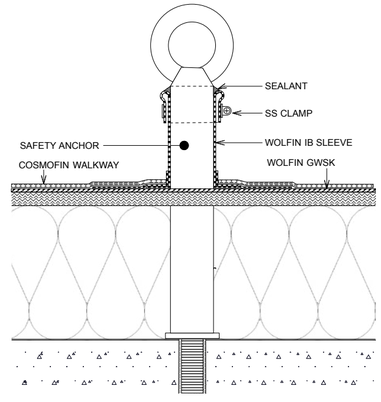
WOLFIN DETAIL AT COMPRESSED FC JOINTS



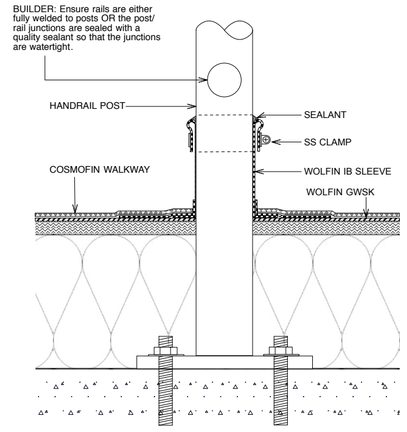
COSMOFIN WALKWAY PROTECTION LAYER

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PROJEX GROUP PTY LTD - CONCEPT/SHOP DWG.	WATERPROOFING MEMBRANE DETAILS	SCALE: 1:2 @ A3
NOTE: Membrane thickness has been exagerated for clarity REV 1: 10/05/17 Alternative construction above slab.	DANGROVE STORAGE FACILITY 12-20 MANDIBLE STREET ALEXANDRIA	DATE: 8/03/17
		DWG. No: W3748-Sk05 REV 1



DETAIL: TYPICAL SAFETY ANCHOR



DETAIL: TYPICAL HANDRAIL POST

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PROJEX GROUP PTY LTD - CONCEPT/SHOP DWG.	WATERPROOFING MEMBRANE DETAILS	SCALE: 1:2 @ A3
NOTE: Membrane thickness has been exagerated for clarity	DANGROVE STORAGE FACILITY 12-20 MANDIBLE STREET ALEXANDRIA	DATE: 2/08/17
		DWG. No: W3748-Sk06

system to be installed along the front of the property across Mandible Street extending 200 metres down the street.

The cost and approval time of these works would have had a negative impact on the completion of Dangrove.

A siphonic drainage system was implemented – through careful engineering, it deposits water into the newly constructed onsite detention system (OSD).

Fire detection services

At Dangrove, as well as providing the best technical solutions for the storing of art, it was also vital that both the stored art and staff working in the premises were well protected.

Fire detection in the carpark and the loading dock was covered by the design of a wet sprinkler protection.

Fire detection throughout the remainder of the facility was covered by a general smoke detection system. While the art stores were designed to provide fire separation of four hours, the design intent was to exclude any wet services from the art stores.

A design compliant with the client brief and the fire engineering report was developed which would satisfy our obligations under the head contract, which was for smoke detectors that are used industry wide.

We identified an ongoing maintenance issue, due to the height of the structure, and another potential problem with the ever-changing layouts that could be expected over time within the art stores. Regular inspection and certification was required for each of the smoke detectors; access to some of them would be very difficult given their locations. We discussed the option of replacing those with a VESDA system.

The VESDA system is effectively a conduit system, in appropriate locations, connected to a vacuum pump. The pump creates a negative pressure in the conduit that delivers the air within the space to a panel. This panel then detects the smallest of smoke particles within the space through the use of a laser spectrum. The pump and panel for this system are located in accessible locations; the conduits, at high level, are not required to be accessed.

The introduction of the VESDA system, although a more expensive capital cost than the nominated smoke detectors, was embraced by Dangrove. It provided a much higher sensitivity of smoke detection, paramount to the protection of the artwork, while also significantly reducing ongoing maintenance costs due to accessibility of the proposed system. As well, it allowed for greater flexibility of stacking and racking within the art stores.

Photovoltaic panels

The sloping roof of the Great Hall was used for the photovoltaic system; as many photovoltaic cells as could be efficiently located were installed on it. It was ideal, being a largely unobstructed, north-facing surface.

While the majority of the roof space was dedicated to photovoltaic cells, the design had to incorporate a safe access system to service and maintain them, along with a safe access system to service and maintain the vertical face of the polycarbonate walls located below the perimeter of the roof. In addition, we also needed to ensure that the installation of the photovoltaic system did not compromise the integrity or warranty of the metal roofing system over the Great Hall.

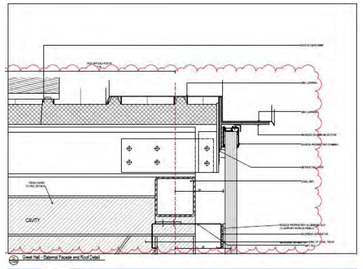
Each panel was 345 W – the final installation count of 558 resulted in a 192 kW system.

A safe access way extended from the lower part of the sloping roof along its east and west sides. From this, there was access to walkways located between the double row of solar panels to enable them to be cleaned, and replaced if need be.

The system by which the panels were fixed to the roofing required additional consideration. The proprietary framing system would not allow enough space under the solar panels to clean the roof sheeting, as required to maintain the warranty of its coating. A Schletter rail system was used instead; with this, panels can be raised and still maintain the engineering integrity.

Mechanical services

The mechanical and air-conditioning system at Dangrove was the most critical of the services, given that it was paramount to the protection of the artwork. It was essential that the correct climatic conditions within the storerooms be created so that the artwork would be preserved indefinitely.

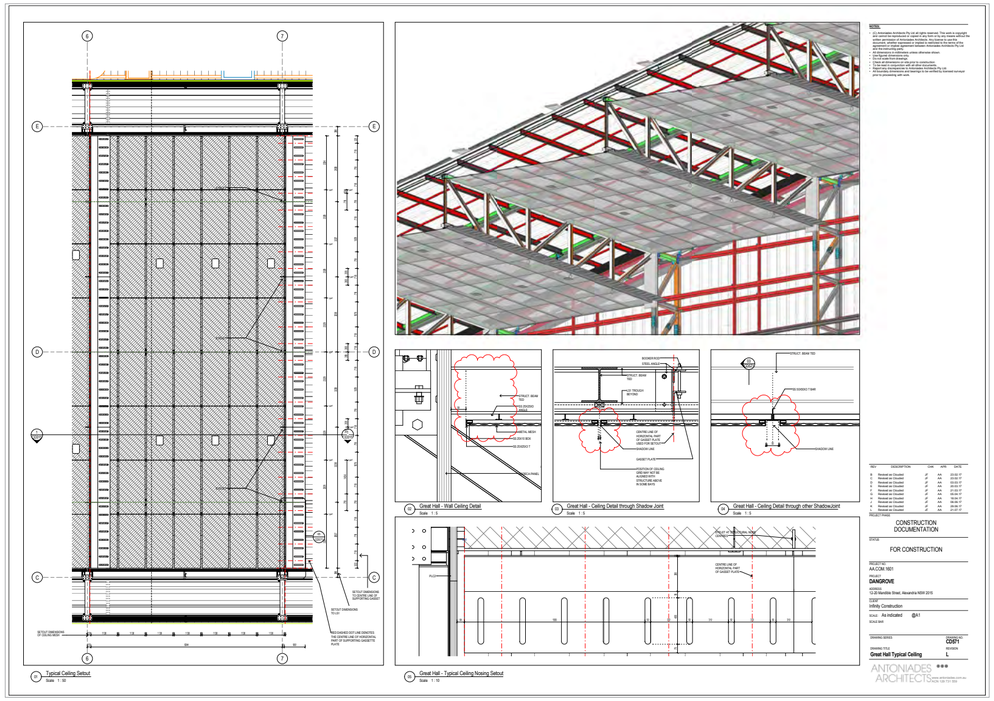


Great Hall - Sabmet Façade and Roof Detail

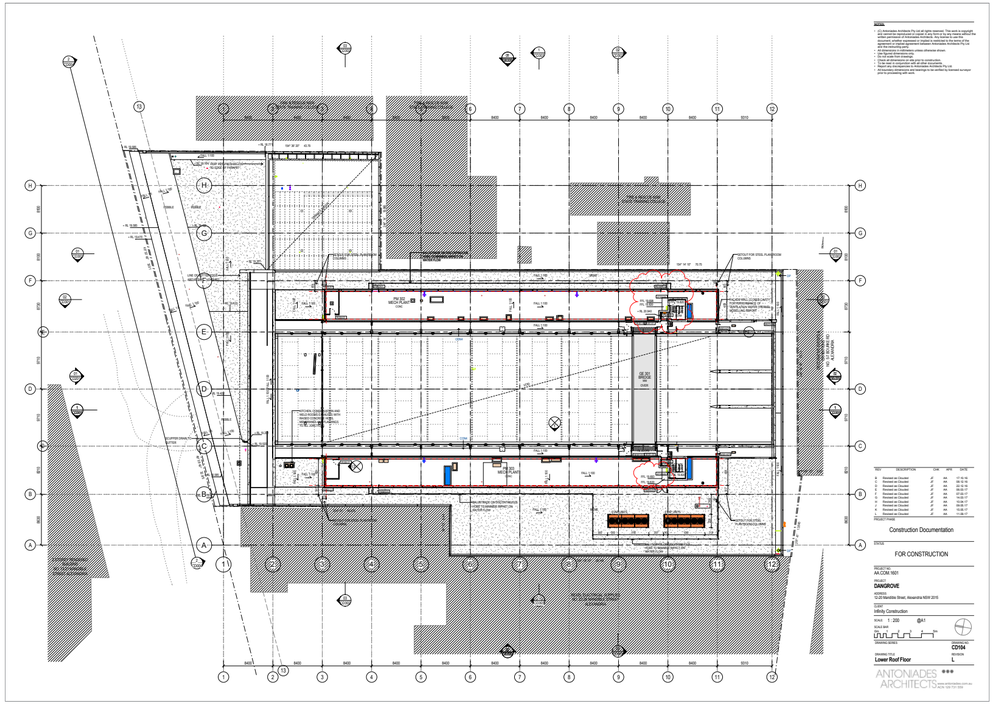




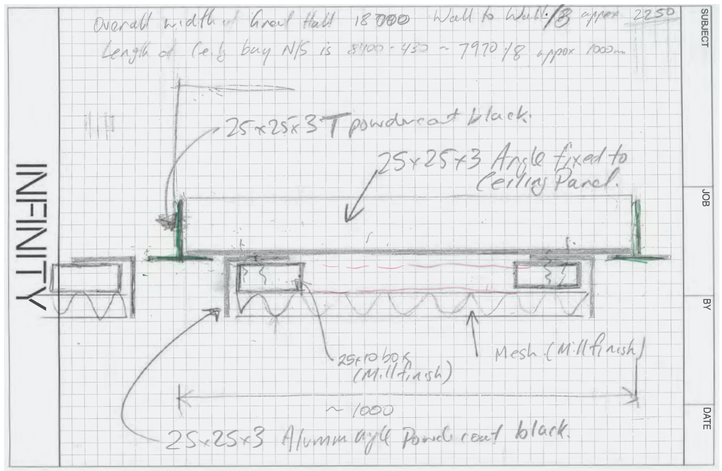
From top: Updated EB1 detail showing the flashings and connection detail to the roof structure and Rodeca panel below; EB1 as installed on the raked side of the roof prior to installation of roof sheetings and flashings; EB1 in manufacture.



Great Hall typical ceiling.



Lower roof level reflected ceiling plan.



An early hand sketch of the cross-section through what would be the Dangrove ceilings.

The functional description was collaboratively developed by Infinity, Steensen Varming (on behalf of Dangrove), Active Air (Bob Kerslake Mechanical on behalf of Active Air) and Northrop (on behalf of Infinity).

As a consequence of the delicate and complex nature of the proposed system, several mechanical design consultants in addition to the mechanical design engineers undertook a peer review of the design as it was developed.

Infinity's engagement through the head contract required that the mechanical system was undertaken as a design and construct solution. The timing required that this design aspect was undertaken by the subcontractor. To ensure that there was critical engineering oversight of the works, a multi-level group of engineers was used:

- Steensen Varming peer reviewed on behalf of Dangrove.
- Active Air was engaged as the D&C mechanical contractor. At Infinity's request, Active Air also engaged Bob Kerslake, mechanical engineer, to peer review their design as it was being developed, and also attend and review commissioning, and review results throughout the 12-month defects liability period.
- Northrop mechanical engineering was engaged by Infinity to provide peer review on behalf of Infinity in addition to the peer review being provided by Steensen Varming.

As the performance of the mechanical system was so critical to the preservation of the artwork, Infinity needed to be sure that that the design development and performance of the mechanical system was monitored by more than one peer review.

The design brief contained many concepts which pushed the bounds of even the most sophisticated design. During the development of construction methodologies with a focus on buildability, longevity and maintenance, Infinity and the designers found themselves in some robust debates over the best solution to adopt to satisfy the group's objectives, and to deliver the best result for the client. These related in particular to the volume of outside air being specified and the use of bypass ducts within the air handling units to achieve the specified humidification setpoints and rate of change. The careful balancing of these inclusions would have effects on environmental conditions and energy use.

The air conditioning system required for Dangrove art stores required close control to maintain the environmental conditions of:

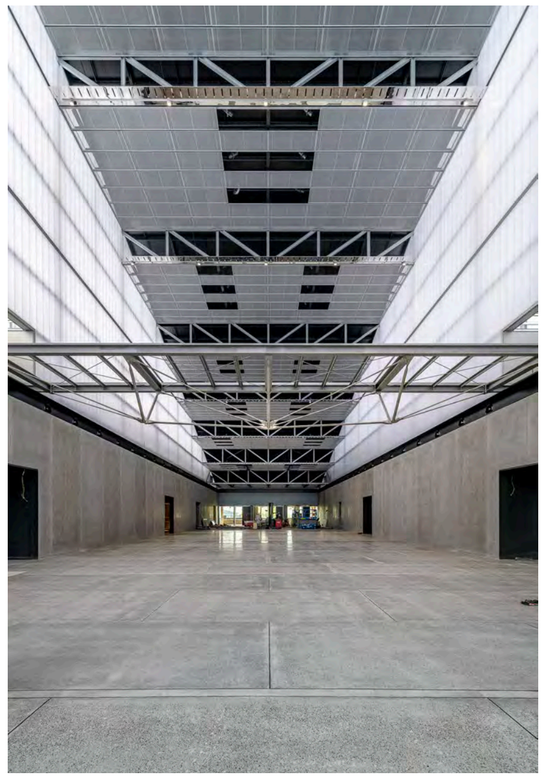
- Relative humidity at 50 per cent, plus or minus 5 per cent.
- Temperature of 20°C, plus or minus 2°C.
- Maximum rate of change of 2°C and 3 per cent relative humidity per hour.

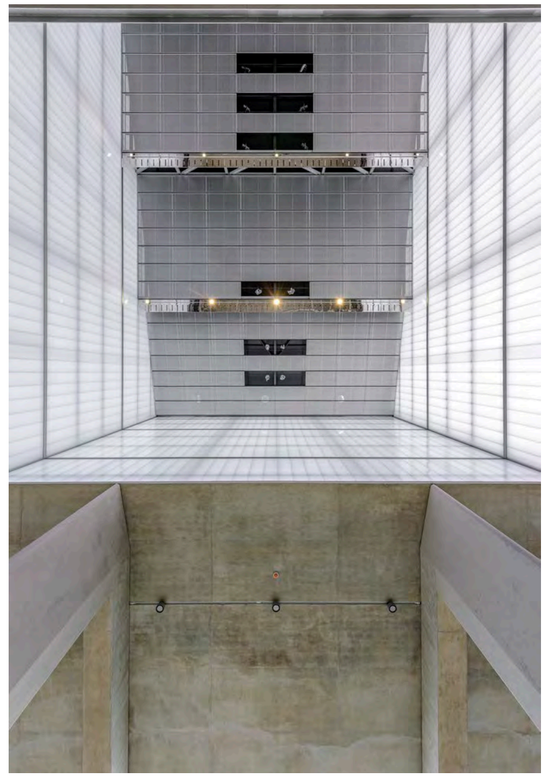
The specification briefing as provided by Steensen Varming required a design and construction approach to maintain the art stores' air environment within those parameters.

Steensen Varming had undertaken an extensive thermal modelling of the building, and provided us with an initial selection of air handling units, fans, coils, humidifiers and water

Left: Installation of the ceiling tiles prior to the installation of the final panels with lighting cut-outs.

Right: View looking up to the Great Hall Ceiling, 27 metres above finished floor level.





heaters. A decision was made to retain the number, type and location of air handling units as far as possible.

The use of cooling towers and Westinghouse chillers was noted in the briefing documents, along with STULZ atomising humidifiers.

A critical design issue was identified by Infinity early in the project; the fire egress stairs in the south-west corner of the building would need to extend into the main plant room that was housing the Westinghouse chillers.

The loss of this space was critical as the chillers could not be positioned anywhere else. The use of cooling towers was always considered problematic by the design team, in particular the Project Manager and architect, given the required maintenance and regulatory controls needed for them, and the stigma they have with legionnaire's disease.

Prior to the loss of space, Infinity had recommended a change from the use of cooling towers to evaporative chillers. Careful design analysis confirmed that the evaporative chillers provided equal or better heat rejection than the cooling towers. This led to a design change, with the evaporative chillers being positioned on the south-west corner of the roof.

Dehumidification of the air was achieved by the use of the chilled water and heating coils within the air handling units.

Humidification was achieved by the use of in-duct STULZ atomising humidifiers.

Because of the orientation of the site and the placement of the building on it, a unique aspect of the project is the extraordinary length of the fire-isolated corridors which only exit onto the front boundary. A fire engineering report, produced by RED Fire, dealt with the length of those corridors, which was up to 108 metres at the most extreme point.

The fire engineering report required a 'push-pull' smoke exhaust system of fans within the fire corridors that would maintain a steady flow of air, and potentially smoke, in a fire event. There was a chance that, due to the number of doors connecting to those corridors, smoke could potentially enter them if multiple doors were opened at the same time.

Unfortunately, the original design called for the western egress corridor exhaust to be positioned within a zone prohibited by Ausgrid at the substation. This was solved by routing the ground level duct up and through the building to a point on the roof, and adding a fan to provide balance to the 'push-pull' airflow.

During the works, while working on the birdcage scaffold to access the high ceilings, we noted that there was a considerable amount of heat build-up in the upper part of the Great Hall ceiling space. This was causing expansion of the polycarbonate panels, and there was a real concern that over a period of months, this heat could cause the expansion of the panels beyond their design tolerance. We solved this problem by installing a controlled exhaust via roof ventilators installed onto the roof of the Great Hall.

For commissioning, Dangrove appointed WT Consultancy as an additional consultant to oversee compliance.

The mechanical plant required careful balancing to ensure the limits were not exceeded; it took more than a year of monitoring and balancing to produce the working system.

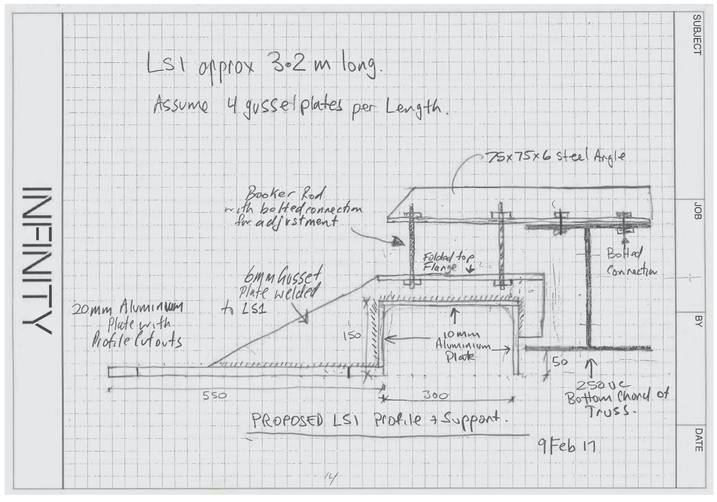
On commencing operation, it was found that while the temperature of any given storeroom was constant, the relative humidity would spike and exceed both the permitted range and rate of change. The very close control and narrow rate of change caused some units to 'hunt' (humidify then dehumidify in rapid cycles) and overcompensate corrections to the humidity of the rooms.

The mechanical consultants made many recommendations and each option offered was tried. These included:

- Reducing and ultimately closing the outside air.
- Opening the outside air further.
- Reducing any air bypass.
- Reducing the chilled water temperature from 6°C to 5.5°C or colder.
- Reducing the air handling units air speed, to increase the dehumidification.
- Repositioning the humidity sensors in the ducts relative to the STULZ humidifiers.
- Increasing the number and type of sensors in each storage space and balancing their readings within the management software.
- Monitoring the doors to the storerooms so that units did not continue to chase conditions when the doors open for many hours while art was moved.

It was finally determined that reducing, but not fully closing, the outside air, keeping the fans at a lower speed, and setting the chilled water to just under 6°C produced the most stable system.

The management software was reprogrammed and completely rewritten three times in the first 12 months of operation. Ralf Wilson, who was appointed the Dangrove facilities manager in 2018, provided the corrections necessary to the management software that ensured that it chilled the coils sufficiently without constant oscillation.



Hand sketch by Alan Yazbek of the proposed fabrication detail for the LS1 architectural beam to the Great Hall ceiling to cater for installation adjustments.

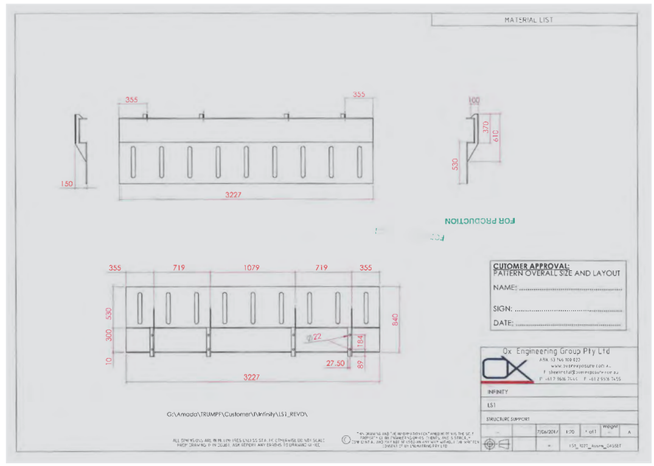


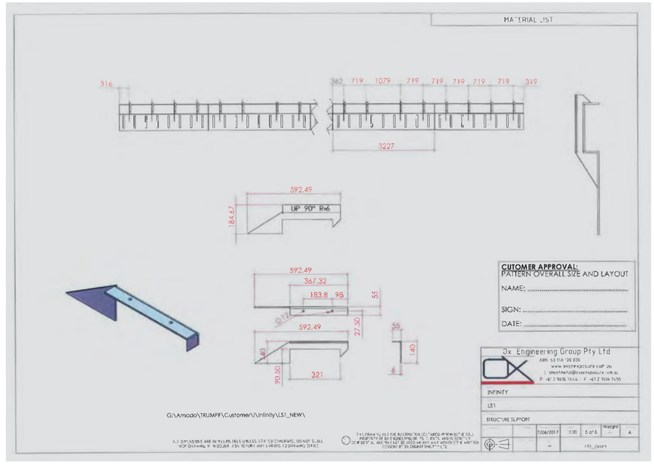


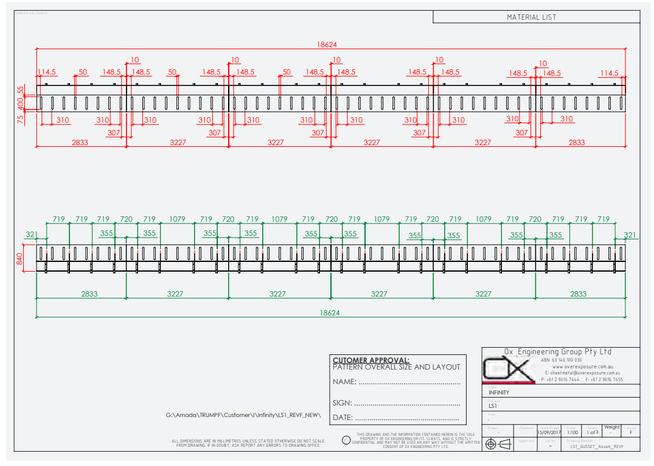




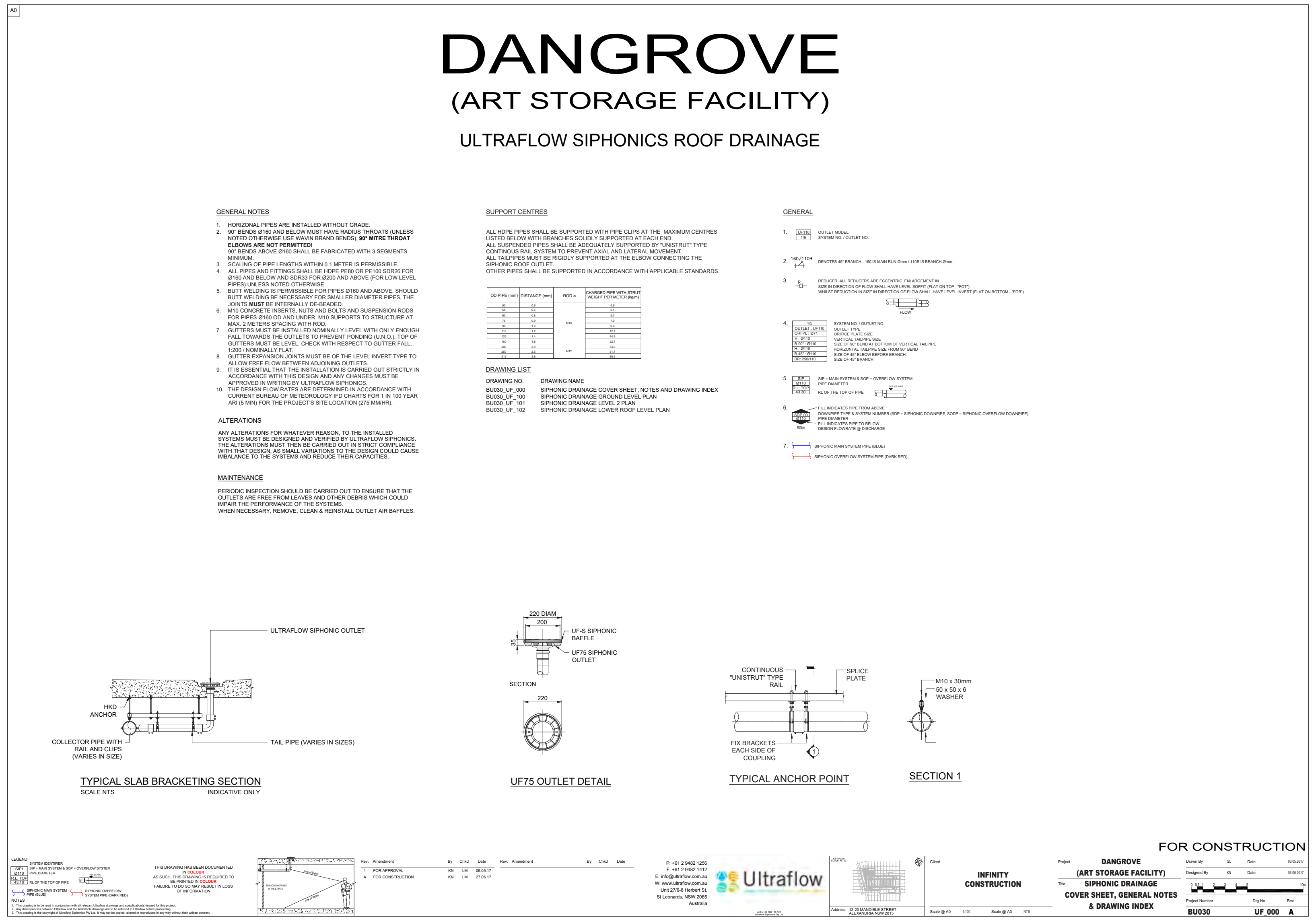
From top: LS1 prototype; LS1 as installed and bolted to the roof structure; from the southern end of the Great Hall looking up to the highest pitch of the ceiling, with ceiling panels visible with lighting and leading LS1s; LS1 panel prior to installation.

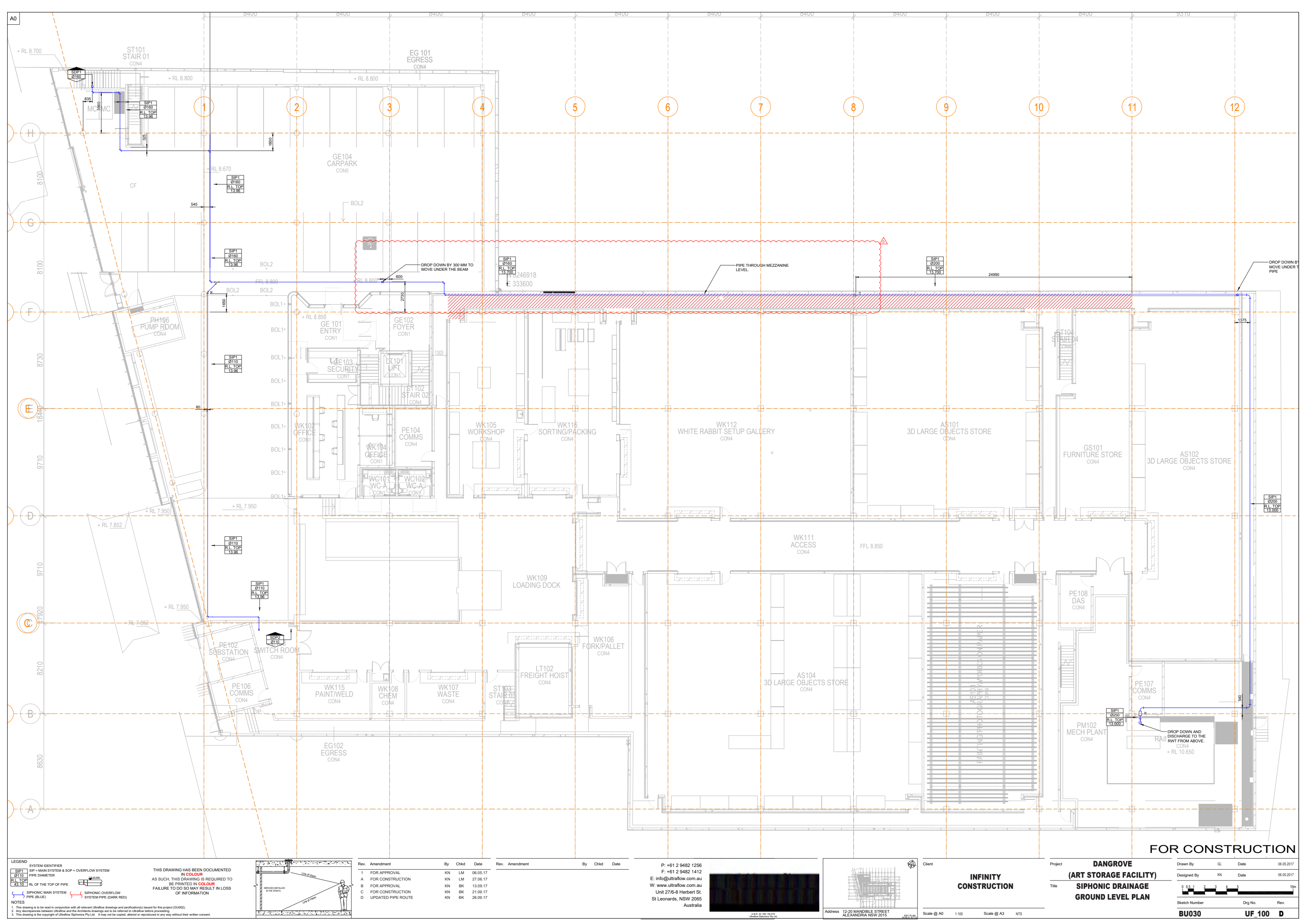




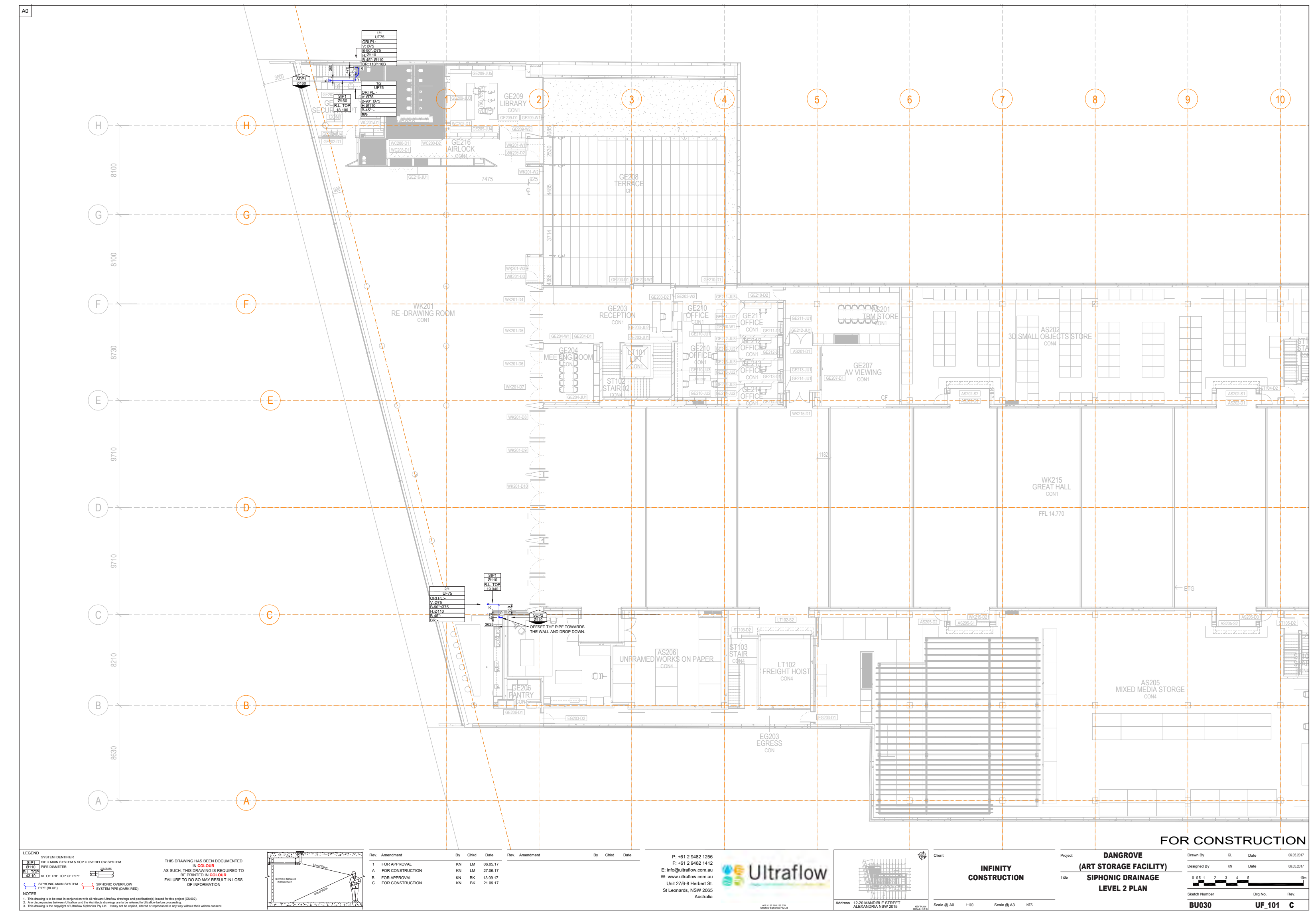


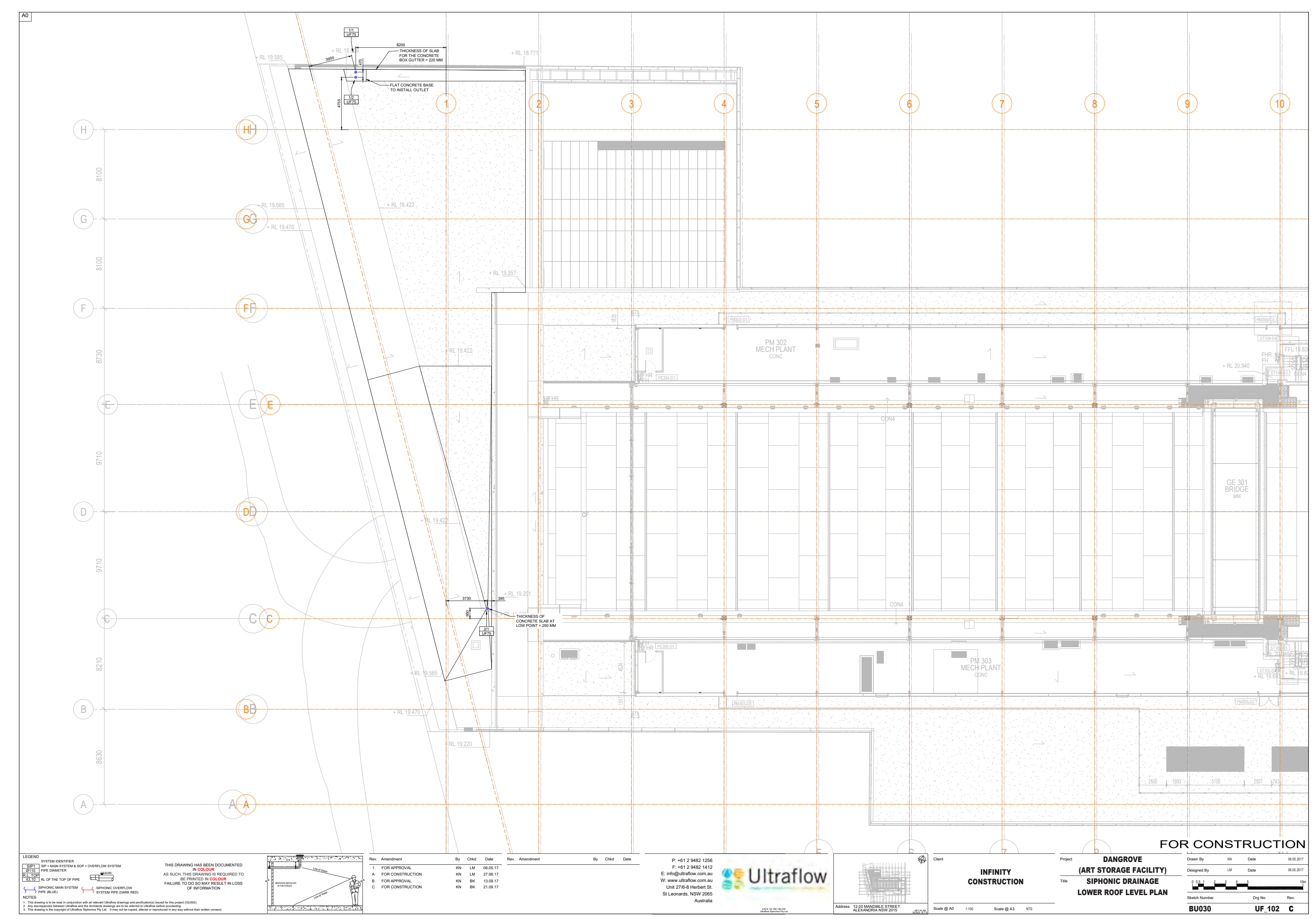
Workshop drawings for the fabrication of the LS1 Great Hall ceiling plates.





The finalised siphonic design results in a flat horizontal run of pipework running 140 metres that, through the fire corridor and away from the storage rooms, deposits rainwater from the northern roof to the onsite detention system in the south at minimal of zero fall in the piping.





Siphonic design drawings.

VESDA VLF

VLF-500



The VESDA VLF-500 detector is a very early warning smoke detector designed to protect small, business-critical environments of less than 500 m² (5,380 sq. ft.)

The detector works by continually drawing air into sampling holes in a pipe network. The air is filtered and passed into a detection chamber where light scattering technology detects the presence of very small amounts of smoke. Detector status information is communicated on the detector display and via relays or optional interface cards.

Out-of-the-box operation

The VLF can be installed and commissioned out-of-the-box without the need for a special interface or software programming tools.

In operation, the unique Smoke Dial™ display provides the user with an instant understanding of a smoke event, even from a distance. Should a fault occur, the user simply opens the field service door and activates the Instant Fault Finder feature to determine the specific fault condition. This information can then be passed onto their fire service company, ensuring that service technicians arrive onsite fully prepared.

Ultrasonic Flow Sensing

The patent-pending Ultrasonic Flow Sensing used in the VLF provides a direct reading of the sampling pipe flow rate. The system is immune to air temperature and pressure changes and is unaffected by contamination. The VLF is the first air sampling smoke detector to use ultrasonic flow sensing.

Features

- Out-of-the-Box Installation and Commissioning
- Ultrasonic Airflow Sensing
- Laser-Based Absolute Smoke Detection
- Pre-engineered pipe network designs
- Programmable Alarm Thresholds
- Clean air barrier optics protection
- Instant Recognition Display
- Instant Fault Finder™
- AutoLearn™ Smoke
- AutoLearn™ Flow
- Field Service Access Door
- Multiple Event Logging in separate logs
- Event log – up to 18000 events
- Offline/online configuration capability
- Up to 500 m² (5,380 sq. ft.) coverage*

Listings/Approvals

- UL
- ULC
- CCC
- FM
- ActivFire
- CE
- LPCB
- VdS
- VNIIPO
- NF
- EN 54-20
  - Class A (30 holes / 0.05% obs/m)
  - Class B (30 holes / 0.15% obs/m)
  - Class C (30 holes / 0.32% obs/m)

Classification of any configuration is determined using ASPIRE.

Regional approvals listings and regulatory compliance vary between VESDA product models. Refer to www.xtralis.com for the latest product approvals matrix.

VESDA by xtralis



The VESDA system, consisting of control box on the left and pump on the right. The VESDA piping from the ceiling reticulates down the wall to the pump.

Top: Upper level of the plant room on the western side of the building, showing chilled water pumps with some of the mechanical air handling units behind.

Centre: Upper level plant room on the eastern side, showing air handling units and chilled and hot water reticulation.

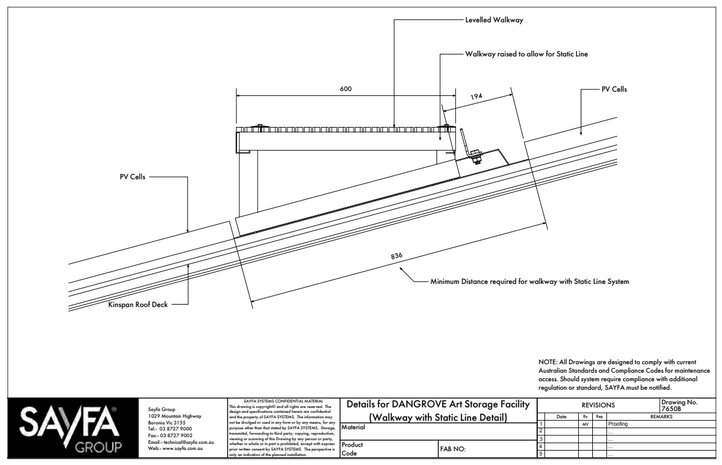
Below: Mezzanine level service piping for fire hydrant, fire hose reel, rainwater, potable water, natural gas and fire services anubar.







As the art storage rooms were of varying sizes, VESDA units of three different capacities were used, the most common being the VLF-500.

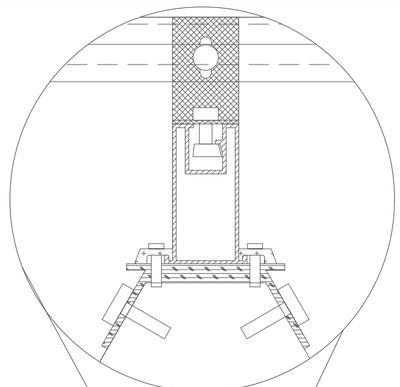


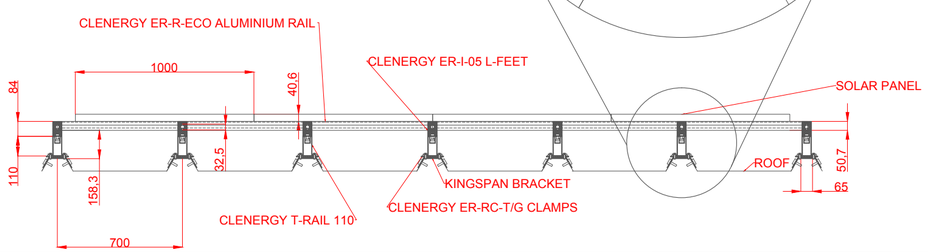
Sample prepared of Kingspan roofing, photovoltaic cells and mock walkway showing all spatial relationships.



The cross-section drawing of the transverse walkways, installed.

NOTES:
- RIDGE MEASURED FROM SAMPLE SUPPLIED
- KINGSPAN BRACKET TO BE 140 mm WIDE
- ESTIMATED BRACKET SPACING 700 mm TBC
- DEPTH OF PENETRATION INTO BRACKET TBC
- BASED ON 43 m HIGH BUILDING, WIND REGION A2





No.	Revision:	By:	Date:
A	ISSUED FOR INSTALL	JB	05/12/16

Scale: 1:4
Date: 05/12/16
Designed By: AN
Drawn By: JB
Checked By: AN

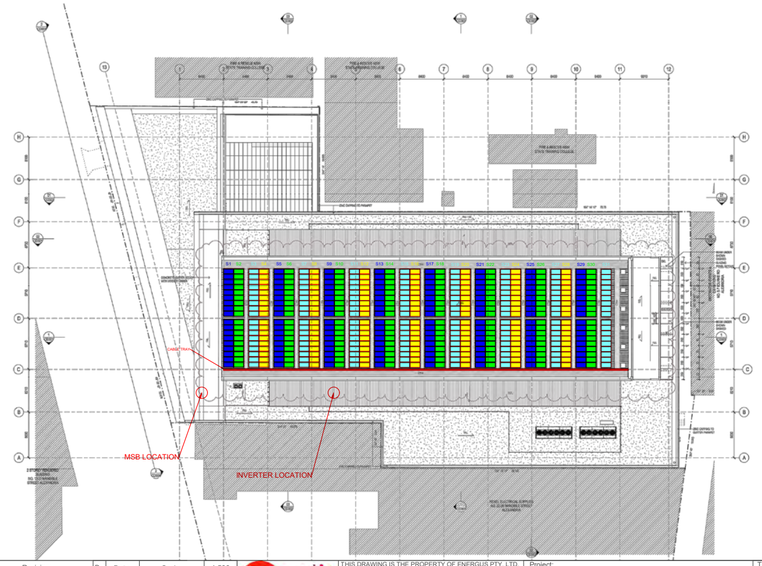
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ADDRESS: SUITE 901 / LEVEL 9, 153 WALKER STREET, NORTH SYDNEY, NSW, 2060
PHONE: (02) 1300 090 187

Project: DANGROVE ART FACILITY

Title: MOUNTING DETAIL

Size: A3 | Drawing Number: DANGROVE-1-L-01 | Rev: A



String	4 mm²	6 mm²
S1	107	
S2	113	
S3	119	
S4	123	
S5	129	
S6	133	
S7	139	
S8	143	
S9	149	
S10	153	
S11	159	
S12	163	
S13	169	
S14	173	
S15	179	
S16	183	
S17		188
S18		193
S19		198
S20		203
S21		208
S22		213
S23		218
S24		223
S25		228
S26		233
S27		238
S28		243
S29		248
S30		253
S31		258
Total	2329	3345

Cable Size (mm²)/Length (m)

No.	Revision:	By:	Date:
A	ISSUED FOR INSTALL	JB	07/06/17

Scale: 1:500
Date: 07/06/17
Designed By: JB
Drawn By: JB
Checked By: AN

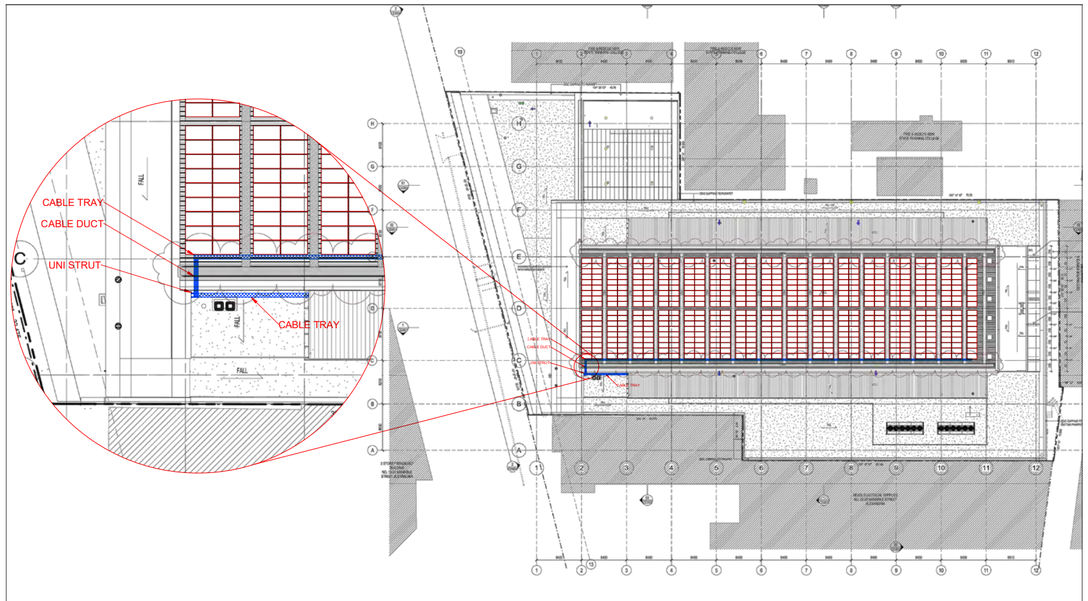
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PHONE: (02) 1300 090 187

Project: DANGROVE ART FACILITY CENTRE

Title: PANEL LAYOUT

Size: A3 | Drawing Number: DANGROVE-1-L-01 | Rev: A



No.	Revision:	By:	Date:
A	ISSUED FOR INSTALL	JB	11/08/17

Scale: 1:500
Date: 11/08/17
Designed By: JB
Drawn By: JB
Checked By: AN

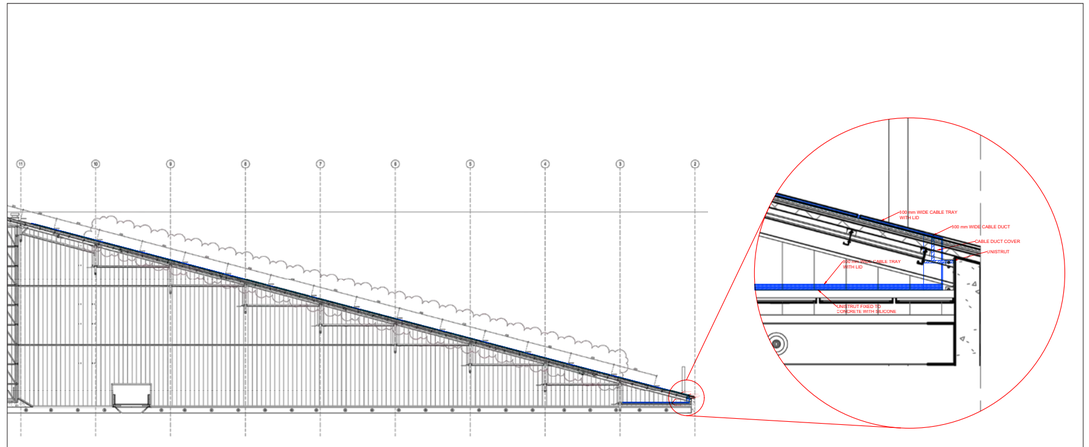
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ADDRESS: SUITE 901 / LEVEL 9, 153 WALKER STREET, NORTH SYDNEY, NSW, 2060
PHONE: (02) 1300 090 187

Project: DANGROVE ART FACILITY CENTRE

Title: CABLE TRAY LAYOUT

Size: A3 | Drawing Number: DANGROVE-1-L-02 | Rev: A



No.	Revision:	By:	Date:
A	ISSUED FOR INSTALL	JB	11/08/17

Scale: 1:300
Date: 11/08/17
Designed By: JB
Drawn By: JB
Checked By: AN

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ADDRESS: SUITE 901 / LEVEL 9, 153 WALKER STREET, NORTH SYDNEY, NSW, 2060
PHONE: (02) 1300 090 187

Project: DANGROVE ART FACILITY CENTRE

Title: CABLE TRAY SECTION

Size: A3 | Drawing Number: DANGROVE-1-L-03 | Rev: A

The basic unit selection, location and type.

SCHEDULE OF SPLIT SYSTEM

REF.	Serving	Room Temp	Total Cooling	Make (Indoor Unit)	Model Number	Configuration	Length	Depth	Height	Weight	Sound Pressure	MCC	Power Input	Electrical Supply	Cooling Capacity	Heating Capacity	Make (Outdoor Unit)	Ref.	Model Number	Length	Depth	Height	Weight	Sound Pressure	MCC	Comment
		C	kW				(mm)	(mm)	(mm)	(kg)	db(A)		kW	V/Ph/Hz	kW	kW				(mm)	(mm)	(mm)	(kg)	db(A)		
DX-01	Comms Room PE104	21	9.5	MITSUBISHI OR APPROVED EQUAL	PKA-RP100KAL	WALL MOUNTED	1170	295	365	21	39	MCC-04	2.9	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-01	PUHZ-RP100VAL	1050	360	945	118	51	MCC-03	
DX-02	Comms Room PE105	21	9.5	MITSUBISHI OR APPROVED EQUAL	PKA-RP100KAL	WALL MOUNTED	1170	295	365	21	39	MCC-03	2.9	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-02	PUHZ-RP100VAL	1050	360	945	118	51	MCC-04	
DX-03	Comms Room	21	9.5	MITSUBISHI OR APPROVED EQUAL	PKA-RP100KAL	WALL MOUNTED	1170	295	365	21	39	MCC-02	2.9	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-03	PUHZ-RP100VAL	1050	360	945	118	51	MCC-02	
DX-04	Switchboard Room	21	4.8	MITSUBISHI OR APPROVED EQUAL	MSZ-GE50VAD	WALL MOUNTED	800	232	300	10	38	MCC-03	1.6	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-04	MUZ-GE50VAD	850	840	330	54	54	MCC-04	
DX-05	Inverter Room	21	4.8	MITSUBISHI OR APPROVED EQUAL	MSZ-GE50VAD	WALL MOUNTED	800	232	300	10	38	MCC-05	1.6	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-05	MUZ-GE50VAD	850	840	330	54	54	MCC-05	
DX-06	Inverter Room	21	4.8	MITSUBISHI OR APPROVED EQUAL	MSZ-GE50VAD	WALL MOUNTED	800	232	300	10	38	MCC-06	1.6	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-06	MUZ-GE50VAD	850	840	330	54	54	MCC-06	
DX-07	Secutiry Apartment	21	3.5	MITSUBISHI OR APPROVED EQUAL	SEZ-KD71VAQ9L	CEILING CONCEALED	1400	732	250	29	39	MCC-04	1.6	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-07	SUZ-KD71	1050	360	945	118	51	MCC-03	
DX-08	Security Room	21/24	3.5	MITSUBISHI OR APPROVED EQUAL	MSZ-GE35AD	WALL MOUNTED	1400	732	250	29	39	MCC-01	1.6	230/1/50	4.8	5.8	MITSUBISHI OR APPROVED EQUAL	CU-07	MUZ-GE35AD	550	800	285	33	47	MCC-03	

FLEXIBLE DUCTWORK

Diameter	Air Quantity	Comments
mm	L/s	-
150	>50	Silent Flex as manufacturerd by Polyaire or approved equal
200	56-120	
250	121-195	
300	196-250	
350	251-355	

SCHEDULE OF FANS

TAG. NO	SERVING	LOCATION	AIR FLOW	STATIC PRESSURE	FAN TYPE	FAN SPEED	MOTOR POWER	ELECTRICAL SUPPLY	CURRENT	INLET PWL (dB) 63	125	250	500	1K	2K	4K	8K	SOUND PRESSURE	FAN WEIGHT	DIAMETER	MCC	COMMENTS
-	-	-	(L/s)	(Pa)		(rps)	(kW)	V / Ph / Hz	FLC(A)/Start(A)									dB(A) @ 3m	(kg)	mm	-	-
TEX-01	LEVEL 1 TOILETS	CAR PARK	300	300	IN-LINE DUCTED	23	0.19	415/3/50	0.61/1.83	80	78	74	71	62	64	63	63	52	18	350	MCC-04	
TEX-02	LEVEL 2 TOILETS	CAR PARK	400	300	IN-LINE DUCTED	23	0.19	415/3/50	0.61/1.83	80	78	74	71	62	64	63	63	52	18	350	MCC-04	
LDE-01	LOADING DOCK	CAR PARK	3000	250	IN-LINE DUCTED	24	2.2	415/3/50	4.8/25.9	85	85	84	82	79	81	76	70	52	18	500	MCC-04	
OA-01	AHU-01-02-03 OUTSIDE AIR	ROOF LEVEL PLANTROOM	590	300	IN-LINE DUCTED	23	0.19	415/3/50	0.61/1.83	80	78	74	71	62	64	63	63	52	18	350	MCC-05	
OA-02	AHU-04-05 OUTSIDE AIR	ROOF LEVEL PLANTROOM	655	300	IN-LINE DUCTED	23	0.19	415/3/50	0.61/1.83	80	78	74	71	62	64	63	63	52	18	350	MCC-05	
OA-03	AHU-06-07 OUTSIDE AIR	ROOF LEVEL PLANTROOM	480	300	IN-LINE DUCTED	23	0.19	415/3/50	0.61/1.83	80	78	74	71	62	64	63	63	52	18	310	MCC-06	
OA-04	AHU-08-09 OUTSIDE AIR	ROOF LEVEL PLANTROOM	300	300	IN-LINE DUCTED	23	0.19	415/3/50	0.61/1.83	80	78	74	71	62	64	63	63	52	18	350	MCC-06	
OA-05	FCU MULTIPURPOSE HALL	ROOF LEVEL PLANTROOM	735	350	IN-LINE DUCTED	22	0.75	415/3/50	2. / 6	77	77	75	72	69	72	69	61	57	36	450	MCC-06	
OA-06	FCU 01-02-03 LOCATED AT LEVEL 1	CAR PARK	160	200	IN-LINE DUCTED	23	0.15	415/1/50	0.66/1.98	82	76	68	65	57	57	55	49	47	25	310	MCC-03	
OA-07	FCUs LOCATED AL LEVEL 2	CAR PARK	390	350	IN-LINE DUCTED	23	0.19	415/3/50	0.83/2.49	80	78	74	71	62	64	63	63	52	18	350	MCC-03	
SC-01	SMOKE CLEARANCE	ROOF LEVEL PLANTROOM	1600	300	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCCE-01	CONNECTED TO FFCP
SC-02	SMOKE CLEARANCE	ROOF LEVEL PLANTROOM	1600	300	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCCE-01	CONNECTED TO FFCP
SC-03	SMOKE CLEARANCE	ROOF LEVEL PLANTROOM	1600	300	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCCE-01	CONNECTED TO FFCP
SC-04	SMOKE CLEARANCE	ROOF LEVEL PLANTROOM	1600	300	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCCE-02	CONNECTED TO FFCP
SC-05	SMOKE CLEARANCE	ROOF LEVEL PLANTROOM	1600	300	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCCE-02	
SC-06	SMOKE CLEARANCE	ROOF LEVEL PLANTROOM	1600	300	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCCE-02	
SPF-01	STAIR PRESS SYSTEM	ROOF LEVEL PLANTROOM	3600	300	IN-LINE DUCTED	24	2.2	415/3/50	4.8/25.9	85	85	84	82	79	81	76	70	52	18	560	MCCE-01	"PUSH AND PULL" SYSTEM. TO FFCP
SPF-02	STAIR PRESS SYSTEM	ROOF LEVEL PLANTROOM	3600	300	IN-LINE DUCTED	24	2.2	415/3/50	4.8/25.9	85	85	84	82	79	81	76	70	52	18	560	MCCE-02	"PUSH AND PULL" SYSTEM. TO FFCP
SPF-03	SMOKE PURGE SYSTEM	SERVICE CORRIDOR LEVEL 1	3600	300	IN-LINE DUCTED	24	2.2	415/3/50	4.8/25.9	85	85	84	82	79	81	76	70	52	18	560	MCCE-01	"PUSH AND PULL" SYSTEM. TO FFCP
SPF-04	SMOKE PURGE SYSTEM	SERVICE CORRIDOR LEVEL 1	3600	300	IN-LINE DUCTED	24	2.2	415/3/50	4.8/25.9	85	85	84	82	79	81	76	70	52	18	560	MCCE-02	"PUSH AND PULL" SYSTEM. TO FFCP
EX-03	CONSERVATION ROOM EXTRACTION SYSTEM	CONSERVATION ROOM	345 MAX	300	WALL MOUNTED	47	0.55	415/3/50	2.36/1.36	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	59	14.3	450	MCC-03	NEDERMAN EXTRACTION SYSTEM-N10
EX-02	PAINT/WASTE ROOM/FORK AND PELLET	ROOF LEVEL PLANTROOM	700	300	ROOF COWL	23	0.19	415/3/50	0.83/2.49	80	78	74	71	62	64	63	63	52	18	350	MCC-06	
EX-01	MAIN PLANTROOM EXHAUST	ROOF LEVEL PLANTROOM	1850	250	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCC-06	
SF-01	MAIN PLANTROOM SUPPLY	ROOF LEVEL PLANTROOM	1650	250	IN-LINE DUCTED	24	1.5	415/3/50	3.4/18.36	82	82	81	79	76	78	73	67	63	58	500	MCC-06	
KEX-01	KITCHEN RANGE HOOD EXHAUST	KITCHEN LEVEL 2	200	250	ROOF COWL	23	0.19	415/3/50	0.61/1.83	80	78	74	71	62	64	63	63	52	18	350	MCC-06	

SCHEDULE OF FAN COIL UNITS

Plant Ref	Serving	Type	Location	Air Flow Rate	Min Outside Air	Indicative External Resistance	Cooling Coil Design GTH	Air On	Air On	Chilled Water Flow	Temp In	Temp Out	Heating GTH	Air On	Hot Water Flow	Temp In	Temp Out	Base FCU Selection Supplier	Model	FCU Dimensions Length	Width	Height	MCC	Indicative Motor Size	Phase
-	-		-	L/s	L/s		KW	°C	°C	l/s	°C	°C	KW	°C db	L/s	°C	°C			(mm)	(mm)	(mm)		kW	
FCU-01	Foyer/Entry	Standard Fan Coil Unit	Level 1	1090	50	250	26.00	24.60	18.20	1.04	6.00	12.00	5.10	12.50	0.06	60.00	80.00	Temperzone	IMD550	1100	1900	525	MCC04	1.50	1
FCU-02	Offices	Standard Fan Coil Unit	Level 1	860	100	250	22.20	25.50	18.70	0.89	6.00	12.00	11.60	19.00	0.14	60.00	80.00	Temperzone	IMD420	1100	1395	525	MCC04	1.50	1
FCU-03	Reception	Standard Fan Coil Unit	Level 1	830	30	250	19.60	24.50	18.10	0.78	6.00	12.00	9.80	20.40	0.12	60.00	80.00	Temperzone	IMD420	1100	1395	525	MCC04	1.50	1
FCU-04	Meeting Room	Vertical Concealed Type	Level 2	250	120	250	6.20	28.30	20.70	0.25	6.00	12.00	4.90	13.8	0.20	60.00	80.00	Ahi-carrier	42N-S-65	1300	220	670	MCC04	0.16	1
FCU-05	Lounge-01	Vertical Concealed Type	Level 2	210	40	250	3.77	25.70	19.00	0.15	6.00	12.00	3.02	18.1	0.12	60.00	80.00	Ahi-carrier	42N-50	1100	220	670	MCC04	0.16	1
FCU-06	Lounge-02	Vertical Concealed Type	Level 2	210	40	250	3.77	25.70	19.00	0.15	6.00	12.00	3.02	18.1	0.12	60.00	80.00	Ahi-carrier	42N-50	1100	220	670	MCC04	0.16	1
FCU-07	Office GE210	Vertical Concealed Type	Level 2	150	40	250	2.96	26.40	19.50	0.12	6.00	12.00	2.30	17.0	0.09	60.00	80.00	Ahi-carrier	42N-33	900	220	670	MCC04	0.16	1
FCU-08	Office GE211	Vertical Concealed Type	Level 2	75	10	250	1.20	25.20	18.70	0.05	6.00	12.00	1.10	19.0	0.04	60.00	80.00	Ahi-carrier	42N-16	700	220	670	MCC04	0.16	1
FCU-09	Office GE212	Vertical Concealed Type	Level 2	75	10	250	1.20	25.20	18.70	0.05	6.00	12.00	1.10	19.0	0.04	60.00	80.00	Ahi-carrier	42N-16	700	220	670	MCC04	0.16	1
FCU-10	Office GE213	Vertical Concealed Type	Level 2	75	10	250	1.20	25.20	18.70	0.05	6.00	12.00	1.10	19.0	0.04	60.00	80.00	Ahi-carrier	42N-16	700	220	670	MCC04	0.16	1
FCU-11	Office GE214	Vertical Concealed Type	Level 2	75	10	250	1.20	25.20	18.70	0.05	6.00	12.00	1.10	19.0	0.04	60.00	80.00	Ahi-carrier	42N-16	700	220	670	MCC04	0.16	1
FCU-12	AV Viewing	Standard Fan Coil Unit	Level 2	625	80	250	16.40	25.70	18.80	0.65	6.00	12.00	8.60	18.80	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC04	0.56	1
FCU-13	Redrawing Room	Standard Fan Coil Unit	Level 2	600	85	250	15.90	25.90	18.90	0.63	6.00	12.00	8.40	18.60	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC03	0.56	1
FCU-14	Redrawing Room	Standard Fan Coil Unit	Level 2	600	85	250	15.90	25.90	18.90	0.63	6.00	12.00	8.40	18.60	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC03	0.56	1
FCU-15	Redrawing Room	Standard Fan Coil Unit	Level 2	600	85	250	15.90	25.90	18.90	0.63	6.00	12.00	8.40	18.60	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC03	0.56	1
FCU-16	Redrawing Room	Standard Fan Coil Unit	Level 2	600	85	250	15.90	25.90	18.90	0.63	6.00	12.00	8.40	18.60	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC03	0.56	1
FCU-17	Redrawing Room	Standard Fan Coil Unit	Level 2	600	85	250	15.90	25.90	18.90	0.63	6.00	12.00	8.40	18.60	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC03	0.56	1
FCU-18	Redrawing Room	Standard Fan Coil Unit	Level 2	600	85	250	15.90	25.90	18.90	0.63	6.00	12.00	8.40	18.60	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC03	0.56	1
FCU-19	Redrawing Room	Standard Fan Coil Unit	Level 3	600	85	250	15.90	25.90	18.90	0.63	6.00	12.00	8.40	18.60	0.10	60.00	80.00	Temperzone	IMD210	1100	1125	525	MCC03	0.56	1
FCU-20	Kitchen	Standard Fan Coil Unit	Level 2	815	140	250	22.20	26.30	19.10	0.89	6.00	12.00	11.80	18.10	0.14	60.00	80.00	Temperzone	IMD210	1100	1395	525	MCC03	0.56	1
FCU-21	Library	Standard Fan Coil Unit	Level 2	300	100	250	5.90	27.30	19.70	0.24	6.00	12.00	3.20	16.80	0.04	60.00	80.00	Temperzone	IMD95	1100	875	420	MCC03	0.37	1

SCHEDULE OF ULTRASONIC HUMIDIFIERS

Plant Ref.	Serving	AHU	Location	Humidifier Capacity	V/Ph/kW	Manufacturer	Base Model Selection	Comments
-				(kg/hr)				
HUM 03	White Rabbit Setup Gallery	AHU-03	Mezzanine Plantroom	5.87	240/1/0.31	Stulz	ENS 6000	Duct Mounted
HUM 04	Art Store AS101	AHU-04	Mezzanine Plantroom	4.64	240/1/0.24	Stulz	ENS 4800	Duct Mounted
HUM 05	Art Store AS102	AHU-05	Mezzanine Plantroom	1.55	240/1/0.125	Stulz	ENS 2400	Duct Mounted
HUM 06	Art Store AS104	AHU-06	Mezzanine Plantroom	3.81	240/1/0.24	Stulz	ENS 4800	Duct Mounted
HUM 07	Art Store AS104	AHU-07	Mezzanine Plantroom	3.81	240/1/0.24	Stulz	ENS 4800	Duct Mounted
HUM 08	Art Store AS103	AHU-08	Mezzanine Plantroom	3.17	240/1/0.185	Stulz	ENS 3600	Duct Mounted
HUM 09	Furniture Store	AHU-09	Mezzanine Plantroom	5.84	240/1/0.31	Stulz	ENS 6000	Duct Mounted
HUM 10	Great Hall	AHU-10	Lower Roof Plantroom	5.55	240/1/0.31	Stulz	ENS 6000	Duct Mounted
HUM 11	Art Store AS201	AHU-11	Lower Roof Plantroom	1.57	240/1/0.125	Stulz	ENS 2400	Duct Mounted
HUM 12	Art Store AS202	AHU-12	Lower Roof Plantroom	2.75	240/1/0.185	Stulz	ENS 3600	Duct Mounted
HUM 13	Art Store AS202	AHU-13	Lower Roof Plantroom	2.74	240/1/0.185	Stulz	ENS 3600	Duct Mounted
HUM 14	Art Store AS203	AHU-14	Lower Roof Plantroom	2.21	240/1/0.125	Stulz	ENS 2400	Duct Mounted
HUM 15	Great Hall	AHU-15	Lower Roof Plantroom	1.42	240/1/0.125	Stulz	ENS 2400	Duct Mounted
HUM 16	Art Evaluation 02	AHU-16	Lower Roof Plantroom	1.42	240/1/0.125	Stulz	ENS 2400	Duct Mounted
HUM 17	Great Hall	AHU-17	Lower Roof Plantroom	5.55	240/1/0.31	Stulz	ENS 6000	Duct Mounted
HUM 18	Art Store AS206	AHU-18	Lower Roof Plantroom	2.21	240/1/0.125	Stulz	ENS 2400	Duct Mounted
HUM 19	Art Store AS205	AHU-19	Lower Roof Plantroom	6.77	240/1/0.375	Stulz	ENS 7200	Duct Mounted
HUM 20	Art Store AS205	AHU-20	Lower Roof Plantroom	4.72	240/1/0.24	Stulz	ENS 4800	Duct Mounted
HUM 21	Art Store AS205	AHU-21	Lower Roof Plantroom	4.40	240/1/0.24	Stulz	ENS 4800	Duct Mounted
HUM 22	Great Hall	AHU-22	Lower Roof Plantroom	5.55	240/1/0.31	Stulz	ENS 6000	Duct Mounted
HUM 23	Art Evaluation 02	AHU-23	Lower Roof Plantroom	1.42	240/1/0.125	Stulz	ENS 2400	Duct Mounted

SCHEDULE OF COOLING TOWERS

Plant Ref	Duty	Location	Total Heat Rejection	Water Flow Rate	Water Temp in	Water Temp out	Air Flow Rate	Air Temp wb	Indicative Motor Size	VSD	Phase	Spectrum (In Duct) dB (Hz) 63	125	250	500	1K	2K	4K	8K	Weighted	Base Selection Manufacturer	Model	Dimensions Length	Width	Height	MCC
-	-		kW	L/s	°C	°C	m³/s	°C	kW		-	Sound Pressure Levels (dB)											mm	mm	mm	
CT 01	Building	Roof	1160	50.5	35.0	29.5	29.5	24.5	11.2	YES	3	79	80	71	65	58	48	44	37	68	Aircoil	PCT1010-P3-L	3200	3200	3650	MCC-05
CT 02	Building	Roof	1160	50.5	35.0	29.5	29.5	24.5	11.2	YES	3	79	80	71	65	58	48	44	37	58	Aircoil	PCT1010-P3-L	3200	3200	3650	MCC-05

SCHEDULE OF ATTENUATORS

TAG. NO.	SERVING	LENGTH	OPEN AREA	STATIC INSERTION LOSS (dB) 63	125	250	500	1K	2K	4K	8K	COMMENTS
-	-	(mm)	%	dB (Hz)								-
ATT-A	TYPICAL AHU SUPPLY	900	50	3	7	12	17	14	12	11	10	SEE NOTE BELOW
ATT-B	TYPICAL AHU SUPPLY	900	45	3	9	13	20	20	14	14	9	SEE NOTE BELOW
ATT-C	TYPICAL AHU SUPPLY	900	40	7	11	14	25	28	17	15	14	SEE NOTE BELOW
ATT-D	TYPICAL AHU SUPPLY	1200	50	4	11	16	22	18	14	12	11	SEE NOTE BELOW
ATT-E	TYPICAL AHU SUPPLY	1200	45	4	11	17	25	24	17	15	10	SEE NOTE BELOW
ATT-F	TYPICAL AHU SUPPLY	1500	50	5	12	19	26	24	16	14	12	SEE NOTE BELOW
ATT-G	TYPICAL AHU SUPPLY	1500	45	6	13	21	30	29	20	16	12	SEE NOTE BELOW
ATT-H	TYPICAL AHU SUPPLY	1500	40	9	15	23	35	36	25	19	16	SEE NOTE BELOW
ATT-I	TYPICAL AHU SUPPLY	1800	45	8	15	25	35	34	23	17	14	SEE NOTE BELOW
ATT-J	TYPICAL AHU SUPPLY	1200	40	8	13	19	30	32	21	17	15	SEE NOTE BELOW

Note: finalisation of acoustic treatments to be based on final acoustic report

SCHEDULE OF AHUs

REF.	SERVING	LOCATION	Air Flow Rate	Min Outside Air	Return Air	Indicative External Resistance	Cooling On-Coil Condition		Off-coil Condition		Cooling Capacity GTH	TSH	Chilled Water Flow	Temp In	Temp Out	Heating Capacity	Coil Air On	Hot Water Flow	Temp In	Temp Out	MCC	Indicative Motor Size	Phase	Manufacturer	Comments
			l/s	l/s	l/s	Pa	°C db	°C wb	°C db	°C wb	kW	kW	L/s	°C	°C	kW	°C	L/s	°C	°C		kW			
AHU-01	Workshop	Plantroom PM04	1118	112	1007	350	22.6	16.4	11.6	10.6	12.70	11.00	0.51	6	12	10.8	19.3	0.13	60	80	MCC-04	2.7	3	Air Design or approved equal	Face-Bypass configuration.
AHU-02	Sorting/Packing	Plantroom PM04	1118	112	1007	350	22.6	16.4	11.6	10.6	12.70	11.00	0.51	6	12	10.8	19.3	0.13	60	80	MCC-04	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-03	White Rabbit Setup Gallery	Plantroom PM04	3667	367	3300	350	22.6	16.4	11.6	10.6	53.10	46.10	2.12	6	12	45.1	19.3	0.54	60	80	MCC-04	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-04	Art Store AS101	Plantroom PM03	2897	290	2607	350	22.6	16.4	11.6	10.6	43.50	37.80	1.73	6	12	37.0	19.3	0.44	60	80	MCC-01	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-05	Furniture Store	Plantroom PM03	972	97	875	350	22.6	16.4	11.6	10.6	10.90	9.50	0.43	6	12	9.3	19.3	0.11	60	80	MCC-02	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-06	Art Store AS104	Plantroom PM01	2383	238	2145	350	22.6	16.4	11.6	10.6	41.20	36.20	1.64	6	12	35.0	19.3	0.42	60	80	MCC-03	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-07	Art Store AS104	Plantroom PM01	2383	238	2145	350	22.6	16.4	11.6	10.6	41.20	36.20	1.64	6	12	35.0	19.3	0.42	60	80	MCC-03	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-08	Art Store AS103	Plantroom PM02	1980	198	1782	350	22.6	16.4	11.6	10.6	28.70	25.30	1.14	6	12	24.4	19.3	0.29	60	80	MCC-02	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-09	Art Store AS102	Plantroom PM02	3648	365	3284	350	22.6	16.4	11.6	10.6	40.00	35.00	1.59	6	12	34.0	19.3	0.41	60	80	MCC-02	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-10	Great Hall	Plantroom PM06	3471	347	3124	350	22.6	16.4	11.6	10.6	49.5	43	1.97	6	12	42.1	19.3	0.50	60	80	MCC-05	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-11	Art Store AS201	Plantroom PM06	983	98	885	350	22.6	16.4	11.6	10.6	11.1	9.8	0.44	6	12	9.4	19.3	0.11	60	80	MCC-05	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-12	Art Store AS202	Plantroom PM06	1721	172	1549	350	22.6	16.4	11.6	10.6	27.4	23.8	1.09	6	12	23.3	19.3	0.28	60	80	MCC-05	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-13	Art Store AS202	Plantroom PM06	1721	172	1549	350	22.6	16.4	11.6	10.6	27.4	23.8	1.09	6	12	23.3	19.3	0.28	60	80	MCC-05	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-14	Great Hall	Plantroom PM06	3471	347	3124	350	22.6	16.4	11.6	10.6	49.5	43	1.97	6	12	42.1	19.3	0.50	60	80	MCC-05	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-15	Art Store AS203	Plantroom PM06	1377	138	1239	350	22.6	16.4	11.6	10.6	19.3	17.4	0.77	6	12	16.4	19.3	0.20	60	80	MCC-05	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-16	Art Evaluation 02	Plantroom PM06	885	89	797	350	22.6	16.4	11.6	10.6	10.7	9.8	0.43	6	12	9.1	19.3	0.11	60	80	MCC-05	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-17	Great Hall	Plantroom PM05	3471	347	3124	350	22.6	16.4	11.6	10.6	49.5	43	1.97	6	12	42.1	19.3	0.50	60	80	MCC-06	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-18	Art Store AS206	Plantroom PM05	1377	138	1239	350	22.6	16.4	11.6	10.6	19.3	17.4	0.77	6	12	16.4	19.3	0.20	60	80	MCC-06	2.7	3	Air Design or approved equal	Face-Bypass configuration
AHU-19	Art Store AS205	Plantroom PM05	4228	423	3806	350	22.6	16.4	11.6	10.6	65	56.4	2.59	6	12	55.3	19.3	0.66	60	80	MCC-06	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-20	Art Store AS205	Plantroom PM05	2950	295	2655	350	22.6	16.4	11.6	10.6	43.8	39	1.75	6	12	37.2	19.3	0.45	60	80	MCC-06	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-21	Art Store AS205	Plantroom PM05	2760	276	2484	350	22.6	16.4	11.6	10.6	41.6	36.5	1.66	6	12	35.4	19.3	0.42	60	80	MCC-06	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-22	Great Hall	Plantroom PM05	3471	347	3124	350	22.6	16.4	11.6	10.6	49.5	43	1.97	6	12	42.1	19.3	0.50	60	80	MCC-06	5.4	3	Air Design or approved equal	Face-Bypass configuration
AHU-23	Art Evaluation 02	Plantroom PM05	885	89	797	350	22.6	16.4	11.6	10.6	10.7	9.8	0.43	6	12	9.1	19.3	0.11	60	80	MCC-06	2.7	3	Air Design or approved equal	Face-Bypass configuration

SCHEDULE OF FUME CABINET

Reference	No. Off	Serving	Model	Manufacturer	Type
FC-01	1	Conservation Room	1200REC	Dynaflow	Recirculating fume cabinet with activated carbon filters

SCHEDULE OF EXTRACTION ARMS

Room	QTY	Manufacturer	Comments
Conservation	as per architectural layout	Nederman	One extraction arm per workstation

SCHEDULE OF BOILERS

REF.	LOCATION	TYPE	FUEL TYPE	OUTPUT LOAD	GAS CONSUMPTION	POWER CONSUMPTION	FLOWRATE	FLUID ENTERING/LEAVING TEMPERATURE	LENGHT / WIDTH / HEIGHT	OPERATING WEIGHT	MCC	Manufacturer
-				kW	MJ/hr	kW	l/s	°C	mm	kg		
B-01	Level 1 Plantroom	Gas-Fired Condensing	Natural Gas	550	2786	0.9	6.58	80/60	2653/1130/1355	793	MCC-02	Rendemax R600 or approved equal
B-02	Level 1 Plantroom	Gas-Fired Condensing	Natural Gas	550	2786	0.9	6.58	80/60	2653/1130/1355	793	MCC-02	

SCHEDULE OF BUFFER TANKS

REF.	Location	Capacity	Serving	Comments
mm		Litres		-
BT-01	PM102- Main Plantroom	2000	CH-01/02	Vertical - Mild Steel Insulated and Sheathed Vessel
BT-02	PM102- Main Plantroom	500	RO Plant	Vertical - Mild Steel Insulated and Sheathed Vessel

SCHEDULE OF REVERSE OSMOSIS

REF.	Serving	PRODUCT FLOW RATE	MANUFACTURER	MODEL	COMMENT
		Litres per hour			
RO-01	Humidification plant	300	Vertex Hydropore or approved equal	SX-100D	Booster Pump and Buffer tank to be provided

SCHEDULE OF CHILLERS

REF.	DESCRIPTION	LOCATION	MAX COOLING CAPACITY	EVAPORATOR TEMP IN	TEMP OUT	WATER FLOW	CONDENSER TEMP IN	TEMP OUT	WATER FLOW	DIMENSIONS LENGTH	WIDTH	HEIGHT	WEIGHT	MCC	CURRENT NOMINAL	MAX	ELECTRICAL SUPPLY	COP FULL LOAD	PART LOAD 50	COMMENTS
-			kW	°C	°C	l/s	°C	°C	l/s	mm	mm	mm	kg		A	A	V/Ph/Hz			
CH-01	Water Cooled	Level 1 Main Plantroom	700.0	12.0	6.0	27.9	29.5	35.0	50.8	4000	1178	2261	7295	MCC-02	275.0	600.0	400/3/50	6.1	11.6	Carrier 19XRV or approved equal
CH-02	Water Cooled	Level 1 Main Plantroom	700.0	12.0	6.0	27.9	29.5	35.0	50.8	4000	1178	2261	7295	MCC-02	275.0	600.0	400/3/50	6.1	11.6	Carrier 19XRV or approved equal

SCHEDULE OF DUST COLLECTOR

REF.	Type	Air Suction Capacity	Serving	Motor Power	Noise	Overall Dimensions L x W x H			model	Manufacturer	Comments
		m3/h		kW/Hz	dB	mm	mm	mm			-
DEX-01	Portable Dust Cyclone	2500	Workshop	2.25/ 50	78	1200	670	2700	S200	Airtight Solutions	TBC by client

SCHEDULE OF PUMPS

Ref.	Serving	Location	Flow Rate	INDICATIVE HEAD	TYPE	WATER TEMP.	INDICATIVE MOTOR	PHASE	VSD	MCC	COMMENTS
-	-	-	l/s	kPa	-	°C	kW	-	-	-	-
CHWP-01	CH-01	Level 1 Main Plantroom	27.8	150	End-Suction Centrifugal	6 12	7.46	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
CHWP-02	CH-02	Level 1 Main Plantroom	27.8	150	End-Suction Centrifugal	6 12	7.46	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
CHWP-03	STANDBY	Level 1 Main Plantroom	27.8	150	End-Suction Centrifugal	6 12	7.46	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
CWP-01	CT-01	Level 1 Main Plantroom	50.4	120	End-Suction Centrifugal	29.5/35	11.2	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
CWP-02	CT-02	Level 1 Main Plantroom	50.4	120	End-Suction Centrifugal	29.5/35	11.2	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
CWP-03	STANDBY	Level 1 Main Plantroom	50.4	120	End-Suction Centrifugal	29.5/35	11.2	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
HWP-01	B-01	Level 1 Main Plantroom	6.58	150	End-Suction Centrifugal	80/60	2.24	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
HWP-02	STANDBY	Level 1 Main Plantroom	6.58	150	End-Suction Centrifugal	80/60	2.24	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
RO-1	RO PLANT	Level 1 Main Plantroom	0.05	see note 1 below	Booster pump	na	na	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
RO-2	RO PLANT	Level 1 Main Plantroom	0.05	see note 1 below	Booster pump	na	na	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
RO-3	RO PLANT	Level 1 Main Plantroom	NA	see note 2 below	Distribution pump	na	na	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL
RO-4	RO PLANT	Level 1 Main Plantroom	NA	see note 2 below	Distribution pump	na	na	3-PH	YES	MCC-02	GRUNDFOS OR APPROVED EQUAL

Note 1: Booster pumps to be sized to reach 400 kpa required by the RO unit. Calculations to be carried out by contractor
Note 2: Distribution pumps to be sized to reach 100 kpa required by the index-run humidifier. Calculations to be carried out by contractor

SCHEDULE OF SUPPLY AIR OUTLETS

TAG. NO.	Serving	FLOWRATE	MANUFACTURER	TYPE	MODEL	QUANTITY	FACE SIZE	COMMENT
		L/s					mm	
SA1	ART STORE AREAS / SPACES LEVEL 1	190 - L/s	KRANTZ	HIGH INDUCTION SWIRL DIFFUSER	RADIAL OUTLET RA-N3-500	AS SHOWN ON LAYOUTS	350	KRANTZ OR EQUAL APPROVED.
SA2	MULTIPURPOSE HALL	100 L/s	BRADFLO	DOUBLE DEFLECTION	AUR	AS SHOWN ON LAYOUTS	150 X 450	BRADFLO OR EQUAL APPROVED. SIDE WAY GRILLE
SA3	GREAT HALL	430 l/s	KRANTZ	JET DIFFUSERS	DW-V2-250	AS SHOWN ON LAYOUTS		KRANTZ OR EQUAL APPROVED.

SCHEDULE OF RETURN AIR OUTLETS

TAG. NO	SERVING	FLOWRATE	MANUFACTURER	MODEL	TYPE	QUANTITY	FACE SIZE	COMMENT
		L/s					mm	
RA1	ART STORES	350 L/s	BRADFLO	DOUBLE DEFLECTION	DOUBLE DEFLECTION	AS SHOWN ON LAYOUTS	900 X 300	BRADFLO OR EQUAL APPROVED-LOW LEVEL GRILLE
RA2	MULTIPURPOSE HALL	180 L/s	BRADFLO	DOUBLE DEFLECTION	DOUBLE DEFLECTION	AS SHOWN ON LAYOUTS	150 X 450	BRADFLO OR EQUAL APPROVED

SCHEDULE OF EXHAUST AIR OUTLETS

TAG. NO	SERVING	FLOWRATE	MANUFACTURER	MODEL	TYPE	QUANTITY	FACE SIZE	COMMENT
		L/s					mm	
EA-01	TOILETS/STORE ROOM	50-100 L/s	BRADFLO	EGG GRATE GRILLE	EGG GRATE GRILLE	AS SHOWN ON LAYOUTS	150 X 150	BRADFLO OR EQUAL APPROVED

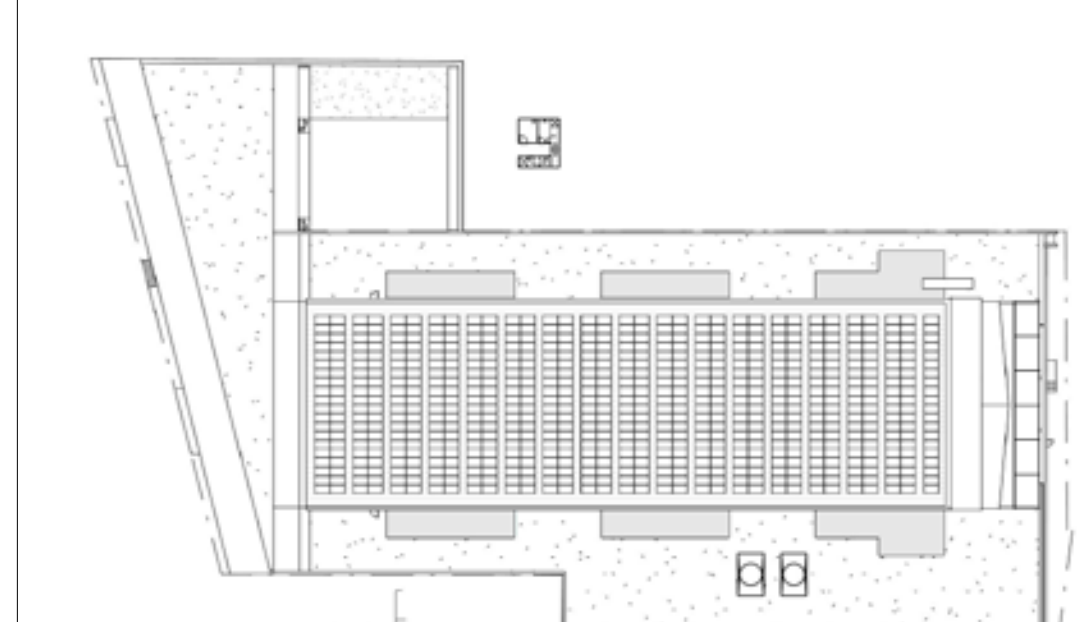
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STATUS

TENDER ISSUE

NOTES



AMENDMENTS

REV	DESCRIPTION	DATE
A	TENDER ISSUE	16.10.2015
B	TENDER SUBMISSION	22.10.2015

FOR TENDER
THIS IS NOT A WORKSHOP DRAWING
NOT FOR CONSTRUCTION. IT IS THE CONTRACTORS RESPONSIBILITY TO PROVIDE CONSTRUCTIONAL DIMENSIONED WORKSHOP DRAWINGS IN ACCORDANCE WITH THE RELEVANT SECTIONS IN THE SPECIFICATION

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STEENSEN VARMING

PROJECT
DANGROVE ART STORAGE FACILITY (DASF)
12-20 MANDIBLE STREET, ALEXANDRIA NSW 2015

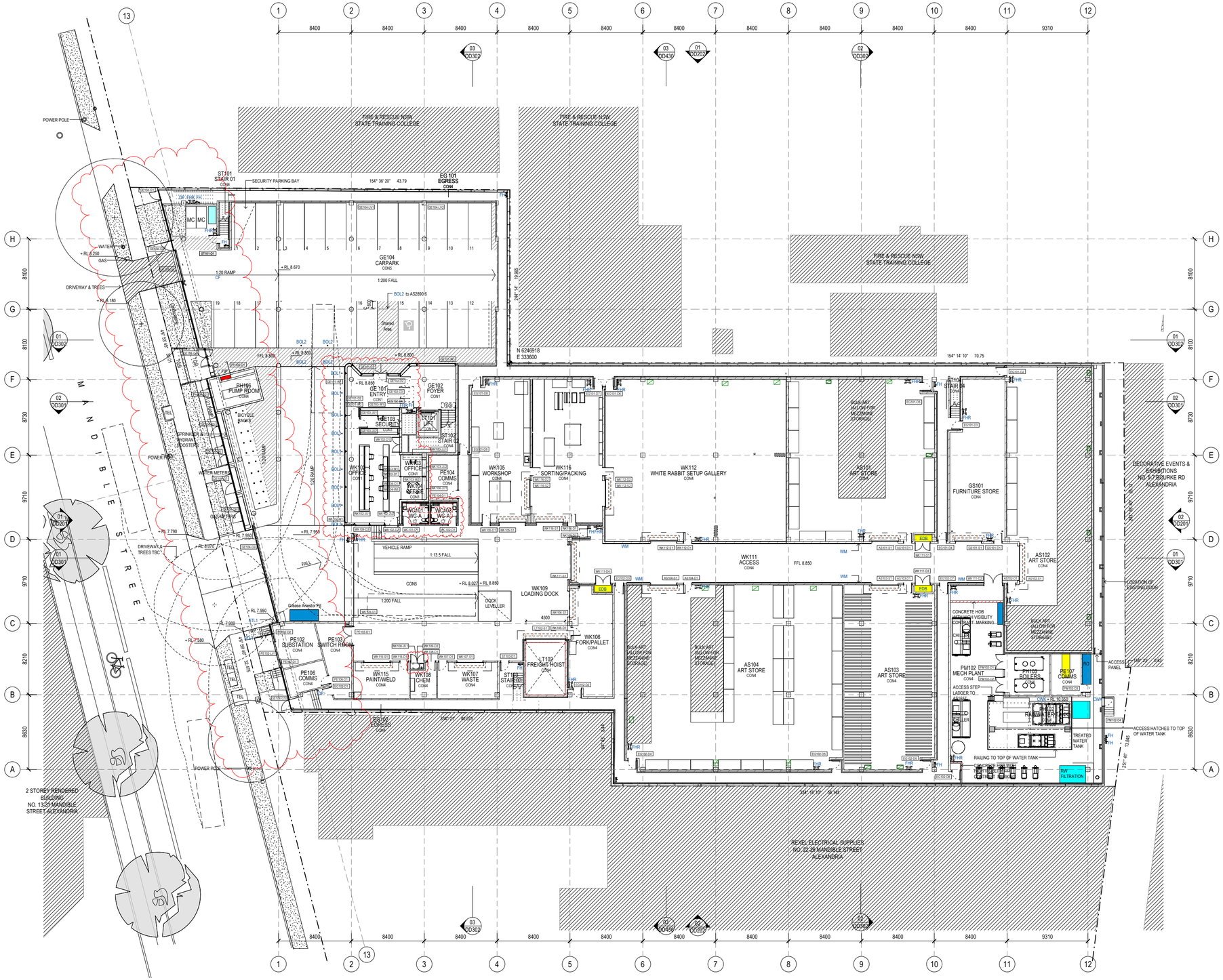
DRAWING TITLE
MECHANICAL SERVICES EQUIPMENT SCHEDULES

A1

CREATED	DRAWN	DESIGNED	CHECKED
JUL'15	TW	RB	AB
APPROVED	SCALE	NORTHPOINT	
CA			
PROJECT No.	DRAWING No.	REVISION	
14778	M1005	B	

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On this, and the following pages, the progression from the original design DD to the finalised layout CD. Of particular note is the area at grid 10 on the lower and mezzanine floors where the fire egress paths changed and greatly reduced the space available in the main plant room.



GENERAL NOTES

Verify Dimensions on site prior to commencement of work. Check existing RL's on site. Advise Superintendent of any discrepancies before commencement. Allow for adjustments to suit discrepancies.
Comply with relevant authorities requirements. Comply with Building Code of Australia requirements. Comply with relevant Australian Standards for materials and construction practice. Comply with Basix Certificate.
Do not scale from drawings.

REV.	DESCRIPTION	DATE
A	Cost Plan Hold Point	10.07.15
B	For Information Only	21.08.15
C	For Information Only	11.09.15
D	For Information Only	21.09.15
E	For Review	07.10.15
F	Issued for Draft Tender Review	12.10.15
G	Issued for Tender	21.10.15
H	Draft Issue For information	14.12.15

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DESIGN INTENT DOCUMENTS FOR TENDER ONLY

DANGROVE
ART STORAGE FACILITY
12-20 Mandible Street, Alexandria NSW 2015

Level 1 Plan

SCALE @ A1	DRAWN	CHECKED
1 : 200	TZ	AT

DOUBLE FOR A3

PROJECT	DRAWING	REVISION
14009	DD101	H



GENERAL NOTES

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tzannes@tzannes.com.au

DESIGN INTENT DOCUMENTS
FOR TENDER ONLY

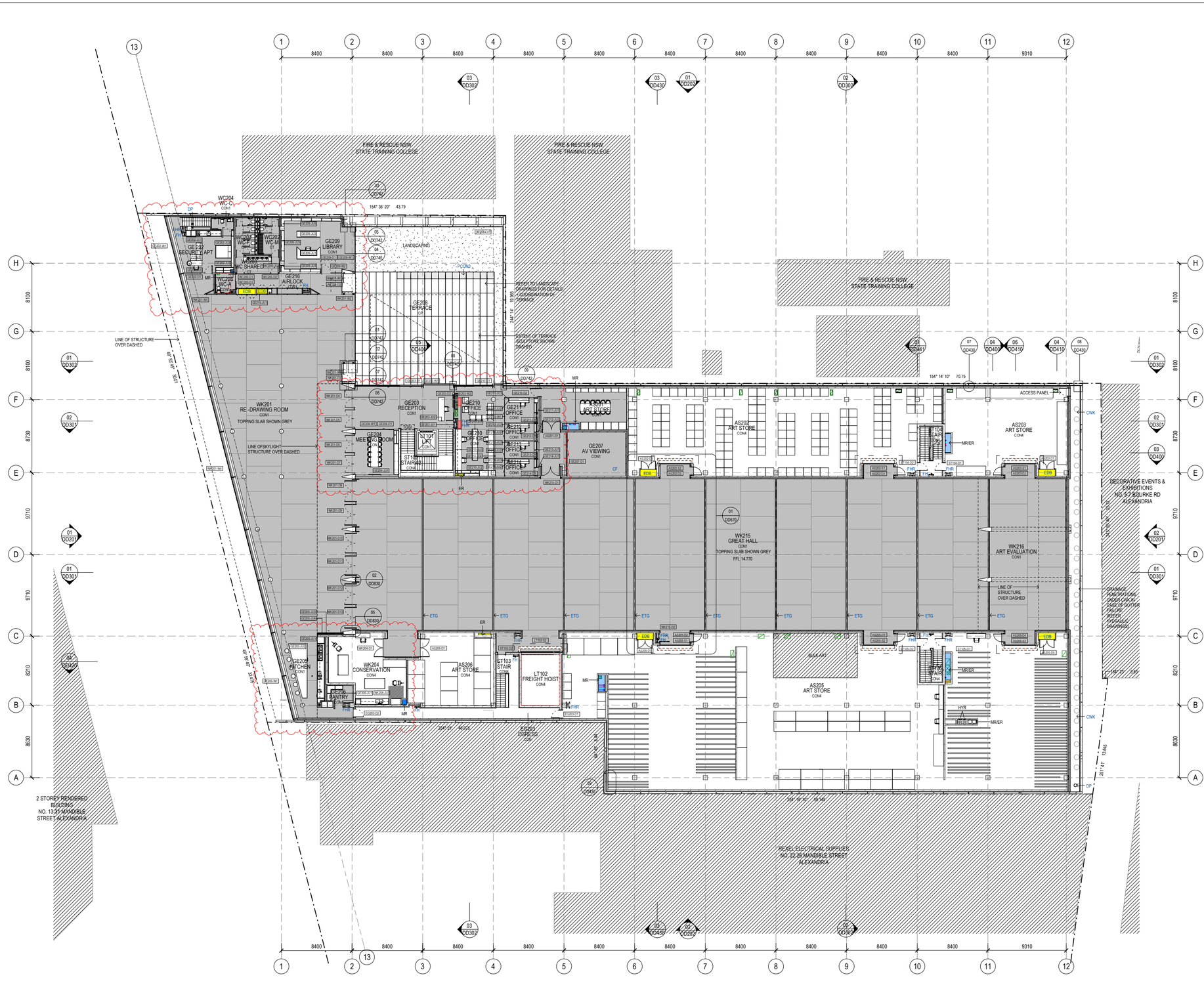
DANGROVE
ART STORAGE FACILITY

12-20 Mandible Street, Alexandria NSW 2015

Mezzanine Plan

SCALE @ A1 1 : 200
DOUBLE FOR A3
DRAWN TZ
CHECKED TZ

PROJECT	DRAWING	REVISION
14009	DD102	G



GENERAL NOTES

Verify Dimensions on site prior to commencement of work. Check existing RL's on site. Advise Superintendent of any discrepancies before commencement. Allow for adjustments to suit discrepancies.
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REV.	DESCRIPTION	DATE
A	Cost Plan Hold Point	10.07.15
B	For Information Only	21.08.15
C	For Information Only	11.09.15
D	For Information Only	21.09.15
E	For Review	07.10.15
F	Issued for Draft Tender Review	12.10.15
G	Issued for Tender	21.10.15
H	Draft Issue For Information	14.12.15

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DESIGN INTENT DOCUMENTS FOR TENDER ONLY

DANGROVE
ART STORAGE FACILITY

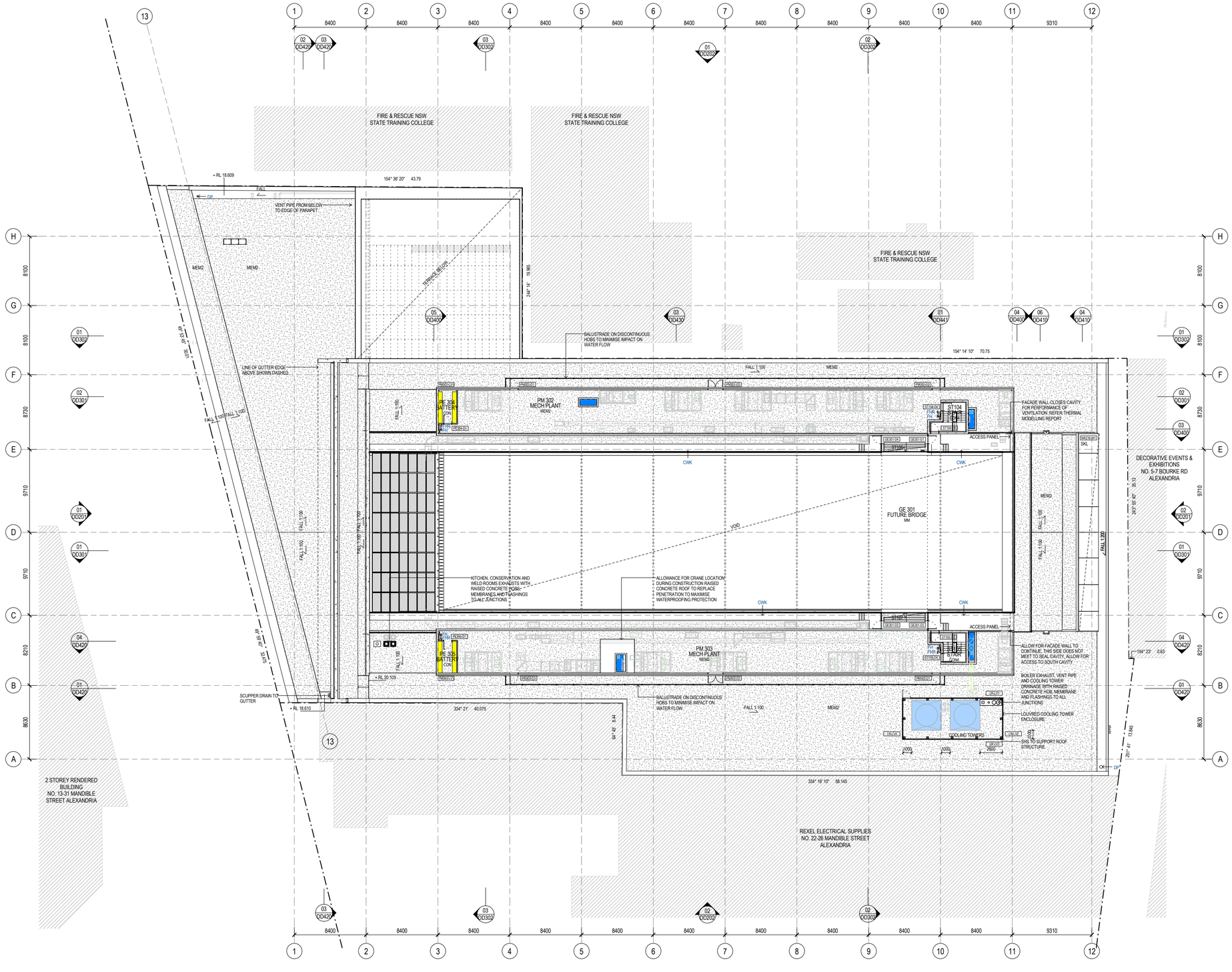
12-20 Mandible Street, Alexandria NSW 2015

Level 2 Plan

SCALE @ A1	DRAWN	CHECKED
1 : 200	TZ	AT

DOUBLE FOR A3

PROJECT	DRAWING	REVISION
14009	DD103	H



GENERAL NOTES

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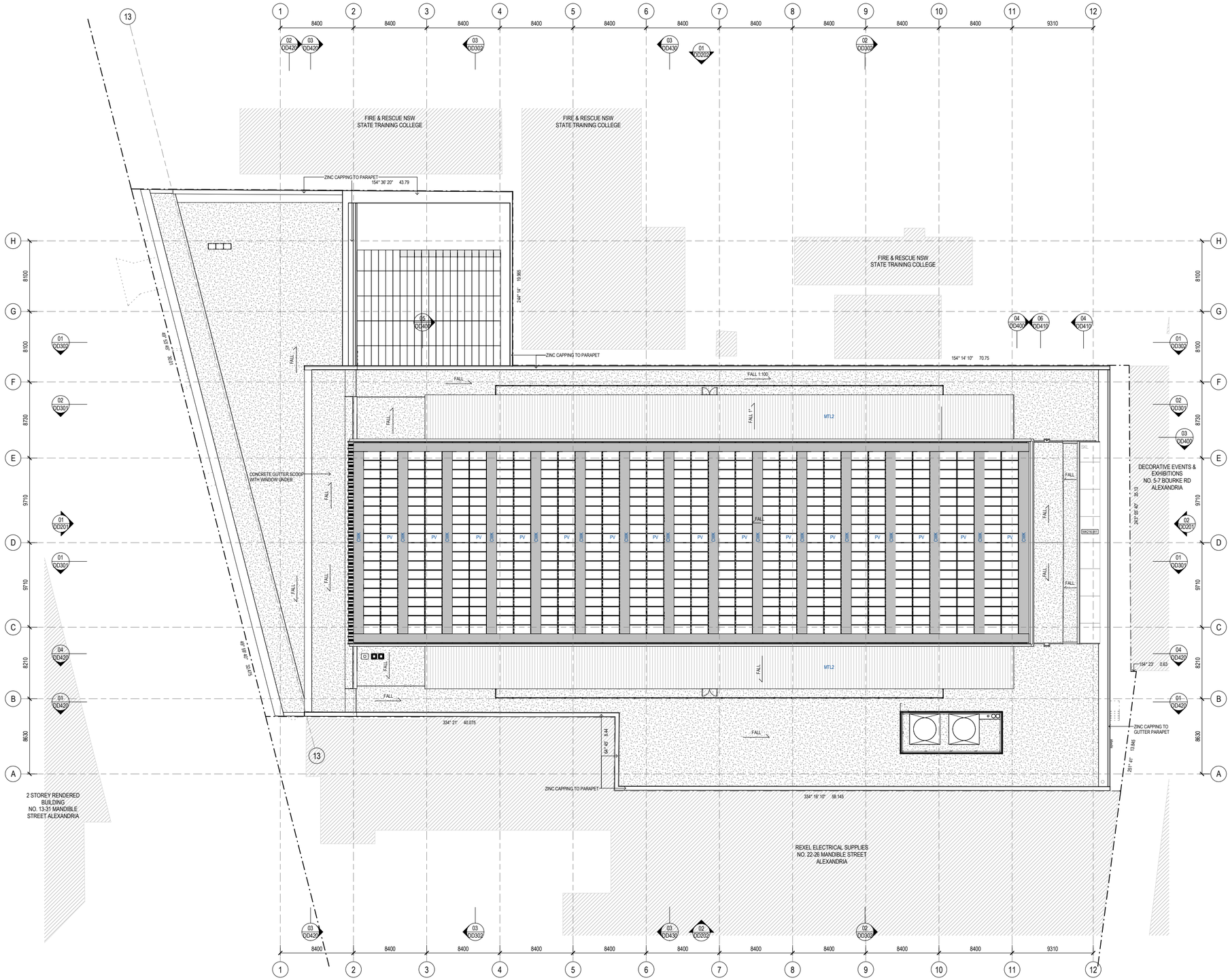
DESIGN INTENT DOCUMENTS
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DANGROVE
ART STORAGE FACILITY
12-20 Mandible Street, Alexandria NSW 2015

Lower Roof Plan

SCALE @ A1 1 : 200
DOUBLE FOR A3
DRAWN TZ
CHECKED TZ

PROJECT	DRAWING	REVISION
14009	DD104	G



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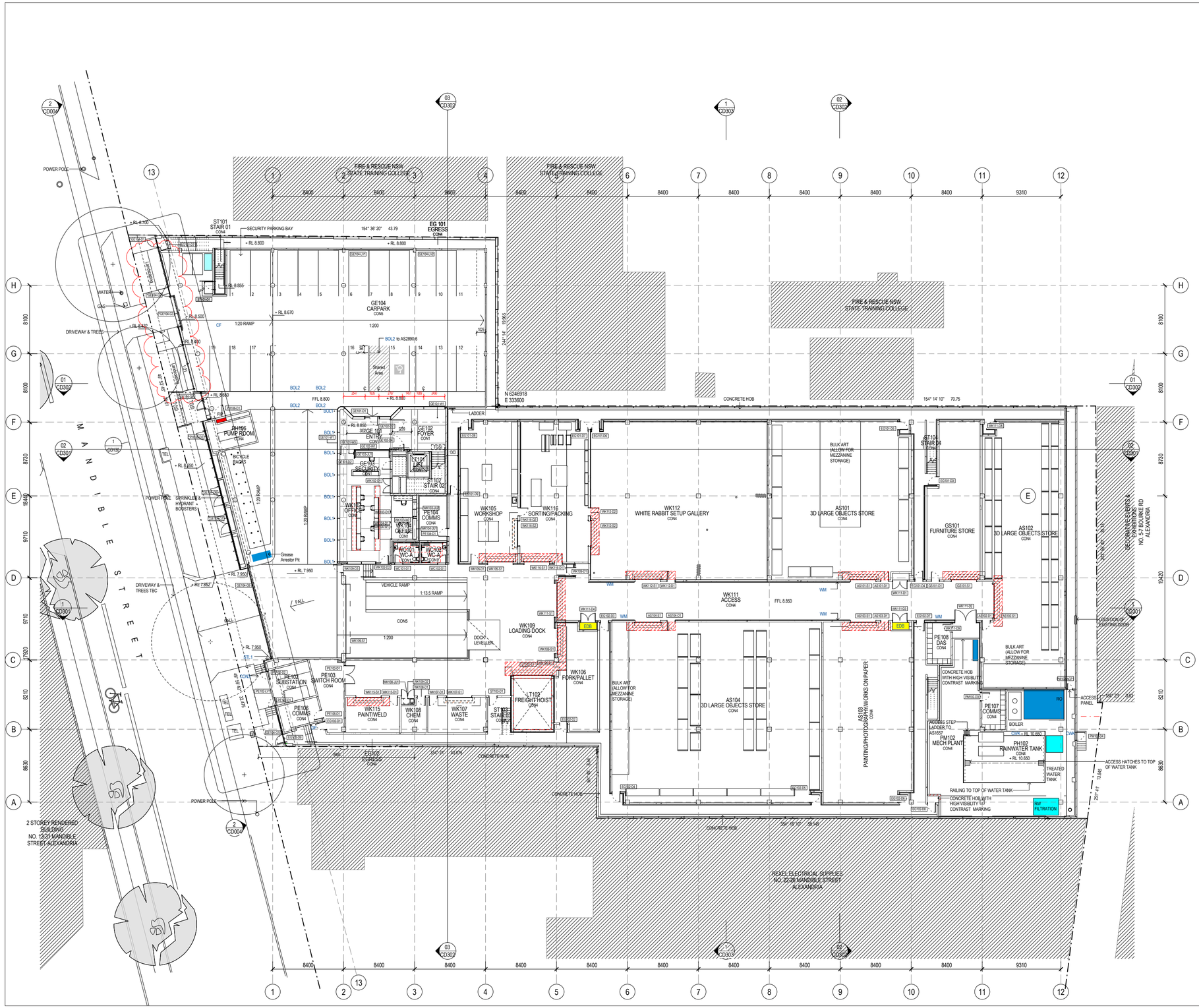
DESIGN INTENT DOCUMENTS
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DANGROVE
ART STORAGE FACILITY
12-20 Mandible Street, Alexandria NSW 2015

Upper Roof Plan

SCALE @ A1 1 : 200
DOUBLE FOR A3
DRAWN TZ
CHECKED TZ

PROJECT	DRAWING	REVISION
14009	DD105	F



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- All boundary dimensions and bearings to be verified by licensed surveyor prior to proceeding with work.

Legend

Floor line marking - 'Keep Clear - No Art Storage'
Refer drawing CD540 for details

REV	DESCRIPTION	CHK	APR	DATE
S	Revised as Clouded	JF	AA	06.03.17
T	Revised as Clouded	JF	AA	18.04.17
U	Revised as Clouded	JF	AA	28.08.17
V	Revised as Clouded	JF	AA	06.11.17
W	Revised as Clouded	JF	AA	13.11.17
X	Revised as Clouded	JF	AA	15.11.17
Y	Revised as Clouded	JF	AA	21.11.17
Z	Revised as Clouded	JF	AA	07.12.17
AA	Revised as Cloude	JF	AA	13.12.17
BB	Revised as Clouded	JF	AA	24.01.18

PROJECT PHASE

CONSTRUCTION DOCUMENTATION

STATUS

FOR CONSTRUCTION

PROJECT NO.
AA.COM.1601

PROJECT
DANGROVE

ADDRESS
12-20 Mandible Street, Alexandria NSW 2015

CLIENT
Infinity Construction

SCALE: As indicated @A1

SCALE BAR
0m 2 4 6 8 10m

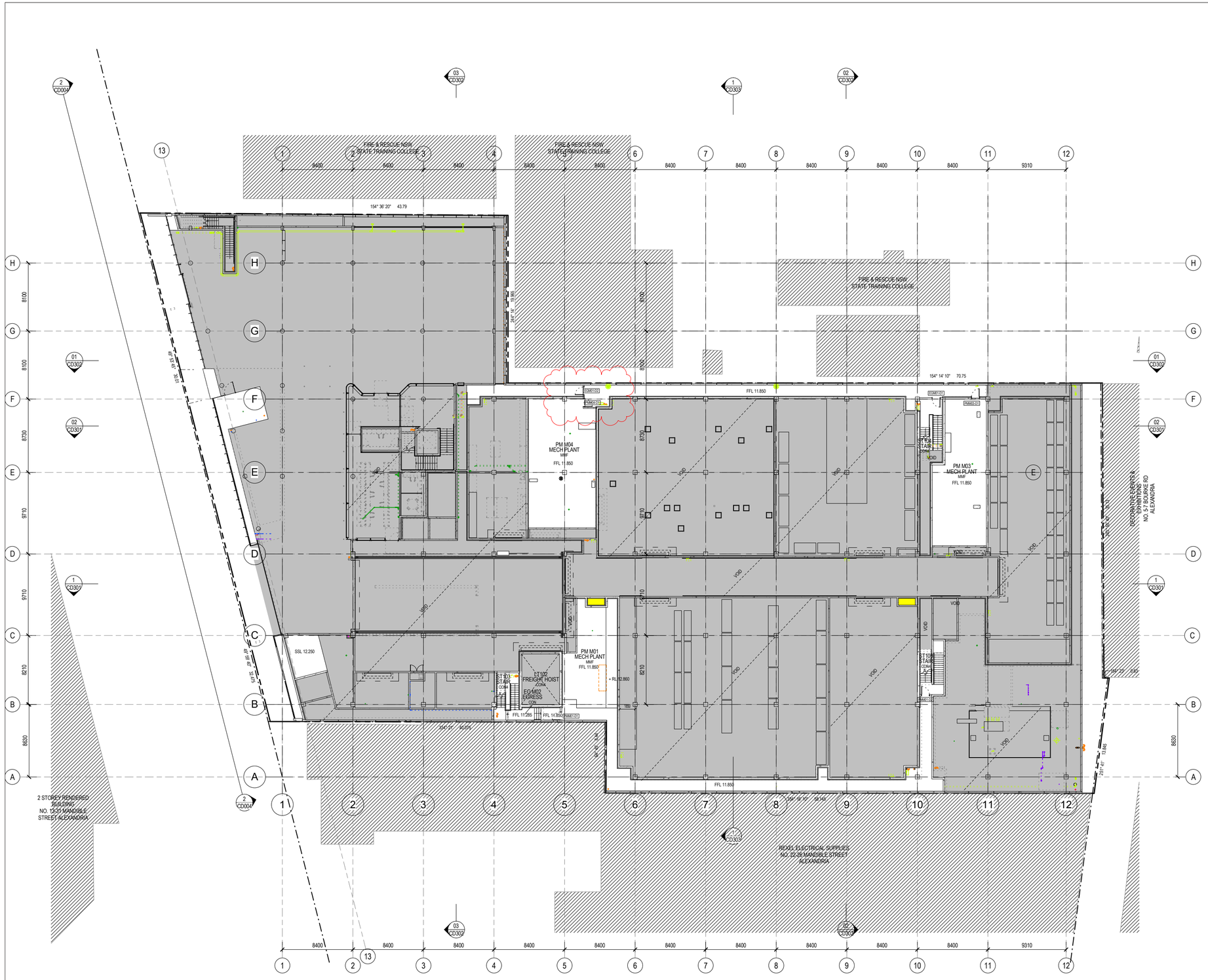
DRAWING SERIES
Plans

DRAWING NO.
CD101

DRAWING TITLE
Level 1 Plan

REVISION
BB

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REV	DESCRIPTION	CHK	APR	DATE
1	Issued for Information	JF	AA	30.06.16
A	Revised as Clouded	JF	AA	26.07.16
B	Revised as Clouded	JF	AA	12.10.16
C	Revised as Clouded	JF	AA	17.10.16
D	Revised as Clouded	JF	AA	20.10.16
E	Revised as Clouded	JF	AA	11.11.16
F	Revised as Clouded	JF	AA	17.11.16
G	Revised as Clouded	JF	AA	06.03.17
H	Revised as Clouded	JF	AA	12.07.17

PROJECT PHASE

CONSTRUCTION DOCUMENTATION

STATUS

FOR CONSTRUCTION

PROJECT NO.
AA.COM.1601

PROJECT
DANGROVE

ADDRESS
12-20 Mandible Street, Alexandria NSW 2015

CLIENT
Infinity Construction

SCALE: 1 : 200 @A1

SCALE BAR
0m 1 2 3 4 5m

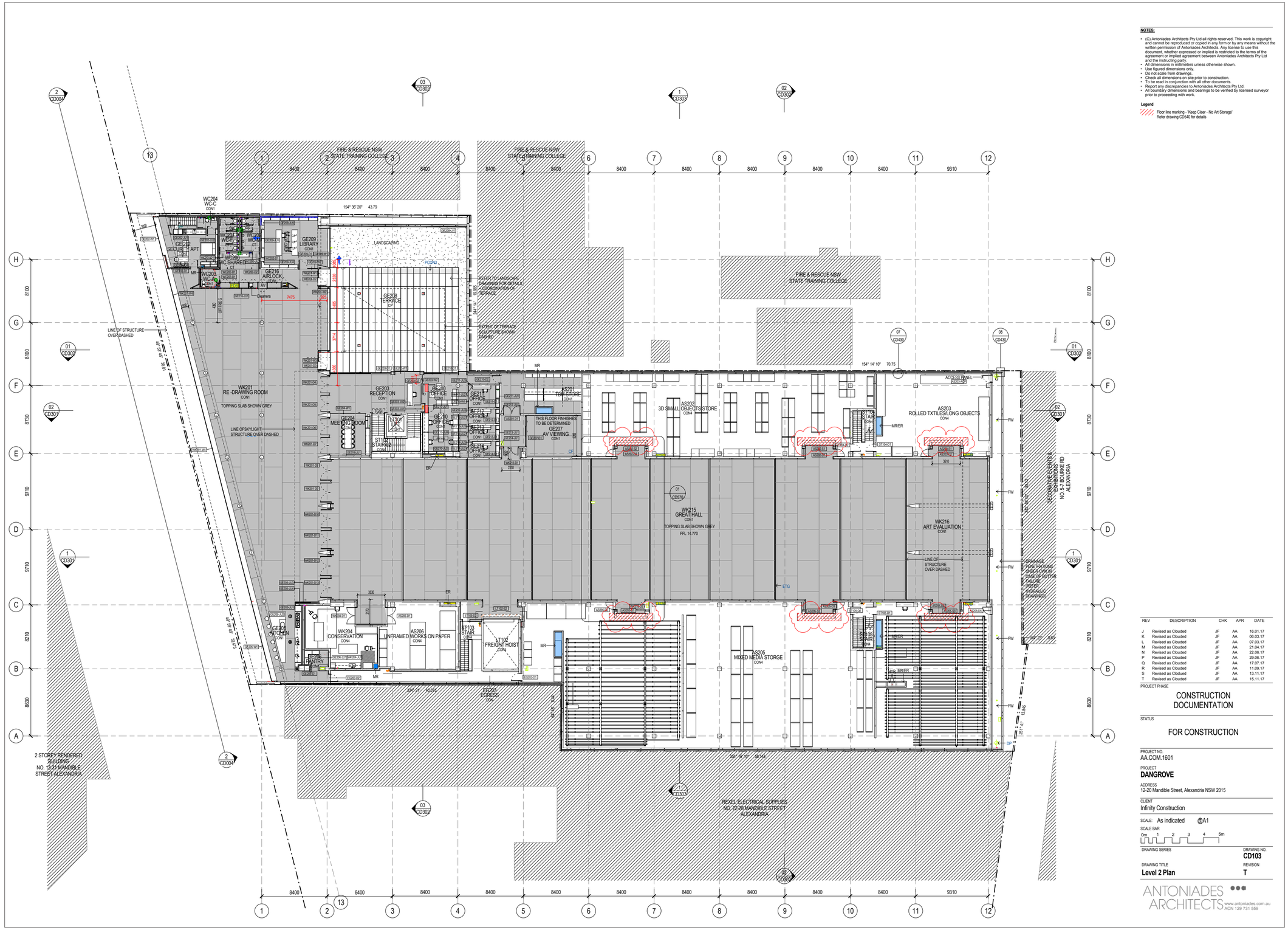
DRAWING SERIES
Plans

DRAWING NO.
CD102

DRAWING TITLE
Mezzanine Plan

REVISION
H

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Legend

Floor line marking - 'Keep Clear - No Art Storage'
Refer drawing CD540 for details

REV	DESCRIPTION	CHK	APR	DATE
J	Revised as Clouded	JF	AA	16.01.17
K	Revised as Clouded	JF	AA	06.03.17
L	Revised as Clouded	JF	AA	07.03.17
M	Revised as Clouded	JF	AA	21.04.17
N	Revised as Clouded	JF	AA	22.06.17
P	Revised as Clouded	JF	AA	29.06.17
Q	Revised as Clouded	JF	AA	17.07.17
R	Revised as Clouded	JF	AA	11.09.17
S	Revised as Clouded	JF	AA	13.11.17
T	Revised as Clouded	JF	AA	15.11.17

PROJECT PHASE

CONSTRUCTION DOCUMENTATION

STATUS

FOR CONSTRUCTION

PROJECT NO.
AA.COM.1601

PROJECT
DANGROVE

ADDRESS
12-20 Mandible Street, Alexandria NSW 2015

CLIENT
Infinity Construction

SCALE: As indicated @A1

SCALE BAR
0m 1 2 3 4 5m

DRAWING SERIES

DRAWING NO.
CD103

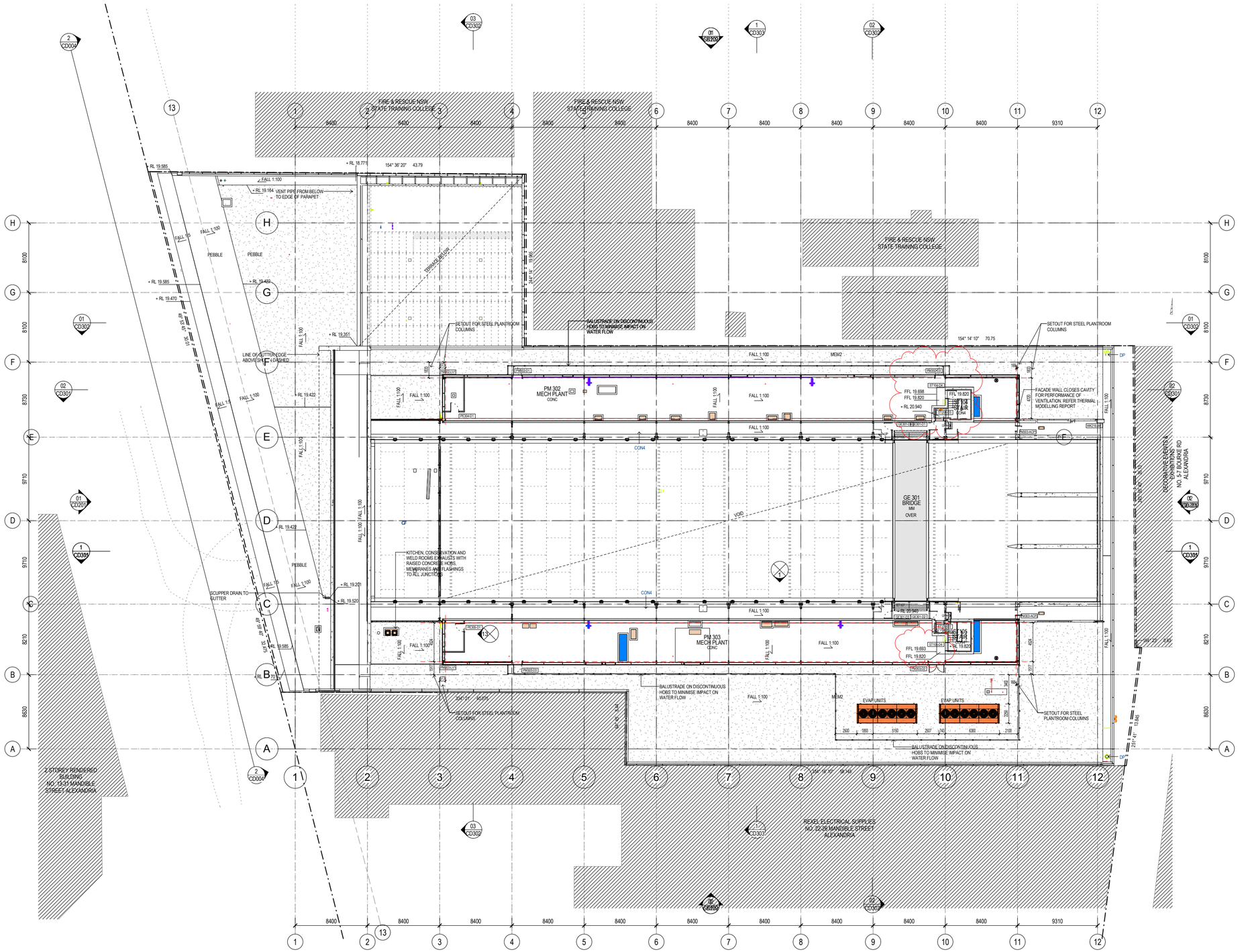
DRAWING TITLE
Level 2 Plan

REVISION
T

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REV	DESCRIPTION	CHK	APR	DATE
B	Revised as Clouded	JF	AA	17.10.16
C	Revised as Clouded	JF	AA	08.12.16
D	Revised as Clouded	JF	AA	22.12.16
E	Revised as Clouded	JF	AA	06.03.17
F	Revised as Clouded	JF	AA	07.03.17
G	Revised as Clouded	JF	AA	14.03.17
H	Revised as Clouded	JF	AA	10.04.17
J	Revised as Clouded	JF	AA	09.05.17
K	Revised as Clouded	JF	AA	15.05.17
L	Revised as Clouded	JF	AA	11.09.17

PROJECT PHASE

Construction Documentation

STATUS

FOR CONSTRUCTION

PROJECT NO.
AA.COM.1601

PROJECT
DANGROVE

ADDRESS
12-20 Mandible Street, Alexandria NSW 2015

CLIENT
Infinity Construction

SCALE: 1 : 200 @A1

SCALE BAR
0m 1 2 3 4 5m

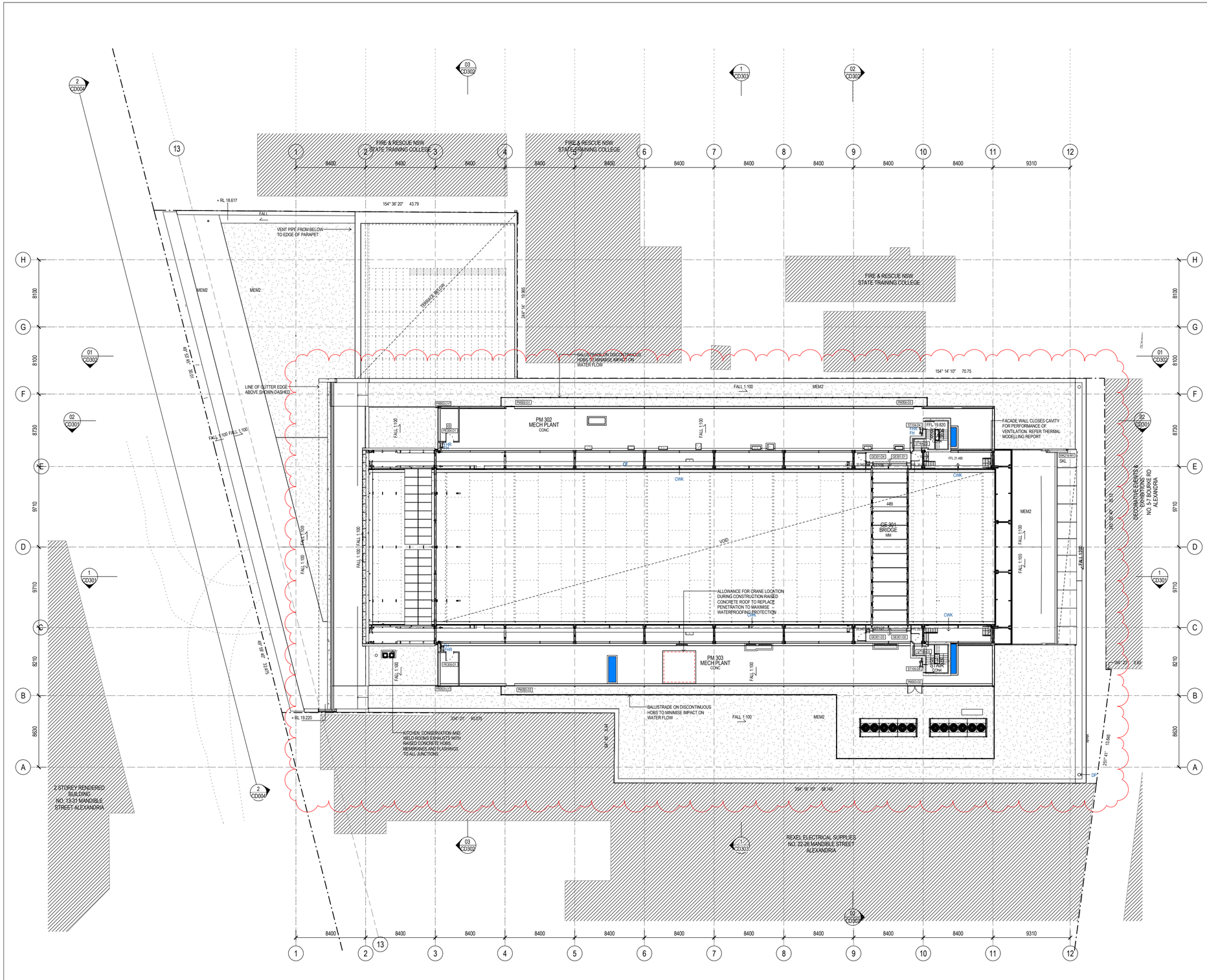
DRAWING SERIES

DRAWING NO.
CD104

DRAWING TITLE
Lower Roof Floor

REVISION
L

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REV	DESCRIPTION	CHK	APR	DATE
1	Issued for Information	JF	AA	17.08.16
A	Revised as Clouded	JF	AA	06.03.17

PROJECT PHASE

Construction Documentation

STATUS

FOR CONSTRUCTION

PROJECT NO.
AA.COM.1601

PROJECT
DANGROVE

ADDRESS
12-20 Mandible Street, Alexandria NSW 2015

CLIENT
Sections

SCALE: 1 : 200 @A1

SCALE BAR
0m 1 2 3 4 5m

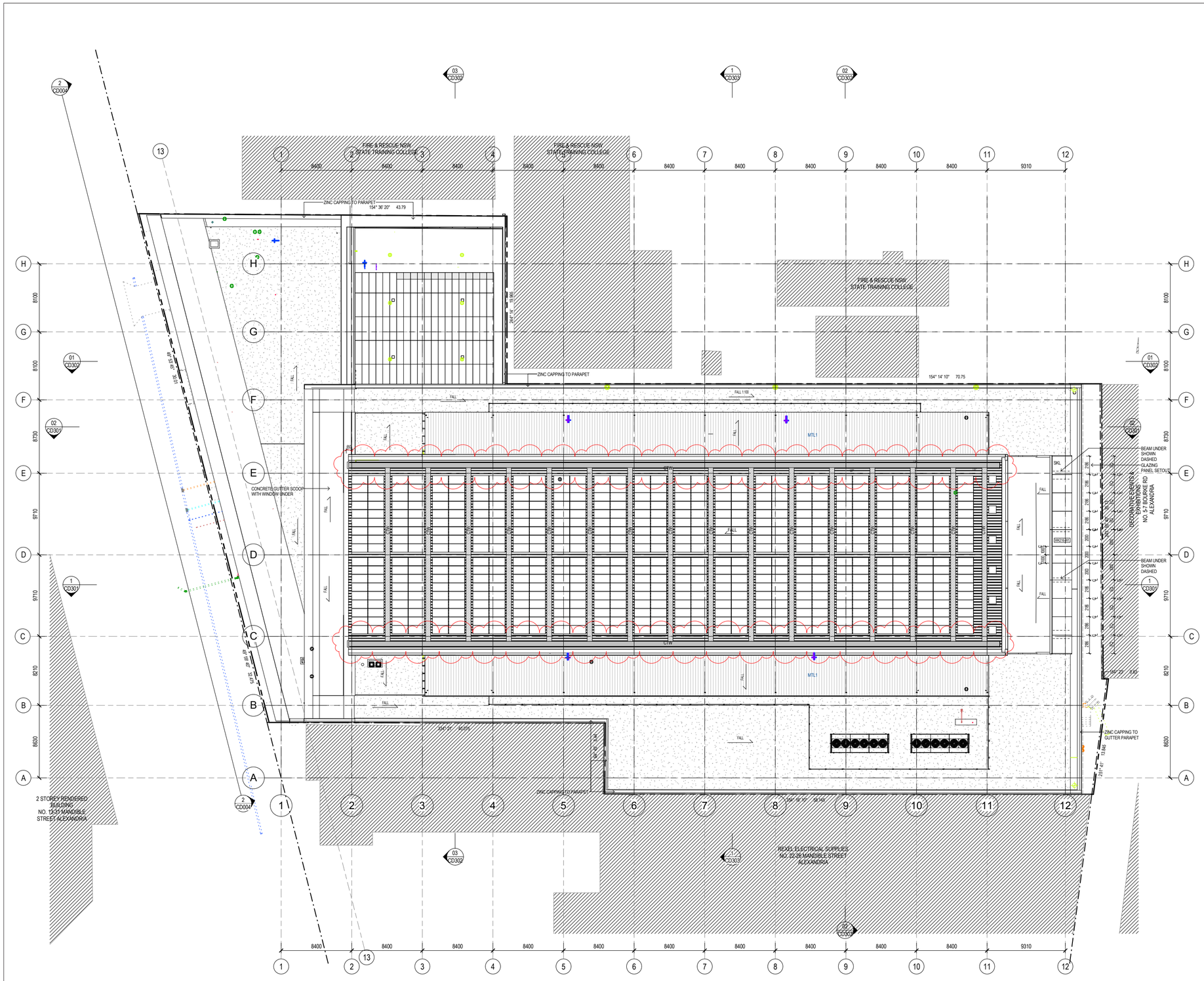
DRAWING SERIES

DRAWING NO.
CD105

DRAWING TITLE
Bridge Plan

REVISION
A

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ACN 129 731 559



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- All dimensions in millimeters unless otherwise shown.
- Use figured dimensions only.
- Do not scale from drawings.
- Check all dimensions on site prior to construction.
- To be read in conjunction with all other documents.
- Report any discrepancies to Antoniades Architects Pty Ltd.
- All boundary dimensions and bearings to be verified by licensed surveyor prior to proceeding with work.

REV	DESCRIPTION	CHK	APR	DATE
1	Issued for Information	JF	AA	20.10.16
A	Revised as Clouded	JF	AA	11.11.16
B	Revised as Clouded	JF	AA	08.12.16
C	Revised as Clouded	JF	AA	16.12.16
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G	Revised as Clouded	JF	AA	03.03.17
H	Revised as Clouded	JF	AA	24.03.17
J	Revised as Clouded	JF	AA	12.07.17

PROJECT PHASE

CONSTRUCTION DOCUMENTATION

STATUS

FOR CONSTRUCTION

PROJECT NO.
AA.COM.1601

PROJECT
DANGROVE

ADDRESS
12-20 Mandible Street, Alexandria NSW 2015

CLIENT
Infinity Construction

SCALE: 1 : 200 @A1

SCALE BAR
0m 1 2 3 4 5m

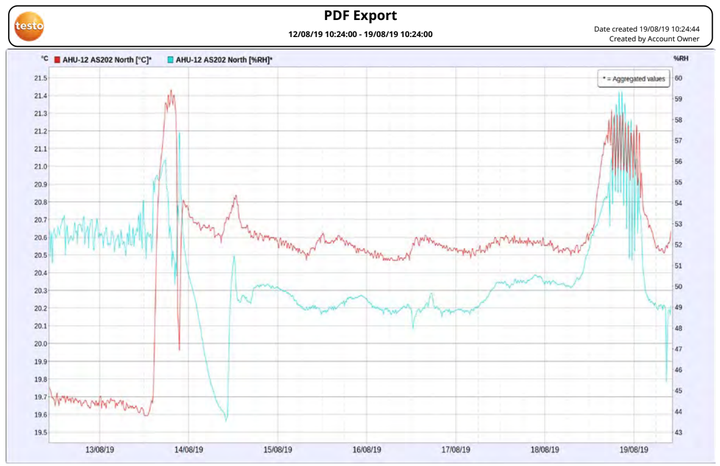
DRAWING SERIES
Plans

DRAWING NO.
CD106

DRAWING TITLE
Upper Roof Plan

REVISION
J

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The graphic is from the mechanical management system and shows spikes in both temperature and relative humidity that had to be controlled.

Communication services

A further issue arose when the mechanical management software needed to be reprogrammed and external programmers had to log on remotely.

As in most commercial IT systems, the communications paths at Dangrove are separated into different virtual private networks to ensure security is maintained at all time. This process was managed by an external IT Management company and administered from Beirut, Lebanon.

External access to the mechanical system was difficult to achieve as most requests for the opening external ports were rejected.

Infinity spent many hours unplugging and plugging network patch leads while timing calls to a time zone seven hours behind Sydney just to have simple connectivity.

This was ultimately solved by Dangrove appointing an internal IT specialist who solved all issues.

Electrical services and lighting

For the electrical services, most of the partial design provided by Steensen Varming was able to be utilised once cable routes were agreed.

The electrical design finalisation was undertaken by Simpson Kotzman on behalf of Comtex electrical as the subcontractor.

Steensen Varming was involved in the approval of all shop drawings for distribution boards, cable routes and lighting.

It was in lighting that some divergence from the briefing documents occurred. In almost the entire building, the briefing documents were found to produce the correct results for lux and light colour.

The divergence occurred in following rooms:

- Conservation: The briefing documents required a light temperature of 5000 K. The fitting type noted in the briefing document was unable to achieve this value and a substitute was used.
- Carpentry workshop: The lux level in this room was increased to 1000 lux based on input from the tradesmen who were using this room.
- Great Hall: On assessment, the wall washer lights were found to be insufficient for the intended purpose. To solve this issue the number of lights in the ceiling was doubled. This led to adjustments in the false ceiling design to accommodate these fittings.

Specialist contractors

The internal architectural solution was largely reliant on the exposed structure with bespoke interiors to create an aesthetic aligned to the building function. The interiors could not be procured in the usual manner due to the limited number of subcontractors and artisans who have the skill sets and passion to be able to deliver these elements.

Infinity collaborated closely with Tzannes in order to ensure the design intent was understood for each speciality item. Infinity then developed sketch details from the documentation provided by Tzannes which considered construction detailing, member sizes, buildability and tolerance requirements. These were then presented and reviewed again with modification made to the sketches until we reached a balance between design intent and what could be produced to satisfy our obligations under the contract.

Infinity has a broad base of artisan contractors with whom we had worked in the past. For Dangrove, the artisans were individually selected based on their skill and resource capacity to deliver the work. We then met with the selected contractors to present the Tzannes drawings and supplementary sketches that had been approved in principle to further develop the design with a focus on meeting all our obligations which comprised resourcing, timing, quality, client expectation and cost. Prior to engaging each of these specialist contractors, meetings were held with Tzannes and Aver to introduce each prospective contractor to the team to ensure everybody had the confidence in their capability and the final design of the element to be delivered.

Shop drawings were then produced with further design development integrating the necessary compliance, structural and services requirements. Partial prototypes were produced in a staged format to enable the team to physically see finishes, member sizes, connection details and the overall aesthetic. Once the team were satisfied that design intent could be achieved, full-size prototypes were produced and presented to the client for approval. Minor modifications were sometimes made prior to production.

The following contractors were involved in this process:

Metal fabricators: DJD Fabrication; Greenwich Fabrication; Ox Engineering Group; All Styled Steel; Ultimate Metal Pty Ltd; Aus Gold Leaf; Briter Door Solutions

Specialist metal joinery: L'Officina by Vincenzo

Joinery: Top Knot Projects; JCS Joinery (NSW) Pty Ltd

Stonemasons: Gitani Stone

Glazing and windows: Distinct Aluminium Solutions; GBI Contracting

Zinc cladding: Combined Roofing Services Aust P/L

Precast concrete: Evolution Precast Systems; AA West Precast Concrete

Concrete polishing: NSW Professional Floor Finishers Pty Ltd

Documenting architect

The challenge of documenting a complex project such as Dangrove is to take a design intent from an architect of the calibre of Tzannes and produce construction documentation. This process involves a large amount of detailed analysis, incorporation of many reports including BCA, NCC, acoustical, fire engineering and high performance service designs co-ordination in order to develop and deliver a full construction set of documents.

In addition to this, the incorporation of bespoke finishes adds to the challenge. The team at Antoniades Architects, led by founder Andreas Antoniades were innovative and agile in their approach to documenting this one-of-a-kind building. They were able to provide excellent design, rationalisation and co-ordination advice to ensure that the building met all statutory requirements and delivered the performance and an aesthetic demanded by the PPR and client group. Antoniades Architects worked closely with the team at Infinity to ensure that buildability and longevity was at the forefront of design detailing. They collaborated with the consultants and the subcontractor group in all phases of documentation to avoid any problematic conditions and to ensure that the delivery of the building was seamless and devoid of rework.

Lessons learnt

The key to success in delivering a bespoke custom building through a design and construct process can be achieved by firstly identifying the critical design intent components that are particular to the building. For Dangrove, these comprised the diverse structure, unique building envelope, high performance services and interior finishes. Performance of all of these elements was a major influence in form and function. A high-performance building has many facets and when the building fabric is so critical to the performance of the space and ultimately housing the services which must function flawlessly, the design solutions for the structure and fabric must be constantly cross-checked and tested.

A detailed schedule of each critical design item was produced which provided milestone dates as to when the design intent would be presented to the contractor. The dates that the corresponding design development needed to be presented and the dates for approval were achieved to meet the critical path time frames for the construction program.

The production of preliminary samples, detailed samples and prototypes, analytical testing, third party engineering review and collaboration between the parties are all part of that design development and approval process.

A team was established comprising key personnel for each design discipline, the Superintendent, and the contractors' Project Director, Senior Design and Project Managers. The individuals selected on the team were experienced in the disciplines they represented. The architects, superintendent and the contractors' representatives held senior positions within their companies and often director-level engagement from all parties. Representatives were empowered to make the required decisions and recommendations in order to maintain program. The team members were available throughout the entire duration of the project and, to ensure consistency in the design philosophy for each discipline, were not substituted during the progression of the project.

The team members understood and appreciated the role, responsibility, obligations and commercial liability that each representative had to their firm and the client. The architect's Project Director, superintendent and the construction Project Director were engaged in the project and motivated the entire project team throughout the journey. This created a very positive attitude at the work face and encouraged people to perform to the best of their ability to ultimately deliver design and construction excellence.

Overview

While there is always access to the best technical experts in the industry, the collaboration betwen like-minded, skilled people, working with an informed, engaged client that can provide a clear and concise brief of the project requirements, will ultimately lead to a successful project that can be appreciated by generations to come.

For Dangrove, the philosophy was to create a project design and delivery team that would commence the process of design and detail resolution collaboratively from the outset. All members were involved in design workshops to ensure that all elements were considered in design decisions. The team was charged with the responsibility of considering all design features in the context of their own discipline to ensure a holistic appraisal of function, cost and longevity.

The design intent led to stringent tolerances and the seamlessness of the interior, structure and services interfaces, which presented a significant challenge that required resolution by the entire project design and delivery team. The primary leaders of the team were the head client-retained architect, Alec Tzannes, and Infinity Constructions Project Director Alan Yazbek. This dual leadership role maintained the focus on the most important aspects of the design and streamlined the process, eliminating ineffectiveness of design decisions and the ultimate hindrance of the rework of design.

The uniqueness of Dangrove in the context of compliance created another challenging design aspect. Each design workshop maintained a focus on the departures and on the engineered solutions to ensure that compliance was achieved. The team undertook a series of compliance reviews throughout the design development and finalisation period and constantly monitored design deliverables to eliminate occupation delays and rework.

Overall, the success of Dangrove was largely due to the disciplined process from concept to delivery and the engagement of professionals with an acute understanding of the entire process of design and construction.

Practice profile

Infinity Constructions Group is an Australian-owned private construction company. The company operates predominantly in New South Wales and Victoria and has established offices in both states. Infinity Constructions was founded in 1992 by Alan Yazbek and has traded as a commercial construction contractor since that time. Active across all markets in the construction and civil engineering fields, it has a client base comprising developers, government agencies and building owners.

From the beginning, Infinity has focused on building quality projects in a collaborative partnering style of design and construction. Our preference is to become involved in a project at concept and work alongside the design team and key stakeholders to develop and deliver design and construction excellence. Infinity is focused on the commercial, industrial, educational and hospitality sectors and in the past, has delivered many prominent single residential projects.

Our philosophy with any project in which we are involved is to understand the client brief, form, function and overall performance of a building and to hold this at the forefront of all decisions. We prefer to partner with the client and design team in order to become part of the design and planning team to improve the buildability and value for money and ensure that the built form responds perfectly to the client's vision. This is the foundation upon which we have built our reputation.

We are focused on innovation in our projects. We embrace technological change, new construction systems and techniques and reengineering for efficiency in time and cost. We work with our construction partners to ensure each design is assessed for form and function. We target problem areas in design and resolve these in collaboration with the design team.

Infinity has an amazing team of professionals. We empower our company members to deliver excellence in every facet of their roles. We acknowledge their importance on an individual basis and how this relates to the overall performance of the company. Our service is our function. Our people are delivering this to clients every day and they are the foundation of Infinity.

Key people

Alan Yazbek, Project Director
Chris Beverley, Estimating Director
Gus Desousa, Senior Project Manager
Glenn Faulkner, Services Specialist
Jane O'Neill, Contract Administration
Peter Jan, Project Engineer
Ryan Pope, Construction Co-ordinator
George Deiri and Bakhous Elaro, Senior Site Managers
George Bowman, Site Manager
Phillip Molinari, Foreman
Alex Mandalidis, Foreman
Garry Davenport, Safety Manager
Tony Carney, Safety Officer
Catherine Vaughan, Business Systems Manager
Aukusitino Chungkwan, Florent Delabre, Matthew Yazbek, Max Swallow, Michael Kalomiros, Nicholas Channells, Peter Golledge and Shiu Ganesh, Construction Workers

THE FOLLOWING CONTRACTORS WERE ALSO INVOLVED IN THE CONSTRUCTION WORKS:

Aco Polycrete Pty Ltd; Architectural Building Elements Pty Ltd; Australian Built Urban Design; Bonn Electrics Pty Ltd; Demolition Resources Pty Ltd; Mastercut Concrete Aust Pty Ltd; Anjie Aus Pty Ltd; TLRT Investment Pty Ltd; Ultraflow Siphonics Pty Ltd; Acoustic Studio Pty Ltd; Active Air Conditioning and Refrigeration Pty; Aldex NSW Pty Ltd; Antoniades Architects Pty Ltd; Artco Waterproofing Solutions Pty Ltd; Australian Prestressing Services Pty Ltd; Australian Safety Systems; Cass Bros; Comtex Group Pty Ltd; Crown Traffic Solutions Pty Ltd; Signarama Alexandria; Artee Signs; Ecc Lighting Australia Pty Ltd; Energus Pty Ltd; Enviro-Acoustics Pty Ltd; F.B.Masonry Pty Ltd; Force Fire & Safety Pty Ltd; Frontrow Plumbing Pty Ltd; Geosurv Pty Ltd; Glenbush Constructions Pty Ltd; GMT Coatings Painting & Decorating Pty Ltd; Go Electrical Pty Ltd; Halkat Electrical Services Pty Ltd; Hillsform Contractors Pty Ltd; Hub Furniture Lighting Living Pty Ltd; Hufcor Pty Ltd; Interior Works Pty Ltd; Jomon Architectural Hardware; Kone Cranes Pty Ltd; Latham Australia Pty Ltd; Leda Security Products Pty Ltd; Loch Garman Roofing Pty Ltd; Modern Design Wardrobes Pty Ltd; Monsoon Industries Pty Ltd; Northrop Consulting Engineers; O'Hearn Consulting Pty Ltd; Otis Elevator Company Pty Ltd; Polyseal Waterproofing Technologies Pty Ltd; Pop Concrete Pty Ltd; Precision Reo Pty Ltd; Rma Constructions Pty Ltd; Rogers Seller & Myhill Pty Ltd; Rowlands Landscapes Pty Ltd; Show Technology Australia Pty Ltd; Simplex Engineering Services Pty Ltd; Southern Cross Crane Services Pty Ltd; Southwell Engineering Pty Ltd; Taylor Thomsom Whitting (NSW) Pty Ltd; Total Hoardings Pty Ltd; Turner Bros Furnishings Pty Ltd; Ultrafloor (Aust) Pty Ltd; Vitrocsa NSW Pty Ltd; Warren Smith & Partners Pty Ltd; West Sydney Ceiling Constructions & Fitout Pty Ltd; Wilken Service Pty Ltd; Winning Appliances Pty Ltd; Zeus Scaffolding Pty Ltd.

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Longevity and Permanence

Philip Oldfield

'Some of our more arrogant and careless buildings are at war with time and change – they always lose. Some buildings though, seem to flow with time, they flow with us...'

Stewart Brand[1]

All buildings, like animals or plants, have a life cycle. A select group may last hundreds of years. Others, pavilions and pop-ups perhaps, may only 'live' for a few months, their role far more ephemeral. Cities can thrive for millennia, but their constituent parts, our buildings, are in a constant state of flux, of build, adapt, refurbish and demolish. Such change can have its downsides. Unfortunately, we are seeing a spate of cultural buildings suffer far shorter life cycles than expected. The Sydney Exhibition Centre, for instance, was opened in Darling Harbour in 1988 to much acclaim, but pulled down in 2014, a life cycle of a mere 26 years. Sydney's Football Stadium lasted a few years more, opening in 1988, demolished in 2019, with a shiny new $828 million replacement built on the same site. There are many issues with cultural infrastructure like this being torn down after only a couple of decades, not least the environmental impact of replacing buildings that could have effectively continued to provide service to society for a far longer period.

Part of the challenge is our buildings often face uncertain, and even unknowable, futures. It is challenging to predict changes in economy, user needs, how materials and technologies will fare or develop over time, how the local urban fabric might evolve, and more. And how these changes might influence our occupation of, and demand for, buildings in decades to come. Such uncertainty means that life cycle rarely acts as a major driver in architectural design. Instead, architecture takes place in 'the now', meeting the needs of the current, and the immediate – rather than addressing a longer-term future. Dangrove, however, is different. Judith Neilson's aspiration for the building is for it to house the largest collection of contemporary Chinese art in the world, one which includes pieces of many different scales, media and complexities. Dangrove is the legacy of these works, designed to house them for at least 100 years. Or to be precise, until at least 2120. This is architecture then for the twenty-second century. Such a brief is relatively rare. While many buildings may go on to last a century, few start their life with such conviction. In an era of change and replacement, of restless cities, where buildings are demolished and replaced at increasing rates, what does it mean to create an architecture designed to last at least 100 years? What are the architectural, environmental, spatial and material implications of this? What can we learn from Dangrove as a case study in the present, looking to the future?

To understand the environmental benefits of longevity, we must first critique the building process itself. The creation of our built environment is incredibly linear. We build. We demolish. We build again. This process, of course, can be transformational; creating new housing, greater density, new cultural facilities, and better places and spaces for people and communities. But we must also acknowledge that to build can also be destructive, especially for the environment. Globally, buildings are responsible for 38 per cent of all energy-related CO_2 emissions, with 10 per cent of this due to construction and materials specifically[2]. Our focus on tackling this, historically, has been to improve energy efficiency, using climate responsive and passive design, and the most efficient systems available. This is vital, of course. However, carbon emissions are released not only from operating our buildings, but from manufacturing their materials, and from the construction and refurbishment processes as well – this is known as 'embodied carbon'. A steel frame, for instance, would contribute to greenhouse gas emissions through the extraction of the iron ore at

a mine, the transportation of the ore to a steelworks, the energy needed to create the steel in a blast furnace or electric arc furnace, the fabrication of the steel into a beam, the transportation and erection of that beam, and the eventual disposal or (more likely) recycling of the beam at the end of the building's useful life. Perhaps a decade ago, the consensus was that these 'embodied emissions' contributed maybe 20 per cent of a building's life cycle greenhouse gases, with the operational emissions far more significant – hence our focus on energy efficiency. We now know it's closer to 50/50 in Australia, meaning in most new buildings today, around half of the life cycle emissions will be due to materials and construction. What does this mean for sustainable design? Well, to sufficiently reduce the environmental impact of the built environment and meet our climate targets, it means a whole life cycle approach is needed, where we better consider (and reduce) both embodied carbon and operational carbon. Time and life cycle must therefore become far more significant drivers to architectural design, with greater consideration of the past and where the resources we use come from, and concern for the future to ensure what we build stands the tests of time. In this sense, a building designed to last 100 years has an advantage; while there is an upfront greenhouse gas investment in the creation of Dangrove, this is an investment in a century of service. A building with a shorter life cycle, as suffered by an increasing amount of Sydney's cultural infrastructure, would see demolition and replacement far sooner, generating waste, and the need for repeat resources and energy.

Tackling the climate crisis is not just a long-term issue, but one which takes place in the present, with an urgency for immediate emissions reductions. This is, let's not forget, a climate emergency. In this sense, the creation of a large, predominantly concrete building such as Dangrove should be critiqued. Cement, the main ingredient in concrete, is incredibly carbon intensive, due to the chemical release of CO_2 in its manufacture. Subsequently, there is a growing clamour to use less concrete in the built environment or to substitute it with lower carbon materials such as timber, or other biomaterials. In response, moves have been made to reduce the carbon intensity of concrete at Dangrove. Utilising the existing slab on ground and retaining walls on site reduced Dangrove's embodied carbon by 770 tonnes. The use of recycled steel and fly ash as a cement replacement also helped reduce the ecological footprint of the building by 22 per cent, according to the Footprint Company, who conducted life cycle carbon analysis on the design. Decarbonising the concrete is one thing, but at Dangrove a more fundamental strategy is at play. Here, concrete is used not just to create a frame. The rigour and craft that has gone into its application means exposed concrete creates structure, forms space and finish, funnels in natural light from the exterior along chamfered and sculptured soffits, and helps thermally regulate interior conditions to protect the artwork. This multifunctionality reduces the need for additional finishes and materials, which would otherwise add to the building's embodied carbon. Dangrove, then, provides a lesson that if we are to use carbon-intensive materials, such as concrete, we need to provide them not only with the certainty of longevity, meaning their carbon-intensive manufacture is not just for a short-term benefit, but also to make them work for the building in multiple ways, such as to reduce the need for other materials or systems. Beyond the material, other opportunities have been harnessed to reduce the environmental impact of Dangrove over time. The large 90-metre inclined north-facing roof provides an ideal orientation for the installation of a solar array. Five hundred and fifty-eight photovoltaic panels are estimated to generate 798 MWh per year, which is equivalent to 60 per cent of the energy demand of the HVAC systems.

While the robustness of the concrete provides durability, this alone does not equate to longevity – a catalogue of brutalist buildings demolished in recent years tells us this much. Architect Frank Duffy poses that buildings are made of 'shearing layers', each with a different lifespan. These can be defined as site, structure, skin, services, space and stuff[3]. The structure should last 100 years, perhaps even 200 years or more, if well looked after. The skin, maybe a few decades. At Dangrove, the 'stuff', the artwork, is in a constant state of movement, rotating between storage, curation and exhibition. The key to building longevity is to acknowledge these layers work to different timescales, and to ensure they don't impede each other, for example, that we don't have to demolish structure to access (and replace) services. That the spaces have the diversity or adaptability to accommodate the changing needs of the stuff (the artwork). It's clear such layering is carefully conceived at Dangrove. Services are exposed throughout, forming part of an industrial aesthetic, but also allowing access, upgrade and replacement. The double-layer polycarbonate skin to the Great Hall has a lifespan of 30 years, thus it is detailed with fixings that are easily accessible facilitating its inevitable replacement. Its double-layering provides thermal and waterproof redundancy, but also means one layer can be replaced at a time, thus ensuring protection from the elements even during renovation (across a 100-year life cycle, this will likely happen at least twice). This appreciation of life cycle at Dangrove is apparent both inside and out; the external metalwork was originally conceived as steel, but respecified as structural grade aluminium to ensure longevity and reduce maintenance.

Longevity also requires spatial flexibility, an architecture that can accommodate changing needs, and perhaps most challenging, one that can accommodate the unknown. At Dangrove, this is apparent in the diversity of artistic media that is 'stored' within. Such pieces include physical installations such as paintings and sculpture, but also dance, music and performance, which are captured on film in situ, or presented live to an audience. The spatial requirements of this go beyond what we would consider typical for art storage. The architectural response is a heavyweight ground level, accommodating a series of cellular storage spaces, bunkered down in a controlled and protected environment. Above, the architecture is more dynamic and open, culminating in the spectacular Great Hall. This soaring angular space, 90 metres in length and rising to 30 metres in height at its southern-most end, acts as a place of performance and exhibition, with the polycarbonate skin animating the walls with varying hues of diffuse natural light. This space allows for a diversity of occupation, including the testing of exhibitions before they're publicly displayed, the refinement and reorganisation of collections, and performance to a captive audience. On the lower level, the cellular storage rooms were originally conceived with load-bearing internal walls to reduce the number of columns. However, to enable future flexibility, these were replaced by non-load-bearing walls, which would enable their removal and reconfiguration in time. The scale, ambition and generosity of the Great Hall above contribute to Dangrove's longevity, allowing it to accommodate a variety of futures, both known and unknown, as does the adaptable planning below. This allows a building with an otherwise tightly defined function – an art storage facility – to spatially achieve much more. Storage at Dangrove is a dynamic process and one that has the capacity to change for decades to come.

At the most basic level, Dangrove's function is to protect its irreplaceable collection of art within. To do so requires a redundancy of systems that will cocoon this precious cargo, providing multiple layers of protection against the warming temperatures, extreme weather events, potential water ingress and fire that could occur across the next century. These are the sworn enemy of the artwork, and the highest levels of professional scrutiny and design resolution are apparent in Dangrove to combat them. For instance, each storage space within the building has its own air-handling unit, providing the ability to create finely tuned temperatures and humidity for different pieces and collections, depending on their material needs. While it is highly unlikely one of these systems will fail, over a 100-year period this must be considered a risk, and one that could have devastating consequences. In such a scenario, the exposed concrete floors, walls and ceilings provide thermal mass which can dampen any extremes of temperature and absorb excess moisture from the air, thus forming an inherent back-up system. Water ingress is the bane of all buildings, but in one with a priceless art collection, even more so. Meticulous professional attention has gone into keeping the water out. On the lower-level plan, fire escape corridors run all around the art storage spaces, providing a means of direct egress in an emergency. But they also serve to double-up as a buffer zone between the artwork and the exterior, meaning any water ingress would need to penetrate multiple layers of skin and space before even coming close to a collection.

How can we summarise the lessons learnt from Dangrove? Judith Neilson has put in place all the arrangements to ensure Dangrove lasts and creates a legacy. The architecture rises to this by providing the necessary functionality that an art storage facility requires, but going so much further by capturing the imagination of what such a building can actually be, and how it can accommodate the dynamic activities of curation, conservation, exhibition and performance. Dangrove then is an investment in the future. For the artwork, for the client, but also for the local community who will continue to walk past its linear street frontage, or visit the exhibitions it facilitates, well into the twenty-second century. However, this is not just a material investment. It is an investment of ambition, thought and practice engaged with delivering longevity and performance, from the spatial to the detail. If there's a unique quality this book, and the writings from the various actors and stakeholders at Dangrove captures, it is the level of professional scrutiny, collaboration, meticulous attention to detail and foresight needed by a large team to craft a building of this quality, and to ensure it endures for a century and more.

Professor Philip Oldfield is Head of School at UNSW Built Environment, Faculty of Arts, Design and Architecture, and the author of The Sustainable Tall Building: A Design Primer *(Taylor and Francis, 2019).*

References

1 Brand, S. (1997). *How Buildings Learn*. Episode 1, 'Flow'. BBC TV.

2 UNEP (2020). *2020 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and construction sector*, United Nations Environment program.

3 Brand, S. (1994). *How Buildings Learn: What Happens After They're Built*. Viking Press.

22

Music for, and in, the Great Hall

Damian Barbeler

In Brisbane in the ’80s, I joined St Stephen’s Cathedral choir. From the age of seven to fourteen, I sang weekly in that huge resonant building in the middle of the city. The colour, emotion, mysticism and physicality of performing music in that building is now deeply ingrained in me. It drives my composing today.

An example of how that musical upbringing influences my music today is *Piece for Accordion and Resonant Acoustic,* composed for virtuoso James Crabb and the Dangrove Great Hall. This work, though secular in intent, explores the same intense resonance, rich colourisation and sense of majesty and mystery as the great sacred master works that made such a lasting impression on me.

From the first time I walked into the Dangrove Great Hall, I wanted to compose a piece specifically for it. The idea to write for James Crabb and his accordion came about a year later. James’s is the ideal instrument. His eight octave classical button accordion is like a portable pipe organ. The capacity of that instrument to play full rich chords, mixed with the drama of this lone figure playing with such ferocity in that cavernous space, filling it with kaleidoscopic slabs of music colour, was for me an utterly inspiring compositional scenario.

Piece for Accordion and Resonant Acoustic takes for its inspiration both the physical construction of the Great Hall and the artworks stored in the rooms directly adjacent to it. I took the poetic idea of the maelstrom of complex human emotions and experiences stored on those many canvases and sculptures seeping under the doors and into the architecturally clean space, twisting and contorting James’s otherwise clean, almost geometric performance.

We can hear this poetic process in the musical structure. The opening of the work literally ‘spells out’ the rising, stepped tiers of the Great Hall’s ceiling. Entering from the lower end of the hall, we ‘see’ the series of ceiling panels, each one higher than the first, rising dramatically up and away from us. In the early stages of this work, I interviewed Alec Tzannes about his intent for this space, and he talked about wanting people to have an emotional reaction as they moved through it. This emotion is increased also by the way light works in the space. At sunset, the colours are literally funnelled into the space so that it glows with an unearthly intensity. For me, this was a secular equivalent to the stained glass windows of a cathedral. And so the music in the first section is a direct tribute to these most beautiful design principles. At the start, the piece rises up in a series of wedges; the mood is intense, but also has an austerity, with a determined sense of pulse and bold simple structure. The colours are ultra-chromatic for maximum harmonic brightness.

Soon enough things change, however. The music loses its pulse and becomes more gestural. Emotions are more ‘messy’ as the humanity of the nearby stored artworks start to seep under the doors and take over James’s performance.

The end of the work climaxes with a kind of ‘glorious madness’. In my mind this is the architecture, the paintings, the physical sound swirling around with James at the centre on the edge of coherence.

It is no coincidence that the premiere expression of this work was in the form of an art film. An audio recording alone would not quite express the full scope and intent. In part, this is because the actual acoustic and visuals of the room are so arresting. Conventional concert spaces are designed to be, in essence, neutral, in that they are not supposed to be part of the conscious experience of the music. They should enhance the listening experience so that a range of music can be played and enjoyed. In this case, the acoustics and the visual impact are not neutral. The space has a very specific character, and the seven-second reverb means one cannot just place any sounds in the room and expect them



Use the QR code to link to a video of the making of Damian Barbeler's *Piece for Accordion and Resonant Acoustic* on the Phoenix Central Park YouTube channel.

Opposite: James Crabb.

to work. A film was necessary then, so that the viewer understands that the physical room is a central character, a performer, an equal partner in a duet with James.

A film demonstrates the physicality of James's performance. Many of the musical gestures in this work were designed also with the physical movements in mind. James is a muscular performer, and it was necessary to give him strong physical movements to help him match the architectural strength of the physical space.

In this context, it is interesting to think of the space not just as a co-performer with James, but also as a co-composer. This is not the kind of work that can, or should be, composed purely at home at the composing desk. The particular characteristics of the space meant that working – composing and sketching – in the space itself with James was important. This is for two reasons.

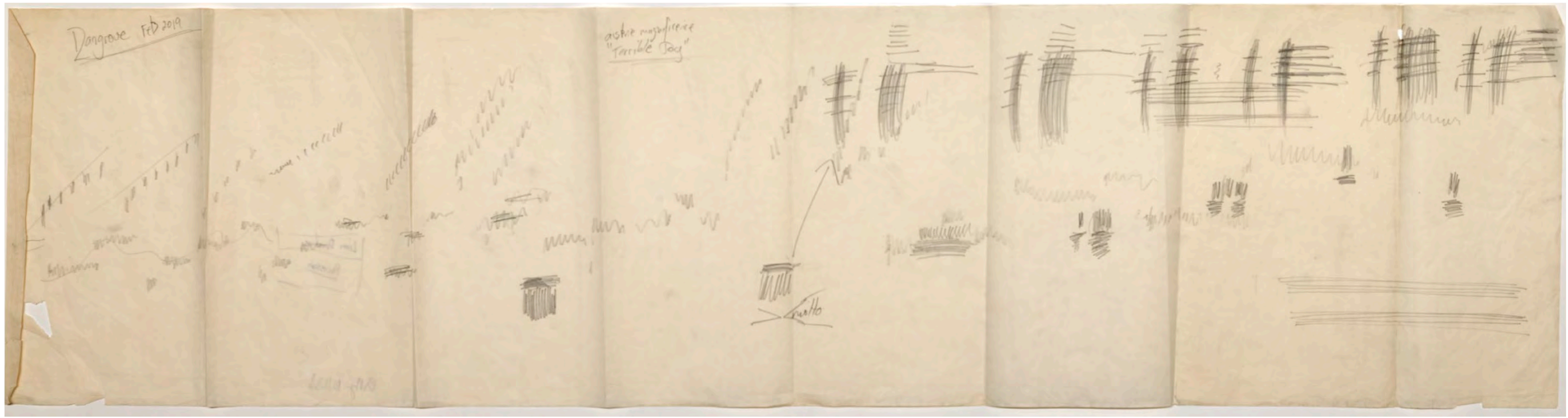
Firstly, there are many things I could have written that would not have worked. An example is intricate melody. Winding, delicate melodies can become blurred as the long reverberation effectively extends every note long after the player has finished playing it, like a piano with the sustain pedal permanently held down. And certain colours of harmony did not, for me, 'gel' with the colour, texture and feel of the place. In fact we were able to be quite specific in this respect. The notes D and E played together as a bass chord (two octaves below middle C) seemed to have the kind of heavy, grey intensity on James's instrument that rhymed with the hall. Virtually all harmonies in the piece then, in some way, are born from just these two notes.

The second reason that working in the space was important was simply imagination. The human imagination is pretty amazing, but I have found that real-life experience of a place always turns up unexpected events or characteristics. These unexpected features of a place are what intrigue me as an artist.
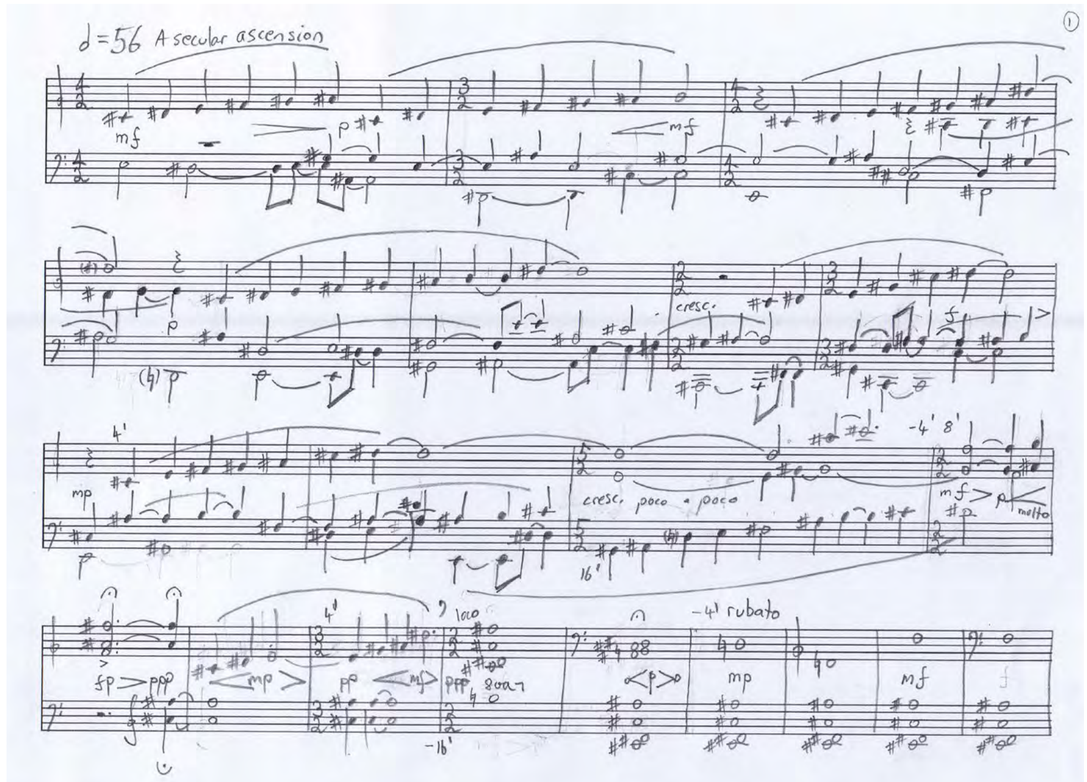
There are two examples of unexpected things I learnt in the Great Hall that excite me to this day. Firstly, extremely soft sounds easily travel through the space. In a normal concert hall, soft sounds can be lost: they lose energy quickly. In this case when James played at the very limit of his dynamic range we discovered that the sound was easily heard from long distances. James said he had never before been able to play as quietly. This opened up all sorts of new expressive possibilities in the work. The second unexpected feature was the way high, bending sounds behaved. They would lose their sense of direction. In the piece I purposely follow more dense musical moments with high notes, tuned to interact with high pitched sounds of electronic devices in the building itself (like the high whining from an air conditioner). At these moments in the footage, we see James look upwards as if the sound of his instrument is no longer coming from his lap but somehow emanating from 20 metres above. As he 'leans' on these notes and they get louder, the sense of direction returns and the piece can slingshot into new turmoil. And so we get a psycho-acoustic illusion of physical movement of sound in the space.

There is little chance I would have conceived these ideas purely intellectually at a writing desk at home. And it makes one wonder about the limits of our imagination. Certainly in the time since composing this work I have come to value more and more the role that real-life personal experience of the physical world plays in composing. After all, painters have long had the tradition of plein-air painting. Even in the age of photography, painters have lugged oils, brushes and easels into far-flung landscapes in order to capture spontaneous imagery. Composers have had less of a tradition of working in this way. But there is no reason for this. Composing for, and in, the Dangrove Great Hall then is a touchstone project for this style of practice-led creation in music. It highlights the necessity for similar practices in my recent travels into the Australian bush. There too, in those timeless outdoor spaces, personal experience can give rise to the same sacred sense of intoxicating colour and mystery, as well as visual and acoustic intrigue.

Damian Barbeler is an award-winning composer and multimedia artist, whose works have been performed and broadcast around the world.



Damian composed the initial drafts for *Piece for Accordion and Resonant Acoustic* as 'graphic sketches'. This technique of effectively improvising from one's imagination onto long sheets of paper was inspired by, and adapted from by a similar practice by architects. Rising waves of sound can be seen which imitate the physical ceiling of the Dangrove Great Hall.



The notated realisation of the graphic sketch.

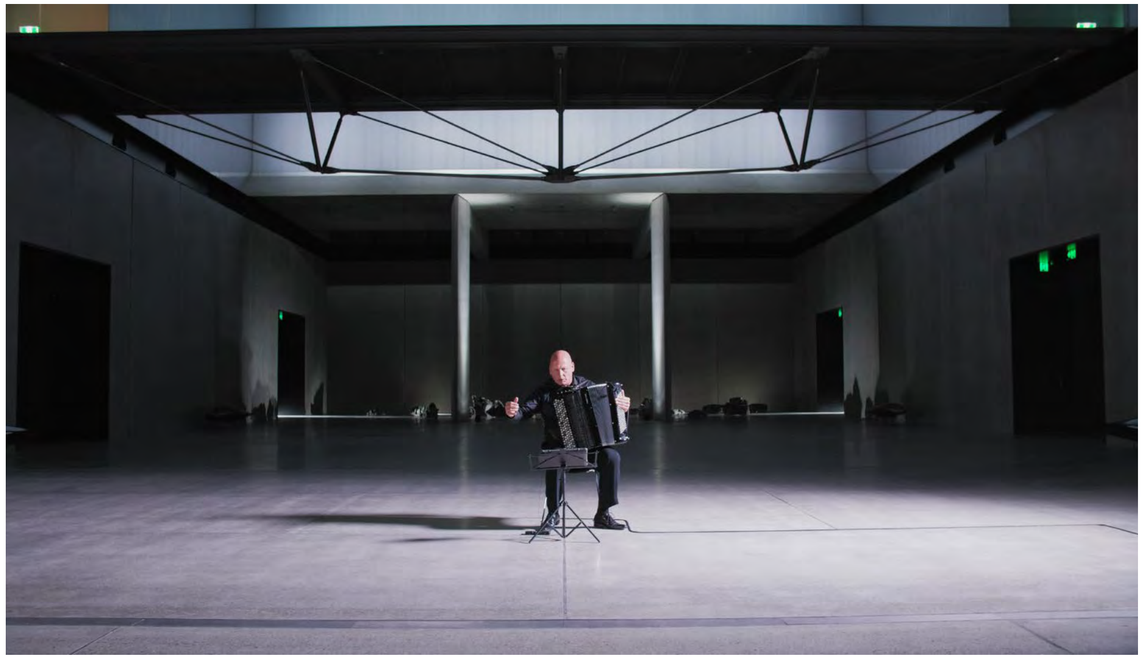




This page, top: Damian and James's early practical experiments testing the response of the Dangrove acoustic to the accordion. With a seven-second reverberation time the hall, in effect, becomes like a sound box for the accordion, a physical feature that it ordinarily lacks.

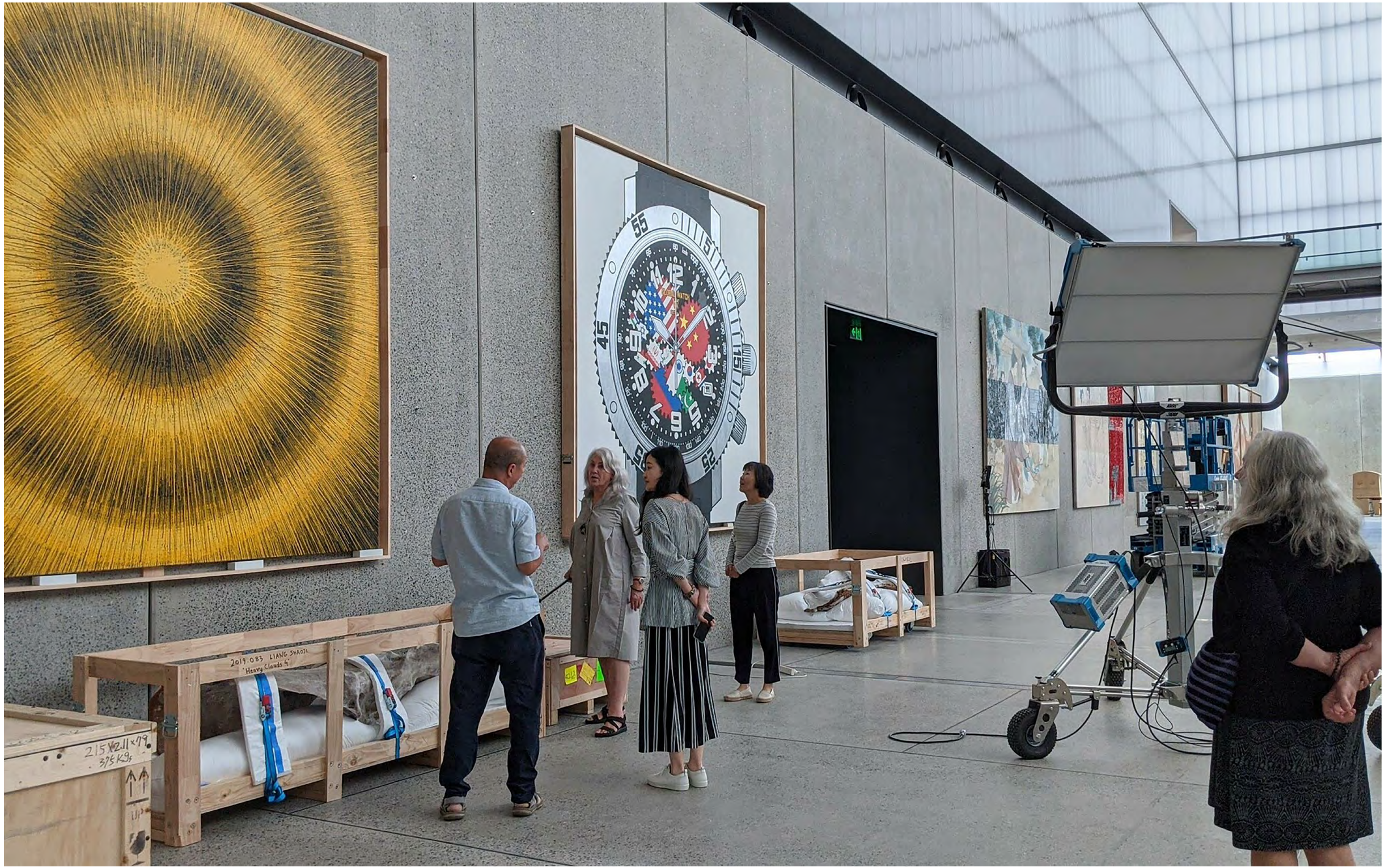
Above: Damian listens at a distance as James interprets one of the graphic sketches.



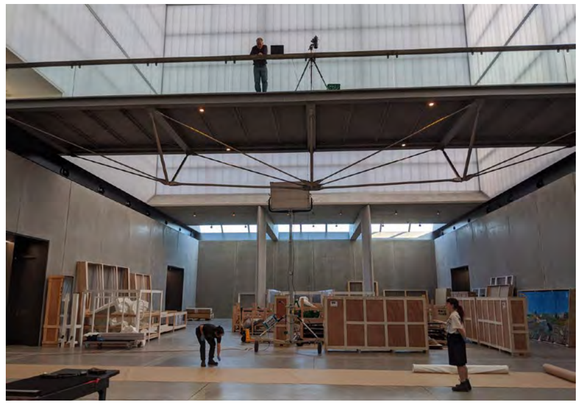


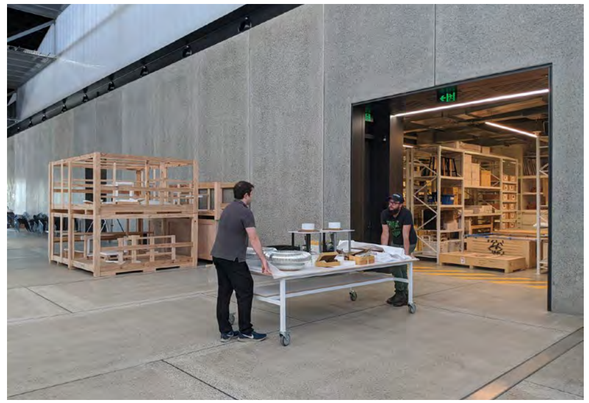
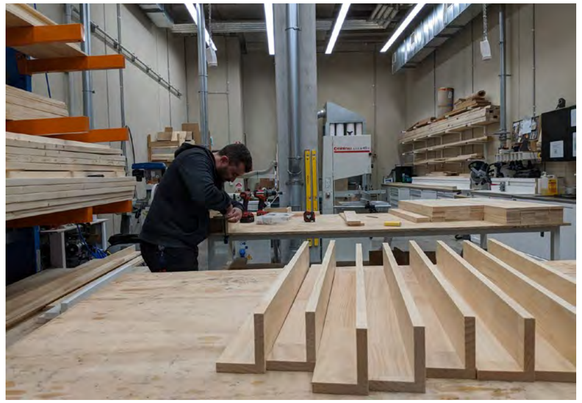
This page, top: Initial sketches for *Piece for Accordion and Resonant Acoustic* were created in situ by Damian with James essentially interpreting graphic sketches as another means of practical experimentation to see what would work in the Dangrove acoustic.

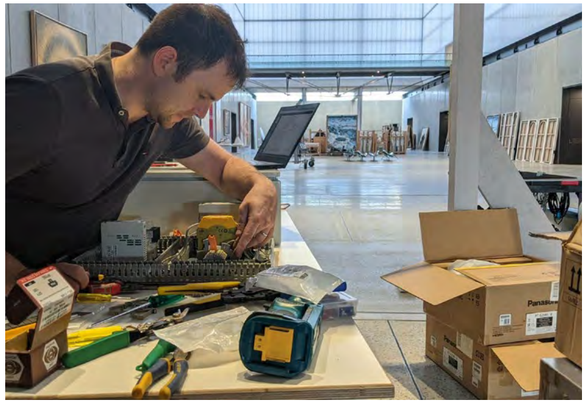
Above: Following the initial experiments, Damian went off to notate a fully realised work. James and Damian returned to Dangrove to film the final work.

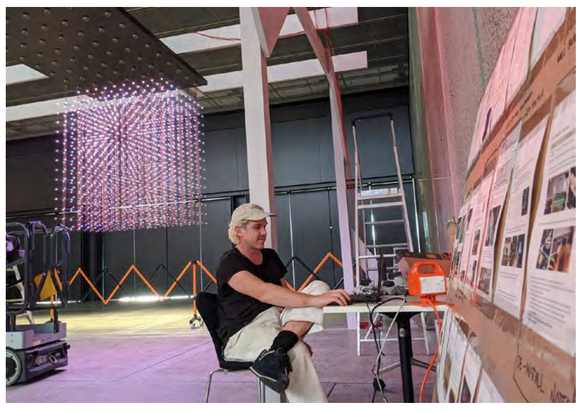
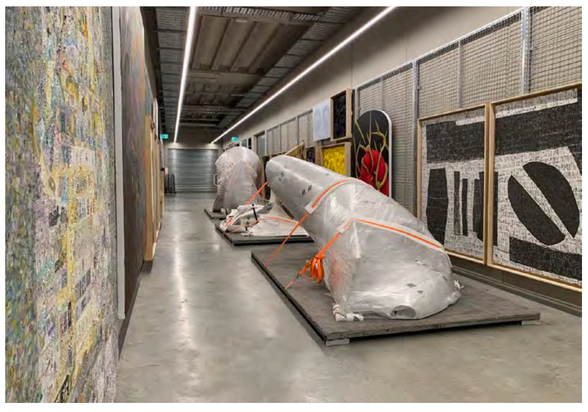

2019.083 LIANG SHAOJI
"Heavy Clouds 4"





18 TOYOTA









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EWI



Published in 2026

Judith Neilson

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