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MASTER'S THESIS

Requalification of Barangaroo Public Domain Art Exhibition

Sydney, Australia

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Family
I was distant from my family throughout my time in Italy. It is very unfortunate that the politics of the Italian consulate in Iran did not allow my sister to visit, which meant my family have not had the chance to attend my graduation. From this distance, I want to tell them I love them and that I look forward to showing them my work and the progress I have made through my studies at Politecnico di Milano.

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Executive Summary

This thesis focuses on the urban regeneration of a significant area bordering the central building district of Sydney, Australia. The NSW (New South Wales) government named the brief to this thesis the “Barangaroo Headland Park and Public Domain Request for Proposals”. This brief calls the landscape architecture, architecture and urban design professions to target key design priorities for Barangaroo’s public domain.

Barangaroo is a 22 hectare site, divided into 3 precincts. These are *Headland Park and Northern Cove*, the *Central Public Domain* and the *Southern Cove Public Domain.* The site was used over the past couple decades for occasional cultural events although due to great controversy between the unionists and corporations over the site’s use, it has of yet not been properly re-qualified from its previous designation.

The waterfront at Barangaroo has changed over the years to reflect technological trends. To the Barangaroo site, containerisation was the last step in nearly 2 centuries of maritime development in Sydney and required a morphological modification of wharves; long finger wharves became redundant giving way to large concrete aprons built for a roll on-roll off method of unloading large ships.

The wharfs had been unusually free of union activity from the beginning of World War II up until the mid 1990s. As of 2006, the controversial Patrick Corporations’ stevedoring facilities who had been occupying Barangaroo, relocated to Port Kembla. Following this, an international urban design competition was held that sought to explore urban form issues and the relationship of Barangaroo to its surroundings. The Competition was held in two stages over 2005 and 2006 and attracted 137 entries. The winning design by Hill Thalis Architecture + Urban Projects Pty Limited, Paul Berkemeier Architects and Jane Irwin Landscape Architecture, was announced and exhibited in March 2006. From this, an agenda of renewal was put forth that supported the local and global aspirations of Sydney.

The NSW government expects infrastructural growth to set the bench-mark for Australian cities, offering an exemplary next generation balance with these key ideas in mind; water positive, zero waste, carbon neutral and community wellbeing.

This thesis is the continuation of the initial March 2006 design, taking into account the government’s December 2009 feedback as principle briefing but also accounting as much as possible for the desires of local activists whose voices can be heard through the media and internet. Presenting from macro to micro-scale; first an urban strategy and master-plan for the entire Barangaroo site, second an architectural proposal for an exhibition centre, carefully blended into the central public domain of Barangaroo, and third a backing structural and technological solution in accordance with the required fields of this degree.

Chapter 1

Introduction

1.1 Geography and Facts

Australia is a country, an island and a continent. The geographic co-ordinates are between 15 and 38 degrees South and 114 and 154 degrees East. It is the sixth largest country in the world with a total land area of 7.7 million square kilometers. The Australian landmass is on the Indo-Australian plate. Surrounded by the Indian, Southern and pacific oceans, Australia is separated from Asia by the Arafura and Timor seas.

Figure 1.1 Australia on the Globe

Australia has 25,760 kilometers of coastline and claims an extensive Exclusive Economic Zone of 8,148,250 square kilometers. This Exclusive Economic Zone does not include the Australian Antarctic Territory. The land area of Australia is almost as great as that of the United States of America (excluding Alaska), about 50% greater than Europe (excluding the former USSR) and 32 times greater than the United Kingdom.

Australia is the lowest, flattest and, apart from Antarctica, the driest of the continents. Unlike Europe and North America, where some landscapes date back to around 20,000 years ago, when great ice sheets retreated, the age of landforms in Australia is general measured millions of years. This gives Australia a very distinctive physical geography.

Australia has a wide variety of landscapes. These include deserts, mountains, from alpine heaths to tropical rainforests and long beaches. The country also hosts a great variety of marsupial animals such as the koala and the kangaroo. Mount Augustus, located in Western Australia, is the world's biggest monolith. But Uluru, also called Ayers Rock, is the most popular monolith and is an icon for Australia. The Great Barrier Reef is the world's largest coral reef. It extends for over 2,000 kilometers on the north-eastern coasts of the country.

Figure 1.2 Australia superimposed on the continent of Europe

Much of the center of Australia is flat, but there are numerous ranges (e.g. Macdonnells, Musgrave) and some individual mountains of which Uluru (Ayers Rock) is probably the best known. Faulting and folding in this area took place long ago. The area was worn to a plain, and the plain was uplifted and then eroded to form the modern ranges on today's plain. In looking at Uluru, one remarkable thing is not so much how it got there, but that so much has been eroded from all around to leave it there.

Figure 1.3 Ayers Rock, Australia

The Australian landforms of today are thus seen to result from long continued processes in a unique setting, giving rise to typical Australian landscapes, which in turn provide the physical basis for the distribution and nature of biological and human activity in Australia.

1.2 Climate

Australia is a continent that experiences a variety of climates due to its size. The weather can range from below zero temperatures in the Snowy Mountains to intolerable heat in the north-west. It is considered to be one of the driest continents on earth. The temperate south has cool, wet winters and warm, dry summers. In the north, a tropical climate prevails with a warm, dry season and a hot, wet season. The extreme north-west experiences the ends of the monsoon systems, while the mountains of the south-east attract seasonal snow to form the Alpine snowfields. The temperatures vary from an average 30 degrees C in midsummer in the Red Centre, to an average of 6 degrees C in the highlands in winter. The inland deserts can remain totally dry for years whilst rains can produce floods.

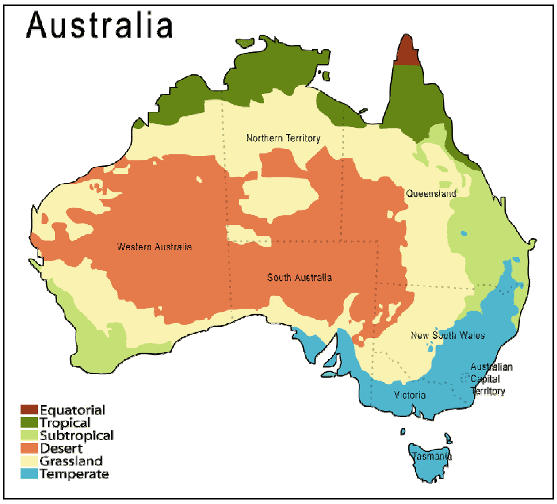

Figure 1.4 Australian Climate Map

1.3 Cultural Characteristics

1.3.1 Aboriginal Australian Culture

As one of the world's most primitive races, the Aboriginal Australian Culture is composite and diverse in nature. This culture has a long historical background that goes to some 150,000 years back when more than 500 different tribe groups or 'nations' existed in the continent.

The Latin word 'Aborigine' means 'original inhabitants'. Aborigines consist of the native Australians, who migrated from places in Asia at least 30,000 years back. The different tribes which comprise Aboriginal Australian Culture shared diverse heritage and beliefs, customs, dialects, languages, rituals, art forms, painting styles, food and hunting habits. All these together contribute towards the gradual growth and development of a diverse aboriginal culture down the ages.

Prior to the arrival of the Europeans in Australia, Aboriginal Australian Culture was highly distinct and exclusive, having several common features. Most of the tribes were partly nomadic hunters and gatherers, earning their living from the particular areas where they resided. People belonging to the Aboriginal Australian Culture established a peculiar affinity with the surrounding nature which was a part of their spiritual life. This is the secret behind their survival for millions of years.

The Aboriginal Australian Culture was basically a primitive one. The tools used by these tribes varied according to location and groups. Mainly, axe-heads, spears, knives and scrapers were some of the life-saving weapons used during this time. The language spoken by the tribal people were diverse in nature. There were about 200 to 250 Aboriginal languages that were randomly used by these tribes.


Figure 1.5 Aboriginal dance

The oral storytelling tradition of the aboriginals' speaks about the vibrant cultural life they led. The tribal songs demonstrate the Dreamtime and other tales of the land. The diagrams drawn in the sand along with their dances go together with the oral tales. Aboriginal music had a distinct identity for its most famous instrument - Didgeridoo. It is a five-foot long wind instrument made of bamboo, producing low, vibrating hum. Didgeridoos were extensively used in formal ceremonies such as circumcisions, sunsets and funerals.

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The relationship existing between the different tribes influenced important social issues like marriage decisions and individual behaviors. The tribes believed that each person has a role to play and something to contribute in all major social decisions taken.


Figure 1.6 Aborigines playing local instruments

Aboriginal Australian Culture is one of the best pre-historic and ancient cultures of the world, which was assorted and exceptional. It a tribal culture of art and storytelling, like other indigenous populations of the world. The culture established a close relationship between man and environment. May be that this culture declined with the European arrival in the continent.

1.3.2 Australian Culture

Australian culture is founded on stories of battlers, bushrangers and brave soldiers. It’s all about a fair go, the great outdoors and a healthy helping of irony. Today Australia also defines itself by its Aboriginal heritage, vibrant mix of cultures, innovative ideas and a thriving arts scene.

The Dreamtime is the sacred ‘time before time’ of the world’s creation. According to Aboriginal belief, symbolic spirit ancestors emerged from the earth and descended from the sky to awaken a dark and silent world. They created the sun, moon and stars, forged mountains, rivers, trees and waterholes and changed into human and animal forms. Spirit ancestors connect this ancient past with the present and future through every aspect of Aboriginal culture.

Australians believe in mate ship and a 'fair go' and have a strong affection for the underdog or 'battler'. These values stem from convicts and early colonialists who struggled against a harsh and unfamiliar land and often unjust authority. Australia's most famous bushranger Ned Kelly protested against the poverty and injustice of a British class system shipped here along with the convicts. This flawed hero's fight for 'justice and liberty' and 'innocent people' has been embraced as part of the national culture and inspired countless books and movies.

On the goldfields of the mid-1850s, diggers were portrayed in stories and songs as romantic heroes, larrikins and villains who embraced democracy. The bloody 1854 Eureka Stockade, where Victorian miners rose up against an authoritarian licensing system, came to symbolize a triumph of social equality. Later, during World War I, the courageous ANZAC soldiers who served in Gallipoli gave new meaning to the term 'tough Aussie'.

Figure 1.7 National Rugby League

It's no secret that Australians are sports mad. With more than 120 national and thousands of local, regional and state sporting organizations, it's estimated that six-and-a-half million people in Australia are registered sport participants. The Australians love sports and watch lot of sport - Australian Rules Football (AFL), National Rugby League (NRL), Cricket, Tennis Australian Open, Hobart Yacht Race and Formula One Grand Prix. Australia is a nation of swimmers and Olympic medals attest to their performance in the pool. The list of sports Australians love goes on.

With more than 80 per cent of Australians living within 50 km of the coast, the beach has become an integral part of Australians famous relaxed lifestyle. Australians love life on their sandy shores. Australians crowd for a spot on packed city beaches, relax at popular holiday spots and drive to secret, secluded beaches in coastal national parks. Australians go to the beach to enjoy the sun and surf or to sail, parasail, fish, snorkel, scuba dive and beach comb. It's where they socialize and play sport, relax and enjoy romance. It's also the site for celebration.

Since 1945 more than six million people from across the world have come to Australia to live. Today, more than 20 per cent of Australians are foreign born and more than 40 per cent are of mixed cultural origin. In Australia there are 226 languages - after English, the most popular are Italian, Greek, Cantonese and Arabic.

Australian rich cultural diversity is reflected in their food, which embraces most of the world's cuisines and artfully fuses quite a few of them. You'll find European flavors, the tantalizing spices of Asia, Africa and the Middle East and bush tucker from Australian backyard on offer everywhere from street stalls to five star restaurants. You can also embrace an Australian melting pot of cultures in the many colorful festivals. See samba and capoeira at Bondi's Brazilian South American festival, dance behind the dragon parade during Chinese New Year or stroll through streets transformed into a lively piazza during the annual Italian celebrations. As a nation, Australia embrace a rainbow of religious belief and you'll find Catholic and Anglican churches, Hindu, Sikh and Buddhist temples, mosques and synagogues lining their streets.

Australia's unique geography and relative isolation has made it a fertile ground for new ideas. In 1879, Australians developed a way for ice to be manufactured artificially, allowing them to export meat to Great Britain on refrigerated ships. In 1906, the surf lifesaving reel was designed so lifesavers could reach distressed swimmers with a rope attached to their vests. In 1929, Alfred Traeger built a pedal-powered radio as the communications for the Royal Flying Doctor Service.

Figure 1.8 Cultural Diversity

Australians were also responsible for more everyday inventions such as notepads (1902), aspirin (1915), the pacemaker (1926), penicillin (1940) the Hills Hoist clothesline (1946), the plastic disposable syringe (1949), the wine cask (1965), the bionic ear (1978), dual-flush toilet flush (1980)anti-counterfeiting technology for banknotes (1992) and long-wearing contact lenses (1999).

Long before European colonization, the Aboriginal people were already leading the world. They invented the aerodynamic boomerang and a type of spear thrower called the woomera. They were also the first society to use ground edges on stone cutting tools and the first to use stone tools to grind seeds, everyday tools which were developed only much later by other societies.

1.3.3 Australian Food Culture

Australian Food, the cocktail of different culture is famous for its miscellany rich cuisines. Traditionally Australian cuisines were based on British cooking from its conception. Current report on Australian food customs states: "Australians have thrown off the British yoke of pub grub and have embraced the great bounty from their own seas along with home-grown fruit and vegetables and the spices of Asia." The nostril-tweaking scents of Asian spices, the hot delight of chilies, the surprising pleasure of finger foods and dipping sauces are to be found not just in restaurants but on Australian tables everywhere.

Figure 1.9 Grilled steak

The palate-tantalizing flavors of Indonesia, Malaysia, India, and Vietnam, brought to Australia by travelers and immigrants, have found a new home and are creating a new tradition of fusion cuisine that is startlingly original, memorable and delicious.
The inhabitants of Australia are fond of both veg and non-veg foods consisting pies, roasted cuts of meat, grilled steak and chops, and other forms of meat generally accompanied by vegetables. For centuries the native Australians are using the fruits and plants growing in their local lands to

make mouth-watering delicacies like, Calamari seasoned with lemon myrtle, Lemon myrtle linguine tossed with local scallops and prawns, Native spinach fettuccine with Springs Smoked Salmon with creamy bush tomato and macadamia sauce etc.

Australian wines have long been making their presence appreciated in world markets, but more recently, visitors to the land down under are bringing back delicious accounts of bush tucker. The basic wilderness foods of the Aboriginals are gaining in popularity and sophisticated preparation. These include herbs like mountain pepper, watercress oil, and wattle seed (with a "coffee-hazelnut flavor") as well as rabbit, kangaroo, wallaby, crocodile, emu, and bunya nuts. Many fruits and vegetables unknown to most of the world await discovery. Examples of these include: greens called warrigal, lemon aspin that looks like a little pumpkin and tastes like citrus fruit, munthari berries with their apple-like taste, and tiny kakadu plums, their size belying their prodigious vitamin C content.

Figure 1.10 Authentic Bush-Tucker

1.4 Economy

Australia has recorded 17 consecutive years of economic growth since 1992 – averaging 3.3 per cent a year. It has been one of the most stable and productive periods of Australia’s modern history, and places Australia in the top class of developed countries in terms of sustained rates of growth. Australia is forecast to grow again at 2.75 per cent in 2009-10 which is above the average growth rate members of the Organization of Economic Cooperation and Development (OECD) of 2.2 per cent. Furthermore, Australia ranks first in the Asia-Pacific region for labour, agricultural and industrial productivity per person employed, according to the IMD World Competitiveness Yearbook. The 2006 OECD Economic Survey noted that living standards in Australia surpass those of all Group of Eight countries except the United States.

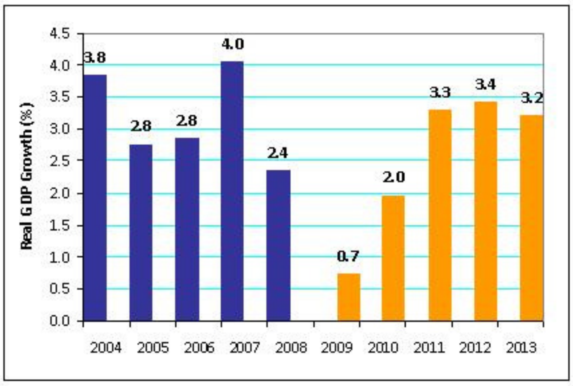


Figure 1.11 Australia’s GDP Growth (%)

Australia’s positive outlook is also sustained by its strong economic position. A sustained period of Government budget surpluses has enabled the Australian Government and many state level Governments to retire large amounts of Government debt. Net Government debt was eliminated in 2005-06 making Australia a net creditor nation. In May 2008, the Australian Government committed to a budget surplus equivalent to 1.8 per cent of GDP – some $21.7 billion. Australia’s independent central bank, the Reserve Bank of Australia (RBA), is responsible for financial policy, in particular to keep consumer price inflation between two and three percent, on average, over business cycles.

In the last century, it could be strongly argued that Australia's economic success was based on its abundant agricultural and later mineral and fuels resources. While these sectors are still important, Australia has increasingly become a knowledge-based economy. Numerous factors have contributed to this development: the pace of technological and social change; advances in transport making travel, and the exchange of ideas, easier; and broader access to higher standards of education. Information and communications technology (ICT) is a key driver of economic growth, and continuing expansion of ICT infrastructure is essential to keep pace with world standards. Australia's ICT market is worth an estimated $89 billion with 25000 companies employing 236000 IT specialists.

1.5 History of Australia

Australia's Aboriginal people were thought to have arrived here by boat from South East Asia during the last Ice Age, at least 50,000 years ago. At the time of European discovery and settlement, up to one million Aboriginal people lived across the continent as hunters and gatherers. They were scattered in 300 clans and spoke 250 languages and 700 dialects. Each clan had a spiritual connection with a specific piece of land. However, they also travelled widely to trade, find water and seasonal produce and for ritual and totemic gatherings.

Despite the diversity of their homelands - from outback deserts and tropical rainforests to snow-capped mountains – all Aboriginal people share a belief in the timeless, magical realm of the Dreamtime. According to Aboriginal myth, totemic spirit ancestors forged all aspects of life during the Dreamtime of the world's creation. These spirit ancestors continue to connect natural phenomena, as well as past, present and future through every aspect of Aboriginal culture.

A number of European explorers sailed the coast of Australia, then known as New Holland, in the 17th century. However it wasn't until 1770 that Captain James Cook chartered the east coast and claimed it for Britain. The new outpost was put to use as a penal colony and on 26 January 1788, the First Fleet of 11 ships carrying 1,500 people – half of them convicts – arrived in Sydney Harbour. Until penal transportation ended in 1868, 160,000 men and women came to Australia as convicts.

While free settlers began to flow in from the early 1790s, life for prisoners was harsh. Women were outnumbered five to one and lived under constant threat of sexual exploitation. Male re-offenders were brutally flogged and could be hung for crimes as petty as stealing. The Aboriginal people displaced by the new settlement suffered even more. The dispossession of land and illness and death from introduced diseases disrupted traditional lifestyles and practices.

By the 1820s, many soldiers, officers and emancipated convicts had turned land they received from the government into flourishing farms. News of Australia's cheap land and bountiful work was bringing more and more boatloads of adventurous migrants from Britain. Settlers or 'squatters' began to move deeper into Aboriginal territories – often

Figure 1.12 Captain James Cook

with a gun - in search of pasture and water for their stock.

In 1825, a party of soldiers and convicts settled in the territory of the Yuggera people, close to modern-day Brisbane. Perth was settled by English gentlemen in 1829, and 1835 a squatter sailed to Port Phillip Bay and chose the location for Melbourne. At the same time a private British company, proud to have no convict links, settled Adelaide in South Australia.

Gold was discovered in New South Wales and central Victoria in 1851, luring thousands of young men and some adventurous young women from the colonies. They were joined by boat loads of prospectors from China and a chaotic carnival of entertainers, publicans, illicit liquor-sellers, prostitutes and quacks from across the world. In Victoria, the British governor's attempts to impose order - a monthly license and heavy-handed troopers - led to the bloody anti-authoritarian struggle of the Eureka stockade in 1854. Despite the violence on the goldfields, the wealth from gold and wool brought immense investment to Melbourne and Sydney and by the 1880s they were stylish modern cities.

Australia's six states became a nation under a single constitution on 1 January 1901. Today Australia is home to people from more than 200 countries.

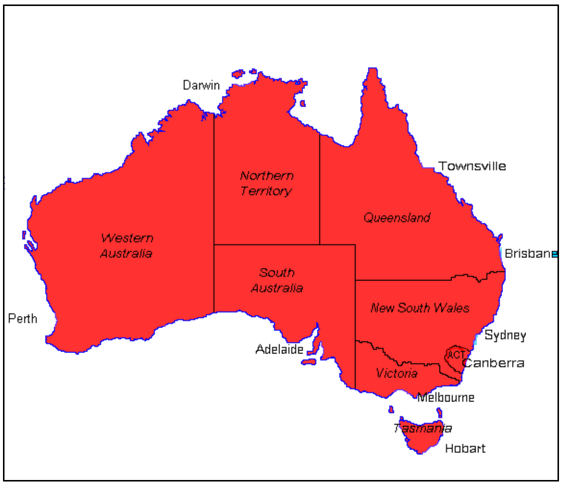


Figure 1.13 Six States of the Commonwealth of Australia

The First World War had a devastating effect on Australia. There were less than 3 million men in 1914, yet almost 400,000 of them volunteered to fight in the war. An estimated 60,000 died and tens of thousands were wounded. In reaction to the grief, the 1920s was a whirlwind of new cars and cinemas, American jazz and movies and fervour for the British Empire. When the Great Depression hit in 1929, social and economic divisions widened and many Australian financial institutions failed. Sport was the national distraction and sporting heroes such as the racehorse Phar Lap and cricketer Donald Bradman gained near-mythical status.

Figure 1.14 Great Depression hit in 1929

During the Second World War, Australian forces made a significant contribution to the Allied victory in Europe, Asia and the Pacific. The generation that fought in the war and survived came out of it with a sense of pride in Australia's capabilities.

After the war ended in 1945, hundreds of thousands of migrants from across Europe and the Middle East arrived in Australia, many finding jobs in the booming manufacturing sector. Many women took factory jobs, while the men were at war continued to work during peacetime.

Australia's economy grew throughout the 1950s with major nation-building projects such as the Snowy Mountains Hydroelectric Scheme in the mountains near Canberra. International demand grew for Australia's major exports of metals, wools, meat and wheat and suburban Australia also prospered. The rate of home ownership rose dramatically from barely 40 per cent in 1947 to more than 70 per cent by the 1960s. Like many other countries, Australia was swept up in the revolutionary atmosphere of the 1960s.Australia's new ethnic diversity, increasing independence from Britain and popular resistance to the Vietnam War all contributed to an atmosphere of political, economic and social change. In 1967, Australians voted overwhelmingly 'yes' in a national referendum to let the federal government make laws on behalf of Aboriginal Australians and include them in future censuses. The result was the culmination of a strong reform campaign by both Aboriginal and white Australians.

Figure 1.15 Formation of Australian Labor Party

In 1972, the Australian Labor Party under the idealistic leadership of lawyer Gough Whitlam was elected to power, ending the post-war domination of the Liberal and Country Party coalition. Over the next three years, his new government ended conscription, abolished university fees and introduced free universal health care. It abandoned the White Australia policy, embraced multiculturalism and introduced no-fault divorce and equal pay for women. However by 1975, inflation and scandal led to the Governor-General dismissing the government. In the subsequent general election, the Labor Party suffered a major defeat and the Liberal–National Coalition ruled until 1983.Between 1983 and 1996, the Hawke–Keating Labor governments introduced a number of economic reforms, such as deregulating the banking system and floating the Australian dollar. In 1996 a Coalition Government led by John Howard won the general election and was re-elected in 1998, 2001 and 2004. The Liberal–National Coalition Government enacted several reforms, including changes in the taxation and industrial relations systems. In 2007 the Labor Party led by Kevin Rudd was elected with an agenda to reform Australia's industrial relations system, climate change policies, and health and education sectors.

Chapter 2

Urban Design

2.1 Study and Analysis

2.1.1 Site Location

Barangaroo is located on the north western edge of the Sydney Central Business District, bounded by Sydney Harbour to the west and north; the historic precinct of Millers Point for the northern half, The Rocks and the Sydney Harbour Bridge approach to the east; and bounded to the south by a range of new development dominated by large CBD commercial tenants. It has a 1.4 km harbour foreshore frontage, with an eastern street frontage to Hickson Road.

The site has been used by commercial shipping for much of the 19th and 20th centuries but stevedoring operations have now ceased and much of the site has been cleared of buildings in preparation for its redevelopment.

The site's legal description and ownership are shown in Table 2.1 and Figure 2.5.

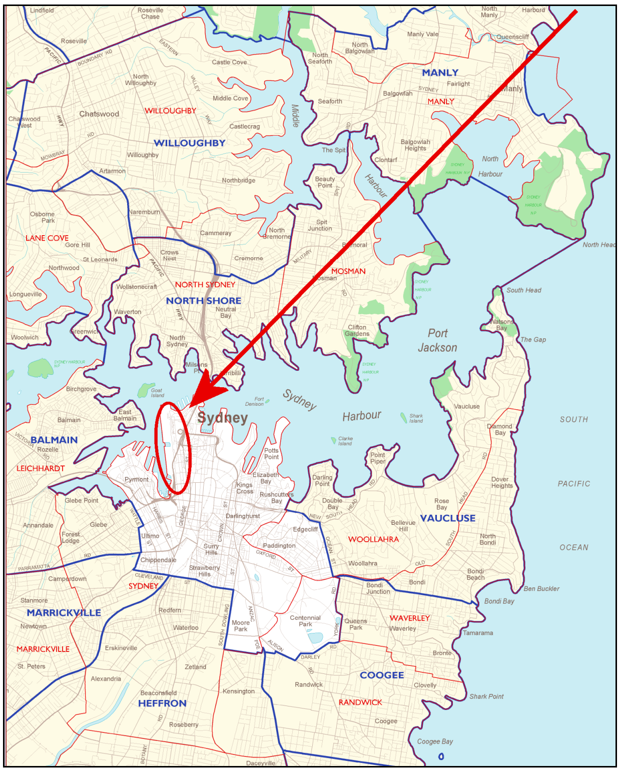


Figure 2.1 Barangaroo, Sydney

Figure 2.2 Barangaroo lengths in meters

Figure 2.3 Barangaroo Site from the West

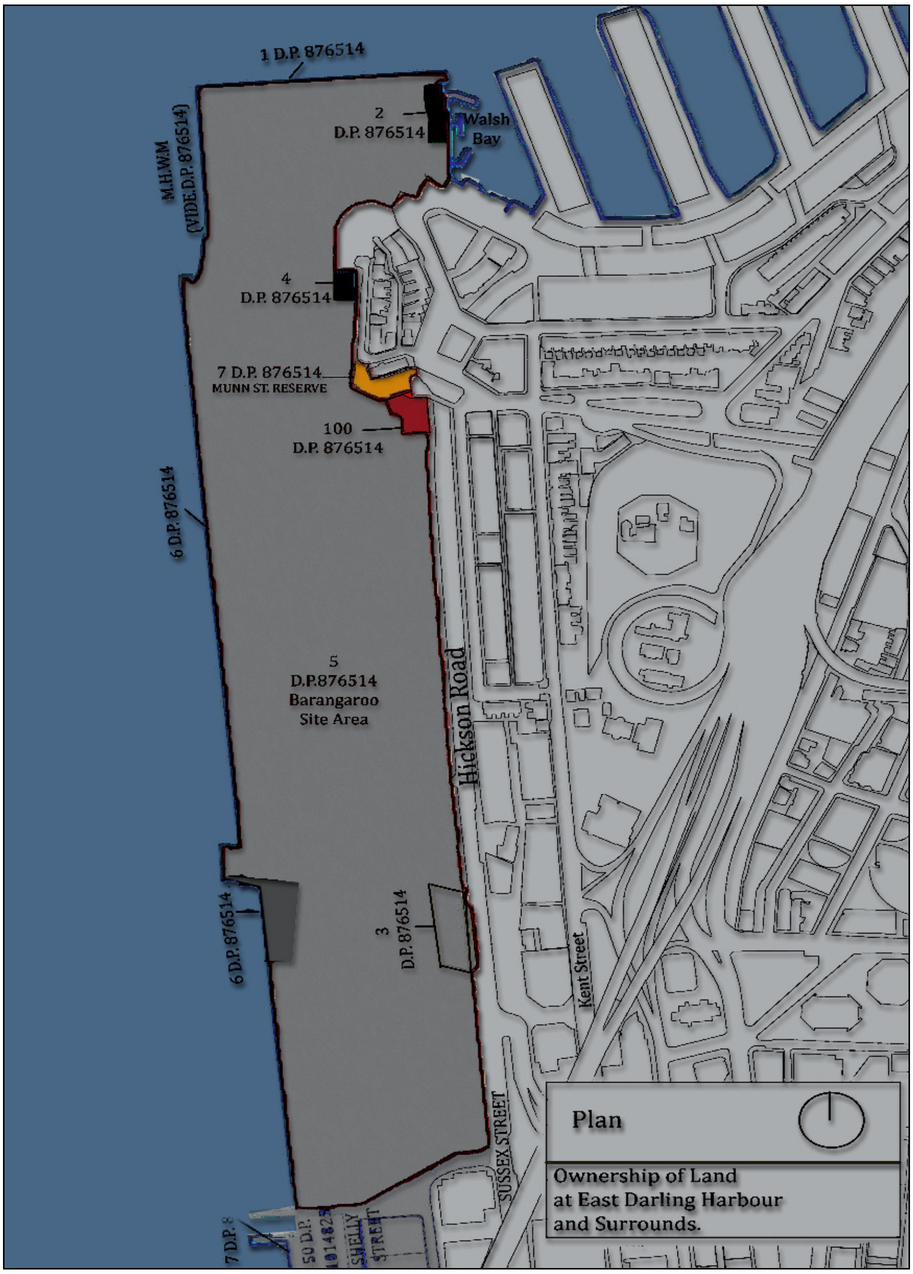


Figure 2.4 Ownership of Land at East Darling Harbour and Surrounds

Legal Description	Land Ownership
Lot 1 DP 876514	Marine Ministerial Holding Corporation
Lot 2 DP 876514	Sydney Ports Corporation
Lot 3 DP 876514	Sydney Harbour Foreshore Authority
Lot 4 DP 876514	Sydney Ports Corporation
Lot 5 DP 876514	Sydney Harbour Foreshore Authority
Lot 6 DP 876514	Marine Ministerial Holding Corporation
Lot 7 DP 43776	Crown (Gov. Gaz. 30.7.1982 Fol 3503)
Lot 100 DP 838323	The Maritime Services Board of NSW
Lot 7 DP 869022	The State of New South Wales
Lot 6 DP 869022	Marine Ministerial Holding Corporation

Table 2.1 Legal Descriptions and Ownership

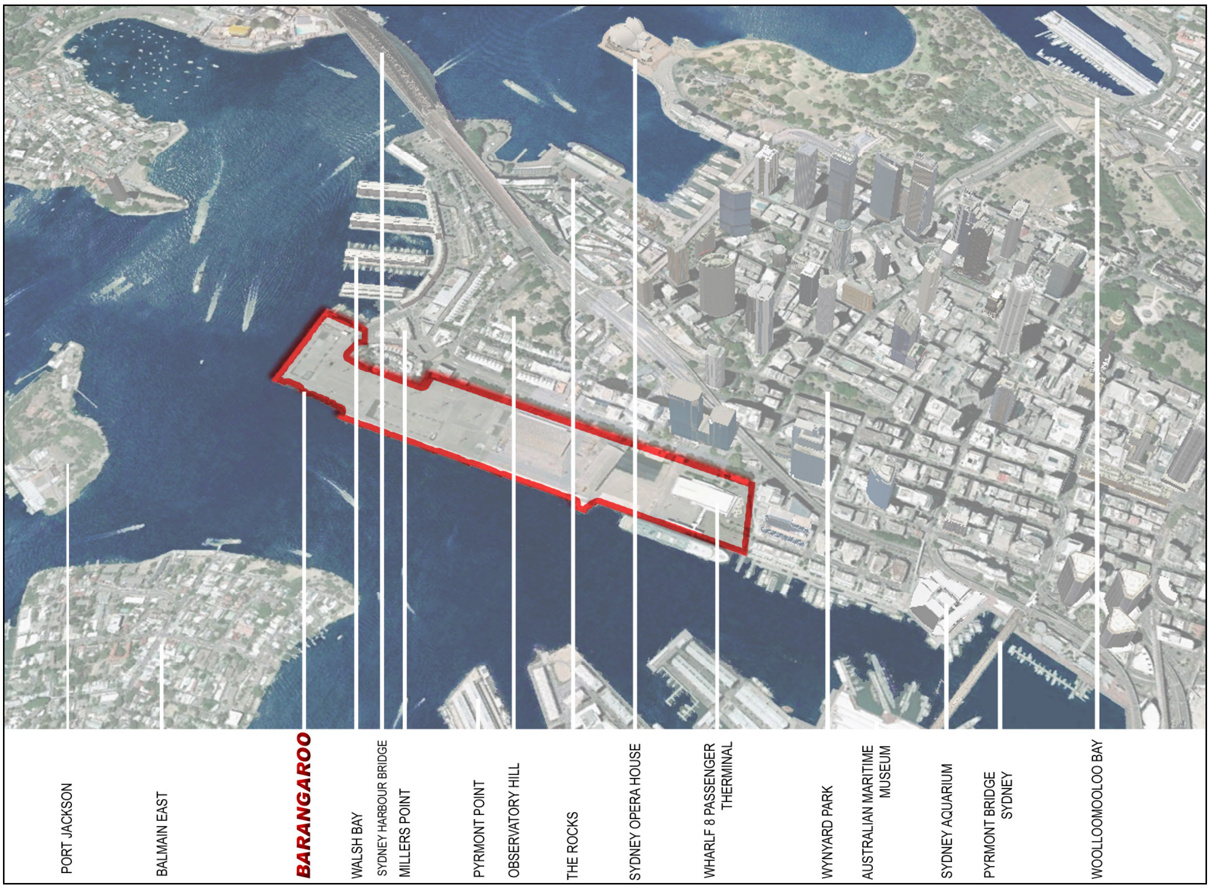


Figure 2.5 Barangaroo’s boundary and local important sites

2.1.2 History of the site

Before we proceed to speak of the history of Barangaroo, it would be remiss of us not to give a visual profile on how Sydney has been shaped throughout history. The site of the first British colony in Australia, Sydney was established in 1788 at Sydney Cove by Arthur Phillip, commodore of the First Fleet as a penal colony. The city is built on hills surrounding Port Jackson which is commonly known as Sydney Harbour, By the middle of the 19th century, 'Sydney' extended to the municipalities of Glebe, Randwick, Waverley, Woollahra, and Marrickville, Newtown, Paddington and Balmain and had a population of 100,000, which was still only approximately a quarter of the State population. These suburbs were linked to the city centre by the emerging tram network.

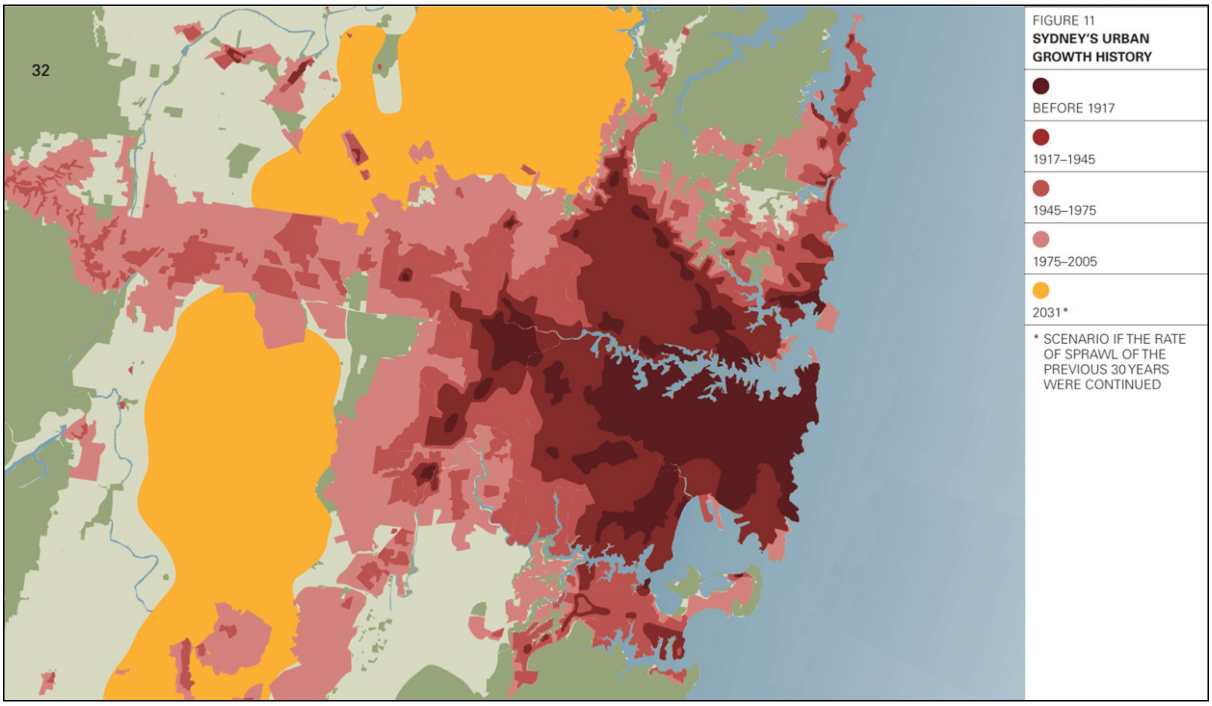


Figure 2.6 Sydney's Urban Growth History

Until, the 1950s, the pattern of the city continued to be dominated by access to the rail and tram network. Old industrial sites have been converted to residential development. The city has continued expanding westwards, with areas between the corridors filling in. With the addition of the North West and South West growth centers, new sub-regions in Western Sydney are emerging.

Over the last 15 to 20 years, Sydney is described as local concentration of linked jobs and gateway infrastructure from Macquarie Park through Chatswood, St Leonards, North Sydney and the CBD to Sydney Airport and Port Botany- has emerged as a critical feature of Sydney and Australia's economy, where the iconic Sydney Opera House and the Harbour Bridge are featured prominently.

Figure 2.7 Sydney Opera House

The Sydney CBD is bounded on the east side by a chain of parkland, and the west by Darling Harbour, a tourist and nightlife precinct. The most significant outer business districts are Parramatta in the central-west, Penrith in the west, Bondi Junction in the east, Liverpool in the southwest, Chatswood to the north, and Hurstville to the south. The extensive area covered by urban Sydney is formally divided into 649 suburbs and administered as 40 local government areas. Sydney has various heritage listed buildings, including Sydney Town Hall, The Queen Victoria Building, Parliament House, and the Australian Museum. There is no architecture style that entirely characterizes the whole of Sydney.

Prominent styles include Gothic Revival, Georgian, Classical, Romanesque, Italianate, Federation, Edwardian, Second Empire, Queen Anne, as well as more contemporary styles.

The summers are hot with high relative humidity and the winters are mild. Sydney has over 340 days of sunshine each year. This creates a perfect atmosphere for outdoor living. If we talk on the open space history; many parks in central downtown have strong ties with local residents.

Three of the biggest parks in this area were all used by the original settlers in the early 1800's. Several parks in Sydney are known for their plant collections. The Royal Botanic Gardens in particular is a prime example. Today there are 248 parks, reserves and open spaces located within the City of Sydney covering 934 acres, roughly 14 % of Sydney's land coverage.

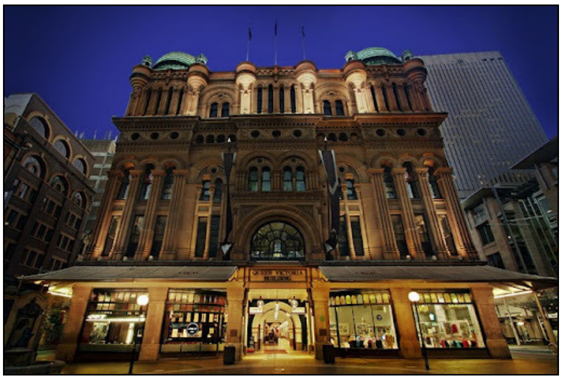


Figure 2.8 Queen Victoria Building

Barangaroo (formerly, East Darling Harbour) has seen dramatic change and growth throughout its history. Historically, the site was an economic trade base for the early colony, and with changes in technology and the formation of important business synergies, it evolved into an important nodal point for the city of Sydney. The area was not only connected to the local community through its relationship to worker housing, merchant housing and places of gathering, but was also connected to Sydney at large, to other cities, and to the international stage through the interchange of goods and the maritime industry.

Millers Point did not develop as quickly as Sydney Cove and The Rocks. The steep terrain and lack of easy land access kept the area fairly quiet and undisturbed for the first few decades of European occupation. Indigenous people used the land around Barangaroo both before and after European occupation.

By the 1820s Millers Point had started to develop. Windmills would have been present, buildings scattered, tracks established, cattle and sheep grazing, convicts working and sailing vessels in the Harbour. Images from the period show undulating topography and sandstone ridges before the modification; quarrying began in the area in the early 1820s, eventually changing the landscape dramatically.

Industry in the early 19th century including whaling and sealing, combined with the rise of the wool industry, created a demand for wharves and docks. In the early decades Millers Point was mainly used as moorage for the unloading of cargoes in Sydney Cove and the newly named Darling Harbour Industry, including the establishment of Dickson's Steam Engine in 1813, followed by Barkers Steam Mill in 1827 stimulated the building of waterfront activities. Urban form was slowly establishing, with the formation of some early streets, e.g. Windmill Street. There was still no direct route to Millers Point from Sydney Cove.

Gas works constructed by 1843 further stimulated wharf construction as coal was supplied to produce gas. The unloading of goods and the building of wharves created the need for a local workforce and hence the provision for worker housing. Grand homes were also built in the more salubrious positions around The Rocks and Millers Point quite often on the higher ridges taking advantage of the views. Recreation facilities were also built just south of the site in the 1830s. Millers Point further developed as a village with the establishment of the areas two most famous pubs, the Lord Nelson Hotel and the Hero of Waterloo. The pubs were important as a local gathering place and a source of accommodation for immigrants to the country.

It was during this period that the landform started to change more dramatically with the reclamation of land and the cutting of land. Sandstone was used in construction, which came from the local quarries, and the Argyle Cut which was commenced in 1843. The cutting down of Millers Point for building lots, maritime facilities and roads continued well into the 20th Century.

The waterfront at what is now known as Barangaroo has changed over the years to reflect the changes in technology. Windmills were built for power provision in the area. The early whaling ships whose products provided power for lighting gave way to gas lighting, and the gas works were built in the 1840s, remaining on site until the 1920s. Sail gave way to steam, and ships became much larger, requiring larger wharves to service them. Manpower and horsepower began to be supplemented with hydraulic power from the 1870s, increasing the weight and height of loads to be lifted. Eventually gas lighting and hydraulic power was replaced by electric power and machinery such as forklifts, and diesel-powered ships replaced steamships.

Containerization was the last step in this process and required the modification of the wharves yet again. In response to this, long finger wharves became redundant and large concrete aprons built for roll on, roll off, method of unloading large ships. With the relocation of Patrick Corporations’ stevedoring facilities to Port Kemble completed and the proposal to redevelop Barangaroo announced, the next stage for the city’s biggest urban renewal project is in progress.

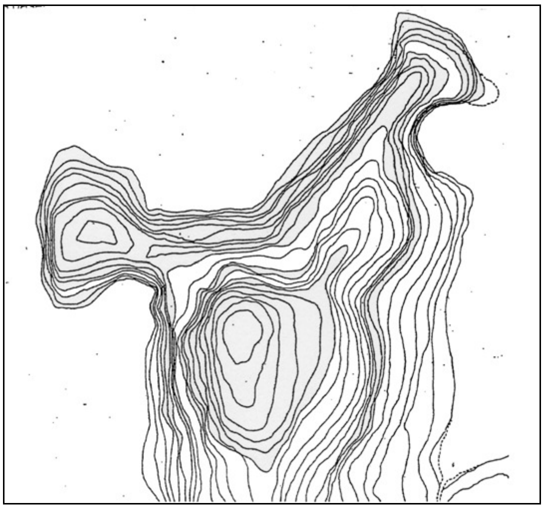


Figure 2.9 Natural Topography before European settlement - 1788.

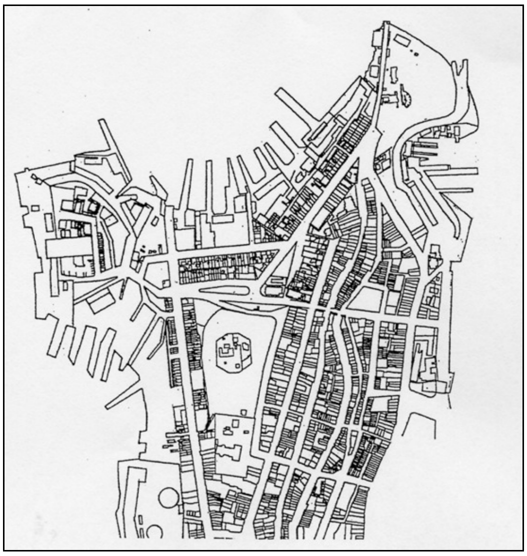


Figure 2.12 Based on Harvey Shore, City of Sydney, Harbour Maps, 1906

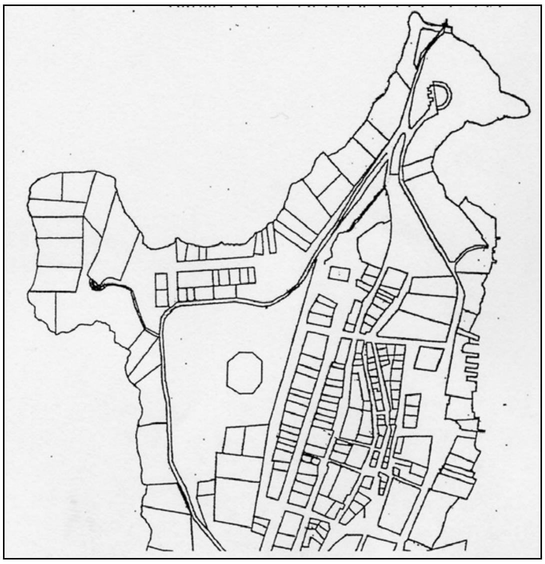


Figure 2.10 Based on 'parish of St. Philip' surveyor general's office Sydney, March 27th 1835.

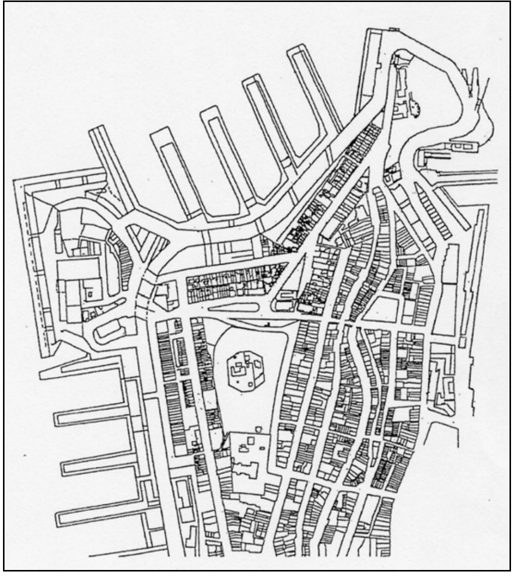


Figure 2.13 Based on Harvey shore, from the quay map, 1926.

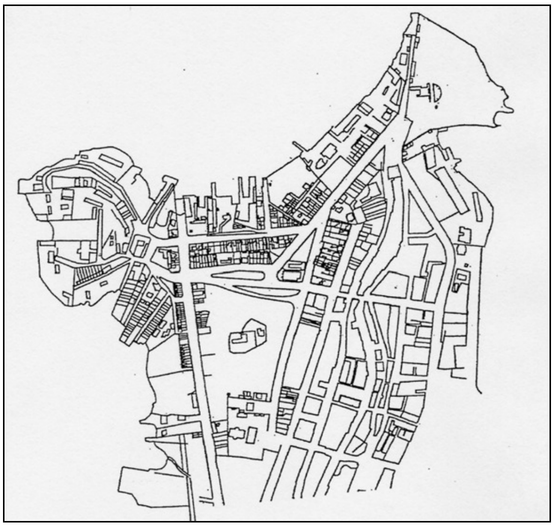


Figure 2.11 Based on Woolcott and Clarkes Map of the City Of Sydney 1854

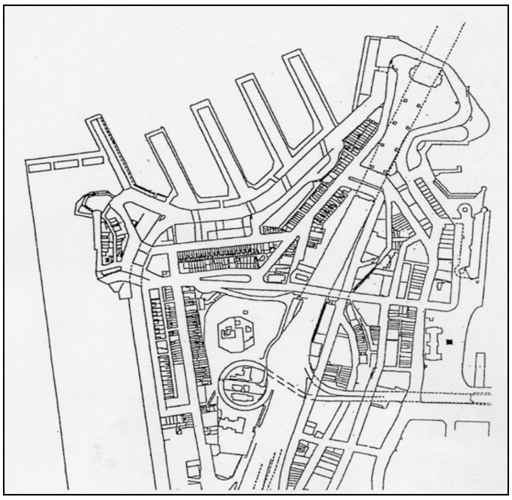


Figure 2.14 Based On City Planning and Building Department, City of Sydney 2000

In July 2006, Cabinet transferred land ownership and appointed the Sydney Harbour Foreshore Authority as manager for the redevelopment of Barangaroo. The Barangaroo Name Between July to November 2006, a NSW Government Statewide naming competition received over 1,600 entries. The winning name "Barangaroo" was announced to honor a determined and independent Wangal woman who played an important role in the early days of colonial Sydney. Barangaroo was also the wife of Bennelong, after whom Bennelong Point – the site of the Sydney Opera House – is named. The name therefore completes an historical bookending between the eastern and western points of Sydney's CBD. The name Barangaroo was published in 2007.

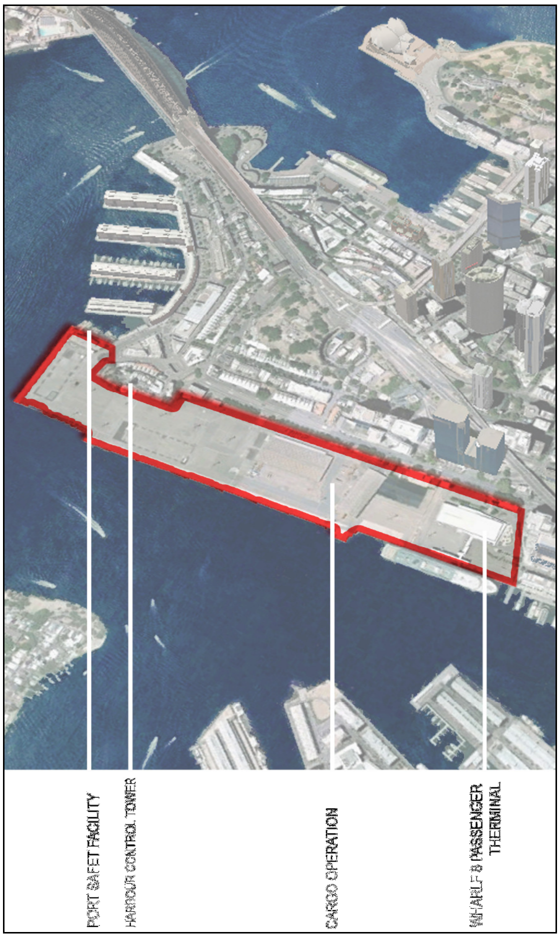


Figure 2.15 Previous existing site functions

2.1.3 Buildings and points of importance

Barangaroo is a 22-hectare site located on the foreshore of Sydney Harbour, adjacent to the city's central business district.

Moore's Wharf on Walsh Bay at Millers Point was established in the 1830 by Henry Moore, the first Australian P&O agent. The sandstone warehouse built by William Long using convict labour and stone quarried on site. Moore bought the wharf and accompanying building from Long in 1837. The warehouse was originally located further west but in 1978 was moved, stone by stone, to its present location when it became the Operational Headquarters of the Sydney Ports Corporation. The vessels moored at Moore's Wharf are used by Sydney Ports Corporation on Sydney Harbour.

Built in 1858, Sydney Observatory is Australia's oldest observatory and one of the most significant sites in the nation's scientific history Observatory Hill Park is a popular attraction for locals, workers and tourists boasting one of the City's best terrestrial vantage points for unobstructed panoramic views of Sydney Harbour and the Harbour Bridge.

The Agar Steps provide pedestrian access from Kent Street and a cutting through the Harbour Bridge pylons provides pedestrian and cycle access from Cumberland Street. However no parking is available within Observatory Hill Park. The park contains numerous works of public art and a wooden rotunda flanked by magnificent mature Port Jackson Figs.

Figure 2.16 Buildings and points of importance.

Millers Point is an urban locality within Sydney's city centre, in the state of New South Wales, Australia. Millers Point is located on the north-western edge of the Sydney central business district, adjacent to The Rocks and is part of the local government area of the City of Sydney. A small mill that was owned by Jack Leighton was located here. The area became known as Jack, the Miller's Point. Millers Point is the oldest existing place of Catholic worship in Australia. Two separate pubs in the area claim to be Sydney's oldest surviving pubs, the Lord Nelson here at Millers Point and the Fortune of War nearby at The Rocks. Where it is called as ‘Windmill st.’ in the 1820s windmills were built out on what was to become known as Millers Point and European settlers started constructing houses and building a small village. In 1859 a direct route from the Rocks to Millers Point was created, The Argyle Cut. This made the journey back and forth from the main colony much safer and quicker. The route was a major catalyst for development in east Darling Harbor and Millers Point.

At the end of the 19th century, without a seawall, the Walsh Bay foreshore was awash with rubbish and infested with rats. A major disaster changed everything in 1900 when Arthur Payne, a van driver, became the first person to contract the Bubonic Plague, which arrived in Sydney in January. The rats were brought under control and by August the outbreak was over. In October that year The Sydney Harbour Trust was established to rebuild the port of Sydney.

Wharves were renewed and whole streets disappeared as the cliffs were cut down to form Hickson Road. New double-decked finger wharves were built with a series of bridges, which connected the upper levels to the high roads of Millers Point. In 1919, the wharves between Dawes point and Millers point were named Walsh Bay after the Trust’s Engineer in

Chief, H.D.Walsh. By the early seventies the wharves fell into a period of disuse. It languished for a time until in 1982 Pier One was turned into a shopping and amusement complex. But the real transformation started when the Sydney Theatre Company and the restaurant took over wharves 4 and 5. Today, Walsh Bay is Sydney's cultural hub.

Clyne Reserve is between Merriman Street and Dalgety Terrace, Millers Point. In the 1830s the prime residences in Millers Point were clustered around this area. At the end of Merriman Street, Crown Road (later Dibbs Street) ran west to 'Spencer Lodge', the most famous of the area's houses. 'Spencer Lodge' was a twelve-room colonial townhouse with a garden complete with 'lawns, rosaries and plantations of flowering shrubs'.

Soon after the purchase of Long's Wharf in 1837, Henry Moore built 'Moorecliff'.The separate eye hospital was created at 'Moorecliff'. A children's playground was established on 13 June 1950 at the corner of Dibbs Street and Merriman Street on a site leased from the Maritime Services Board. In 1952 the playground was named Clyne Reserve in honour of Hon Daniel Clyne MLA. In 1978 the Maritime Services Board acquired the Clyne Reserve land for excavation and building works to redevelop Darling Harbour as a container port, which was completed in April 1981.

The Board then landscaped the remaining area and handed it back to the Council in September 1981. Four teams of stonemasons worked for six months to construct 420 meters of stone walls around Clyne Reserve. The adjacent Port Operations and Communications Centre tower opened on 12 August 1974.The Port Operations and Communications Centre tower has joined the harbor bridge as a distinct landmark on the harbour foreshore.

King Street Wharf covering approximately five hectares is a former maritime industrial area on the eastern shore of Darling Harbour, an inlet of Sydney Harbour, Australia that has been redeveloped into mixed use tourism, commercial, residential and maritime development as part of the extensive redevelopment in the general area. It is adjacent to the Darling Harbour tourist precinct, and on the western edge of Sydney's central business district.

The residential towers occupy the area bounded by King Street to the South, Shelley Street to the East, Erskine Street to the North and Lime Street to the West. The commercial waterfront is between Lime Street and Darling Harbour, and extends slightly north of the end of Erskine Street. This retail area contains 11 restaurants, the largest of which seats 450 including its outdoor areas. In the south to King Street Wharf, by the mid-1970s Darling Harbour was a series of empty warehouses and rarely used train tracks. Darling Harbour stretches from Paddy's Markets and Sydney Entertainment Centre. Home to the Australian National Maritime Museum, Sydney

Aquarium, IMAX Theatre, Sydney Wildlife World and Powerhouse Museum, it offers some of the finest museums and attractions in Australia.

Wynyard is a major underground City Rail station in the central business district of Sydney, Australia, 2.05 km from Central. The station opened on 28 February 1932. The length from the northwest part of Barangaroo site to Wynyard train station is approximately 1.7km, from the south part is 500m. The passenger concourse is on an intermediate level between the upper and lower platforms.

Wynyard is connected via underground passageways to several surrounding buildings and shopping arcades and is located immediately below Wynyard Park. Direct access via tunnels is possible to George Street, Hunter Street, Pitt Street, Clarence Street and Kent Street. Escalators connect the station concourse with York Street (emerging underneath Transport House) and Carrington Street (under Wynyard Park).

2.1.4 Land use

Figure 2.17 Existing green areas of Sydney

Land-use change detection is one of the basic pillars of global change towards sustainability. Landscape sustainability requires an understanding of the evolution and usage of land and the nature and extent of land resources. Analysis of historical and current land-use helps to determine potential future challenges for policy, planning and governance in pursuing more sustainable land uses.

The Sydney central business district is the main commercial center of Sydney, New South Wales, Australia. It extends southwards for about 3 kilometers from Sydney Cove, the point of first European settlement.

Its north–south axis runs from Circular Quay in the north to Central railway station in the south. Its east–west axis runs from a chain of parkland that includes Hyde Park, The Domain, Royal Botanic Gardens and Farm Cove on Sydney Harbour in the east; to Darling Harbour and the Western Distributor in the west. It is the largest and busiest central business district in Australia.

Darling Harbour is a large recreational and pedestrian precinct that is situated on western outskirts of the Sydney central business district. The locality extends northwards from Chinatown, along both sides of Cockle Bay (part of Barangaroo) to King street Wharf on the east, and to the suburb of Pyrmont on the west.

King Street Wharf covering approximately five hectares is a former maritime industrial area on the eastern shore of Darling Harbour, which has been redeveloped into mixed use tourism, commercial, residential and maritime development as part of the extensive redevelopment in the general area.

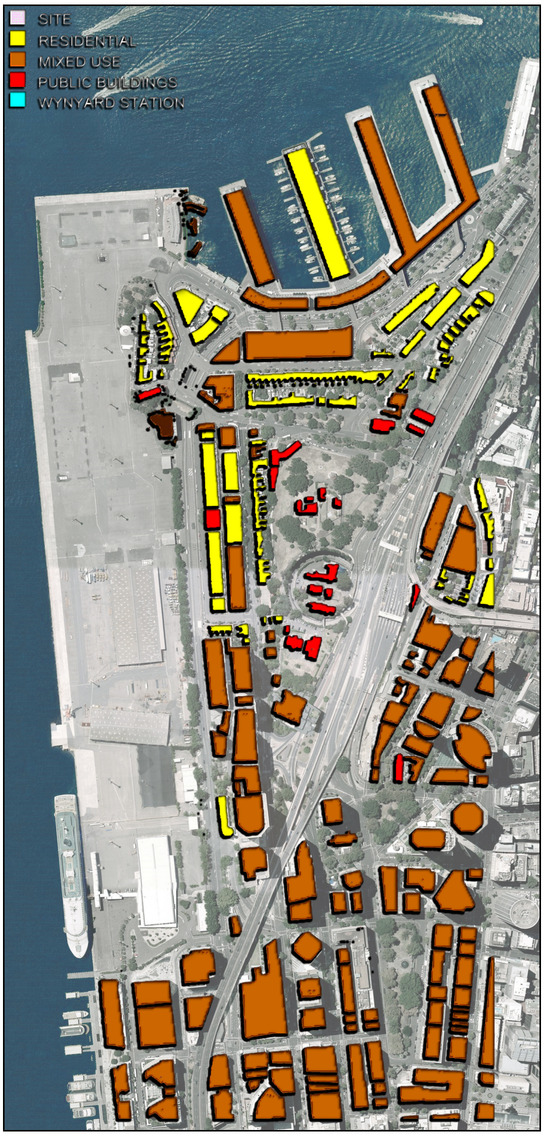


Figure 2.18 Land Use Map, Barangaroo

Circular Quay is made up of walkways, pedestrian malls, parks and restaurants. It hosts a number of ferry quays and a train station.

The figure illustrates the various land use characteristics of the existing buildings and is done so using a self-explanatory color coded legend on the figure itself. Immediately following figure are figure and for the green space network and mobility around Barangaroo area.

2.1.5 Green space network

Green spaces are one of the major features of Sydney's centers and suburbs. Everyone enjoys the benefits of Sydney's green spaces; they are the key to many people's sense of enjoyment of urban life. They exist as a result of acquiring and conserving land for recreation and the environment over many years as part of Sydney's long term planning.

The main elements of Sydney's open space are the regional parks, bush land, sports grounds and trails. These spaces have an important role in community life, for social interaction and to provide a sense of place. The variety of Green spaces contributes to the distinct character of regions. These spaces help make Sydney's centers and cities great places to live.

The domain, the botanical gardens, the cook and Philip Park as well as Hyde Park are in close proximity to the Barangaroo site. These vast parklands offer a diversity of recreational possibilities for the people of Sydney and hold the opposites to a dense and busy city Centre - Quietness, space for big events or for space demanding activities, few sensual impacts and the low noise and pollution level. As such the qualities of this natural resource are needed ingredients in a busy city.

Trees are an important urban asset that can transform the City's streets and provide environmental, aesthetic, cultural and economic benefits.

Trees create a sense of place. Tree lined streets provide orientation and contribute to the City's character. They provide a human scale that contrasts with the towers that dominate some city streets. Trees diminish traffic noise, screen unwanted views, reduce glare and provide summer shade for the comfort of pedestrians and residents.

The City of Sydney's street trees are one of the most important assets of people living in Sydney. These trees are crucial to maintaining the high quality of people's public realm and provide numerous environmental, social, health and financial benefits to the City and community.

Figure 2.19 Tree Lined Streets near Barangaroo

The City's street tree population consists of approximately 28,500 trees, of over 120 differing species, that are both native and exotic species, evergreen and deciduous and range in age, size and condition.

Some 49 per cent of the Sydney region is made up of national parks, state forests, regional parks, nature reserves and recreational areas - protected from any future development. There is 31,000 hectares in the Sydney urban green space network. In Sydney, 91 per cent of people live within 800 meters or around a 5 to 10 minute walk of some kind of open space, either local or regional parks, sporting fields or bush land. About 90 per cent of Sydney's population lives within at least a 25 minute drive to regional open space.

2.1.6 Transportation and mobility

Sydney's transport system supports the economic growth of the city by getting people to jobs and services and other daily activities in a fast, safe and reliable way, and through efficient freight movements.

If we speak of the moving people, Sydneysiders make 15.5 million trips on an average weekday, at a rate of 3.8 trips per person. On weekends, there are 13.4 million trips, at a rate of 3.3 trips per person. There are regional differences in the way people travel. The further people live from the CBD, the longer their trips tend to be, the greater the reliance on car travel and the less likely they are to walk or ride a bicycle.

In eastern Sydney, almost 30 per cent of all weekday trips are made by walking or cycling, while in north western and south western Sydney, only 11 per cent of trips are made by walking or cycling.

Sydney has the highest use of public transport of all Australian capital cities. Sydney’s transport system includes the public transport networks of rail (heavy and light rail), transit ways and bus services, ferries and taxis; the road network; and walking and cycling networks.

Metro Light Rail run from historic Central Station through vibrant Chinatown and Darling Harbour to the Star City Casino, the Sydney Fish Markets and Wentworth Park 24 hours a day, seven days a week. From central to Lily field it takes approximately 25 minutes. Metro Light Rail role is highly accessible mode for Inner City corridors with segregation from traffic necessary. The system includes high level of safety and security.

Sydney Monorail travels through the City and goes along above Chinatown, the Spanish Quarter, over Sydney's main street, George Street. The monorail leaves every 3-5 minutes and takes approximately 15 minutes to do the circuit. Single trips or day passes can be purchased at every station. The following figure shows the existing transport system networks on Sydney.

Figure 2.20 Sydney’s mono-rail systems

Presently the Barangaroo precinct receives only limited bus service because of the low level of generated demand in the area. Sydney buses covers the metropolitan area, with approximately 300 routes extending to Parramatta in the west, Palm Beach and Chatswood in the north, Miranda in the south, and the eastern suburbs. The main bus terminals are located at Circular Quay, Wynyard, Town Hall and Central Station. The existent close bus-stop to Barangaroo site is located on Millers point and the number 431,433 of buses arrive to this stop.

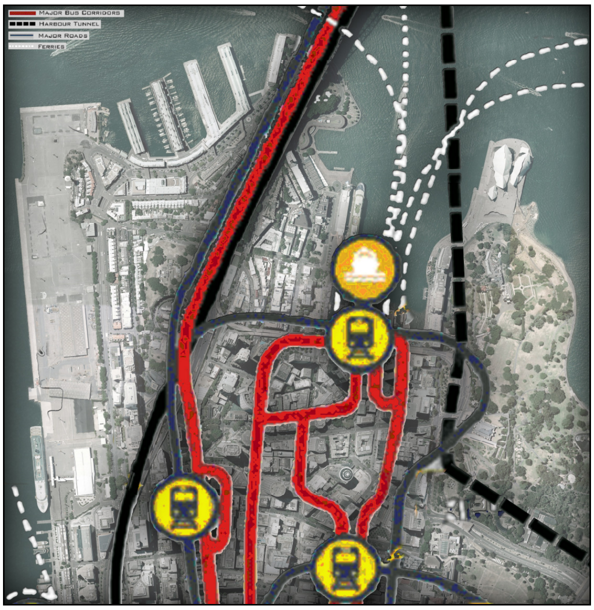


Figure 2.21 Transport Networks

As seen from existing transport networks figure, Circular Quay, Wynyard, Town Hall, Central Museum, St James Stations, and Martin Place are the train stations on Sydney. Besides these train stations connected to all cities around Sydney, the city circle makes up the heart of the Sydney passenger railway network.

The constituent stations of the Circle are (clockwise): Central, Town Hall, Wynyard, Circular Quay, St. James, Museum and back to Central. Owing to the rail providing airport link, to get to the airport from all city circle railway stations takes 15 minutes. From an accessibility perspective, the link between the precinct and the Wynyard transport is crucially important to provide benefits for the Barangaroodevelopment.

Referring to major highway and entry points in Sydney, traffic that does not have a destination in the City Centre should not have to travel on surface streets through the City Centre. Roads such as the Cross City Tunnel play a big role connecting two south part of Sydney city. Connecting the Eastern Distributor to the Sydney Harbour Bridge and Sydney Harbour Tunnel, the 2.3 kilometer Sydney Harbour Tunnel connects the Warringal Freeway on the

Figure 2.22 Sydney Bus Routes

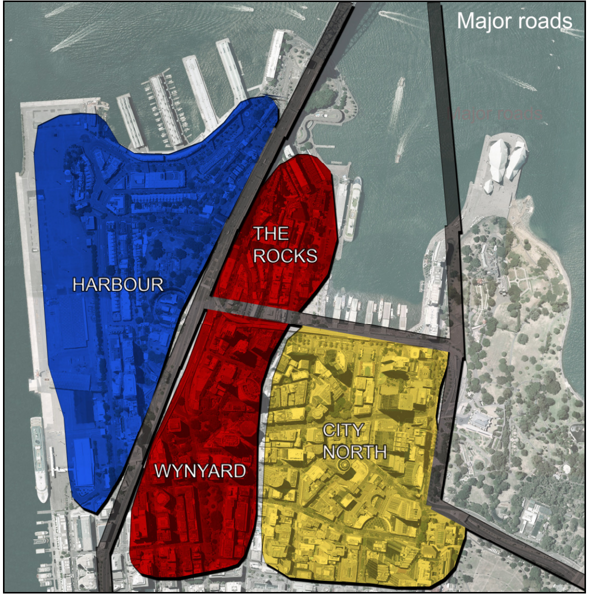


Figure 2.23 Major roads and regions

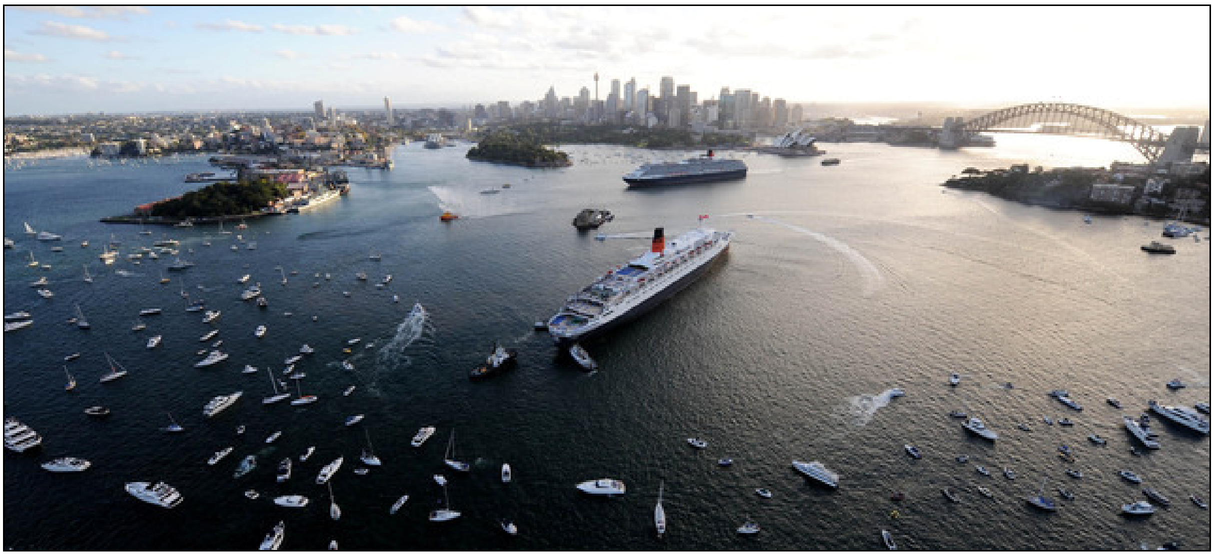


Figure 2.24 Sydney Ferries

northern side of Sydney Harbour to the Cahill Expressway, south of the harbor. The connections from these major roads are being provided by using by-pass routes after entry points of city center. The principle vehicular roads for the Barangaroo site are Sussex Street/Hickson Road and Kent/York Street.

Sydney Ferries make transportation more than 14 million people across Sydney Harbour and the Parramatta River each year. The extensive network connects 39 destinations and spans approximately 37 kilometers from Parramatta in Sydney's west, manly in the north and Watsons Bay in the east. Circular Quay, the hub of the Sydney Ferries network, is located in Sydney Cove between the recognized Sydney Harbour Bridge and the Sydney Opera House. The Ferries destinations are shown on figure. The destinations are: Balmain, Double Bay, Manly, Parramatta, Taronga Zoo, Darling Harbour, and Cockatoo Island. King Street wharf of Darling Harbour is the commuter wharf serving the Sydney locality of Darling Harbour located closely end of Barangaroo site.

2.1.7 SWOT Analysis

Strengths

- City center proximity
- No existing building in site
- Surrounding waterfront
- Wide area for a large scale project

Weaknesses

- Poor link with the rest of the city
- Steep topography
- Pressure of population growth
- Transportation network
- Lack of Green Space

Opportunities

- Historical and cultural values
- Adjacent to Sydney’s Central Business District
- Touristic and cultural activities
- Transportation network

Threats

- Noise and ecological pollution
- Poor connection for pedestrians
- Preservation of heritage buildings

Once the S.W.O.T. Analysis has been listed out it gives us the framework to lay down our goals and objectives, our concepts and visions. This analysis is considered one of the final steps before the objectives and goals.

2.1.8 Comparative analysis.

Now that we have set the foundation for what the various opportunities, strengths, threats and weaknesses are, we are now poised to run a comparative analysis of Barangaroo in terms of size and area in order to be able to develop a sense of the dimensions of the project area. Barangaroo has an area of 220000 m2 which is roughly ten times the area of Duomo in Milan. The following figure compares area of Duomo in Milan and Barangaroo.

Figure 2.25 Scale comparison: Barangaroo, Sydney

Figure 2.26 Scale comparison: Piazza Duomo in Milano

2.2 Vision

Our vision considered for Barangaroo site is to recognize the opportunity to renew Barangaroo as a vibrant commercial and mixed use precinct with significant foreshore parkland. A mixed use development zone, with the remainder of Barangaroo dedicated for waterfront public recreation space as part of the process to renew Barangaroo. The Barangaroo precinct will achieve a new and significant foreshore

accessible areas can be provided through private development sites within the mixed use zone, in the form of squares, streets, open space for Sydney. In addition publicly footpaths, and pedestrian lanes and connections. These strong connections will tie Barangaroo to the City Centre.

The scope of the completion of a 1.4 kilometer foreshore promenade will make Sydney’s Harbor space one of the most publicly accessible in the world. This Barangaroo requalification will promote the sustainable development of Sydney – economically, socially and environmentally. A balance between the commercial and recreational opportunities at Barangaroo will be critical to both the social and economic success of the renewal program.

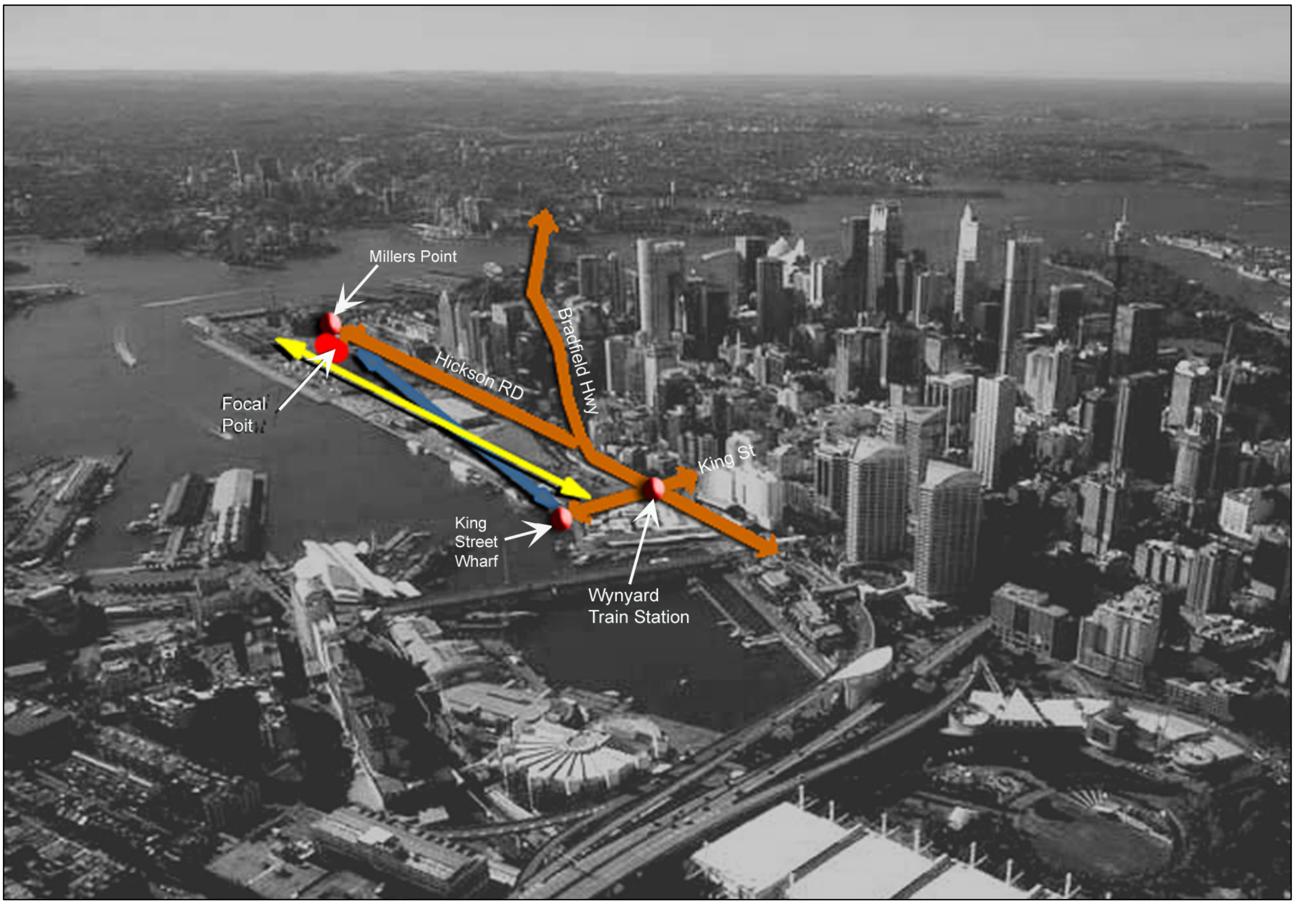


Figure 2.27 Vision connections

2.3 Concept Plan

This section will unfold, step by step, how the original concept plan came about. The urban morphology of the site required first taking into account the northern Headland Park space as this was set by the NSW authority and requires careful attention for its potential to be fully harnessed and enjoyed by sydneysiders in their leisure time.

There are two significant north-south axes, these are the main north-south links between King Street Wharf Ferry Terminal and Millers Point. They offer the freedom for pedestrians and cyclists on site to wander and enjoy the waterside view or cut through the building developments (literally through the art exhibition). The northern cove acts as a transition between the green headland and central part to further define the headland of Barangaroo.

Creating these axes led to identifying the focal point of the site, which rightly enough, was in the central public domain, where the art exhibition is proposed.

The foreshore is considered a significant feature of the site, of which the advantages are exploited as much as possible; it offers a waterside visual connection, open sky, boating and fresh breeze that together improve the potential for attracting any amount of leisurely summer activities.

Within the mixed-use precinct to the south, King Street Wharf Ferry Terminal directly connects Barangaroo to the rest of the city by water. The visual connections of the boat docks and land, has been considered. For this reason a large 15-20m band of park-space eases the view and beckons tourists and first-time visitors to explore the foreshore up to Headland Park.

Wynyard station provides a reasonably close railway connection both to King Streen Wharf Ferry Terminal (less than 500 meters) and to the northern axes that cross Barangaroo.

Finally the east west connections complete the urban grid. These essential arteries strongly affect building shapes and create sectioned visual connections of the waterfront from Hickson Road.

A rail station was proposed in Argyle Cut. People coming to Barangaroo will also be able to use the rail station close to the area.

Due to the expected increase in public use of the site, two new public transportation stops are proposed; the light rail loop, stopping an additional time near the northern cove will improve north-south access in the City. This project also proposes to provide a bus route on Hickson Road to make the area more accessible from the city center.

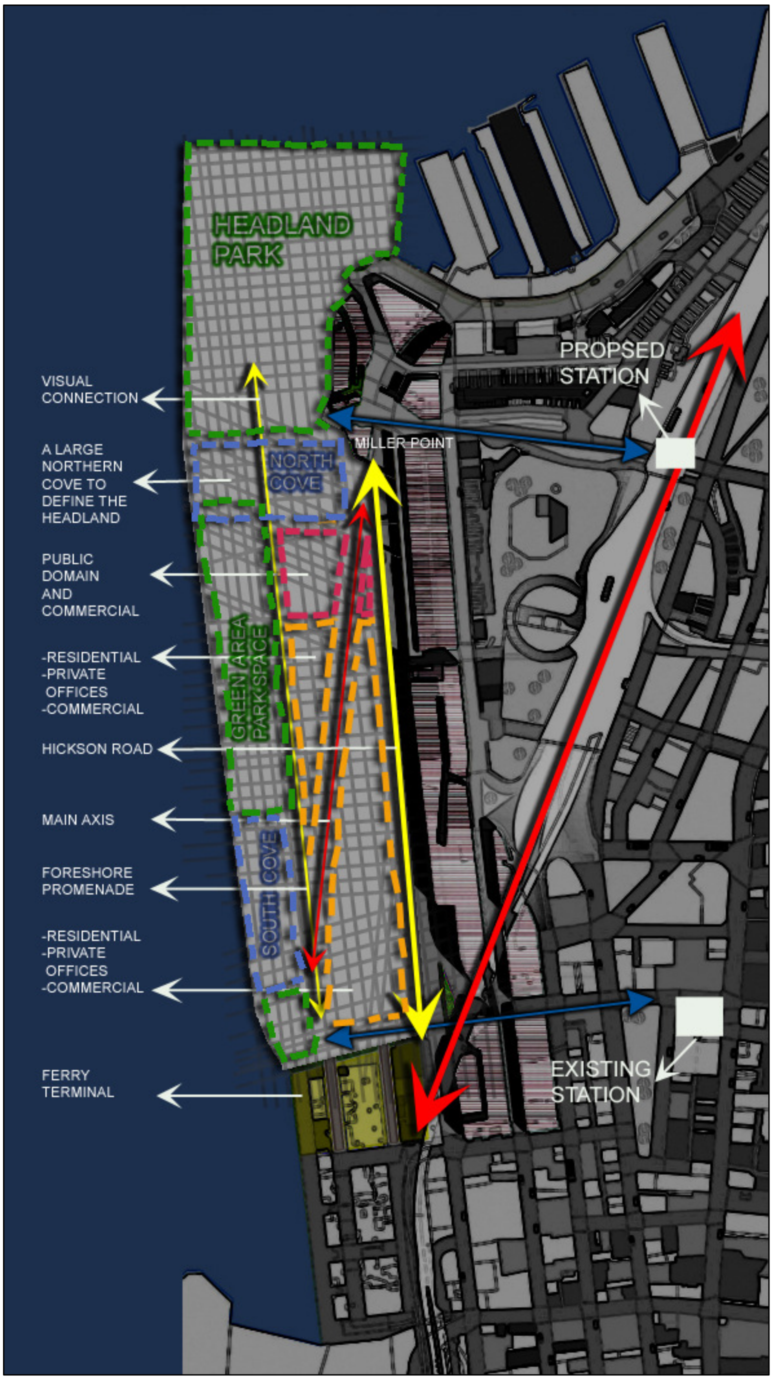


Figure 2.28
Concept plan

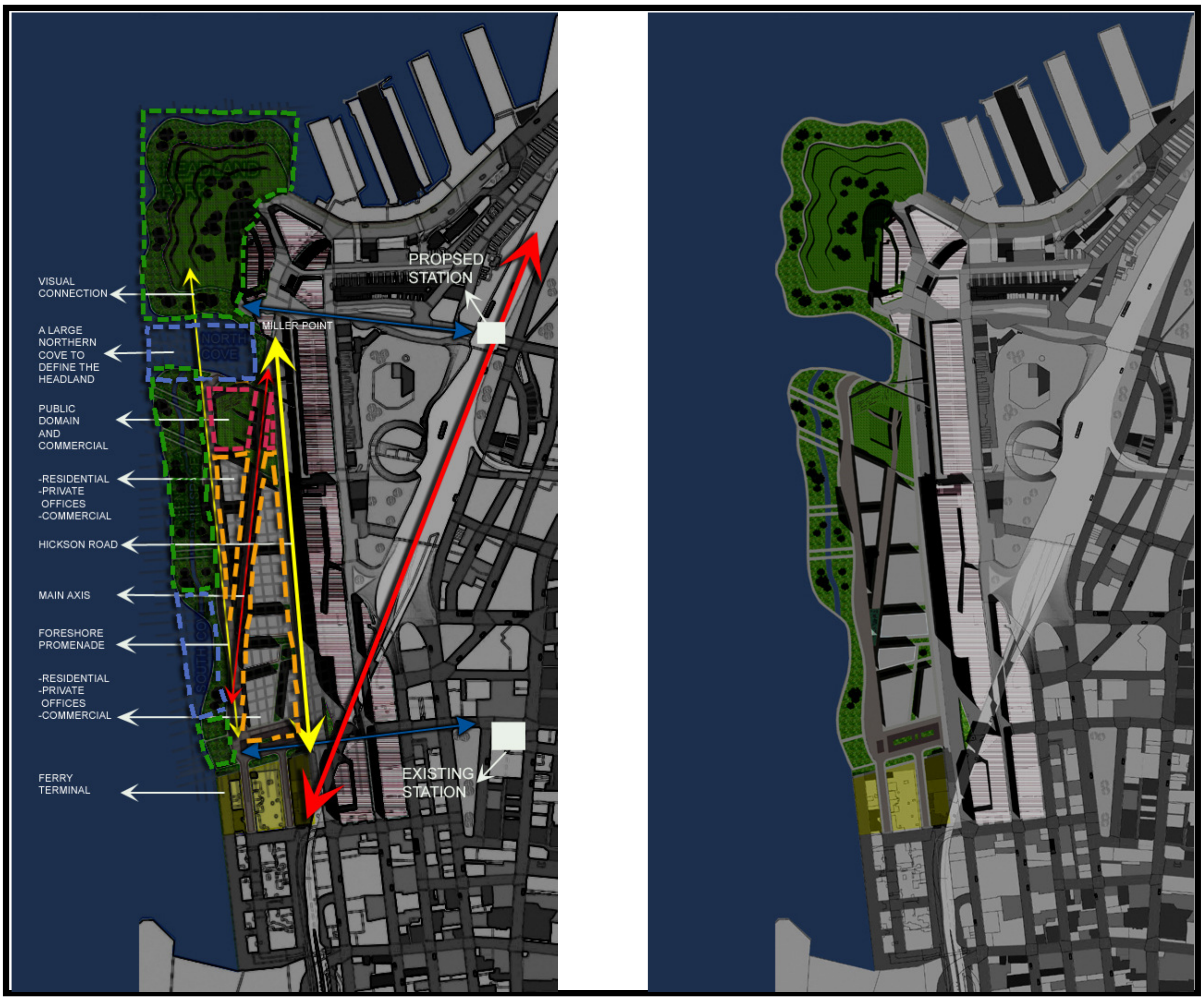


Figure 2.29 Master plan

2.4 Master Plan

The master plan of Barangaroo is a vision aiming to suit stake-holders and end-users alike completing the western edge of the city by creating:

A new civic boulevard connecting Barangaroo to Walsh Bay and King Street Wharf.

A grand harbour side park along the entire length of the waterfront.

A vibrant new commercial quarter integrated with the CBD.

Land spaces are created adjacent to the water's edge in a variety of shapes and sizes. These spaces allow ease of circulation to the waterfront they connect the buildings near the waterfront to the water and they provide visual links throughout the development.

Barangaroo will complete and enhance Sydney's waterfront promenade.

Hickson Road will be one of the key transport arteries; allowing people to move easily from the city's north to south. Hickson road will accommodate a tramway together with a dedicated bus service.

With provided connection from the Barangaroo site to Millers Point, this connection will allow us to exploit links to Rocks through Argyle Street.

The link on Margaret Street is the principal connector from Wynyard to the commercial core of Barangaroo.

The High Street bridge connection provides an opportunity to invite current low-cost housing residents of Millers Point and artisan businesses along Hickson Road to the Barangaroo community.

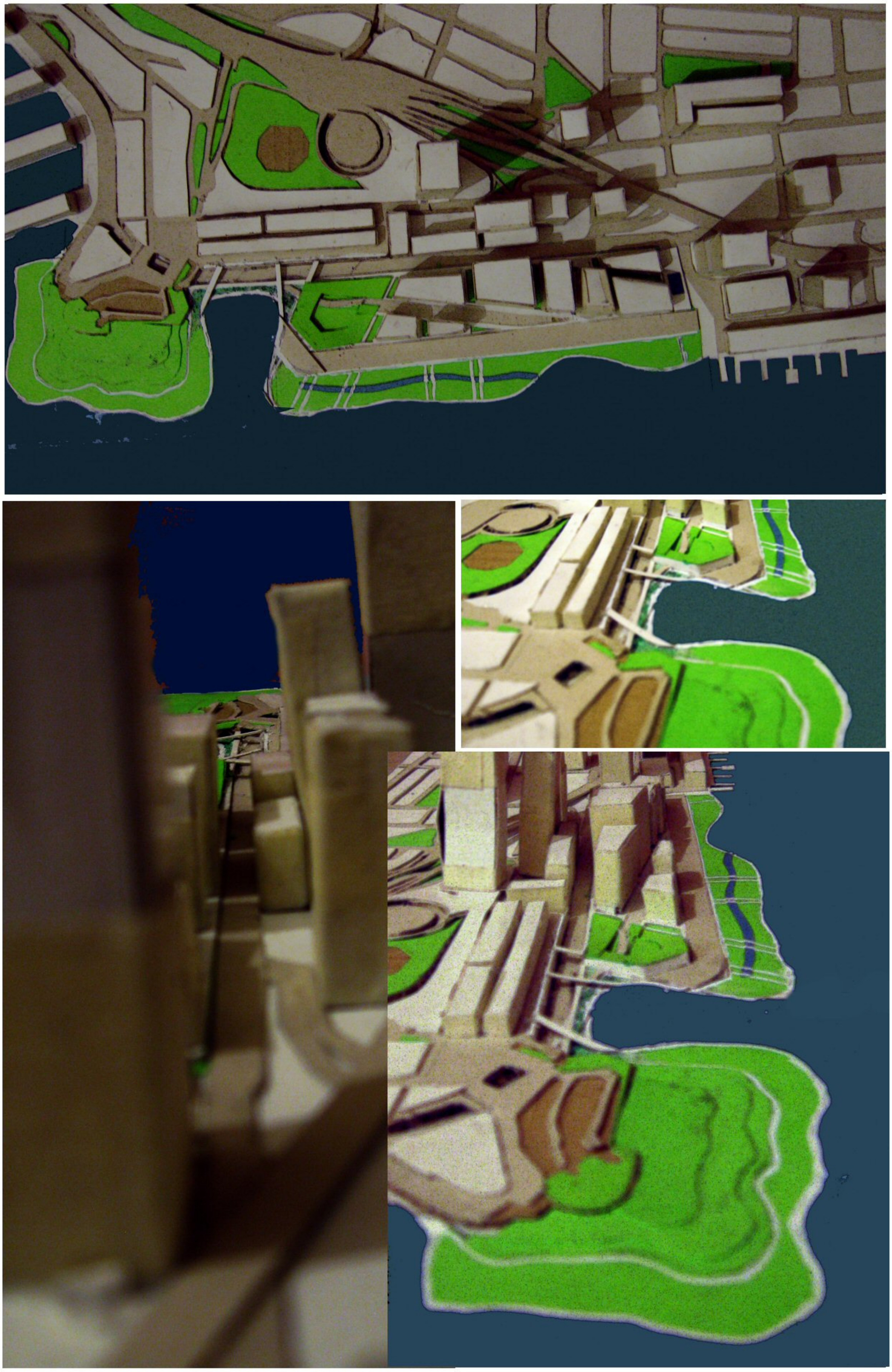


Figure 2.30 Master Plan model

Chapter 3

Architectural Design

3.1 Design Concept and Form

3.1.1 Site use

Following the master plan design of the site, this chapter focuses on an individual building block and defines in more detail the use of space. According to the master plan, the art exhibition center is designed to fit specifically within the central public domain. This area was chosen as the critical intersection point between the axes and thus allows the project to exploit the maximum public usage. This new central public domain attraction may increase the popularity of Barangaroo thanks to this potentially compelling on site attraction.

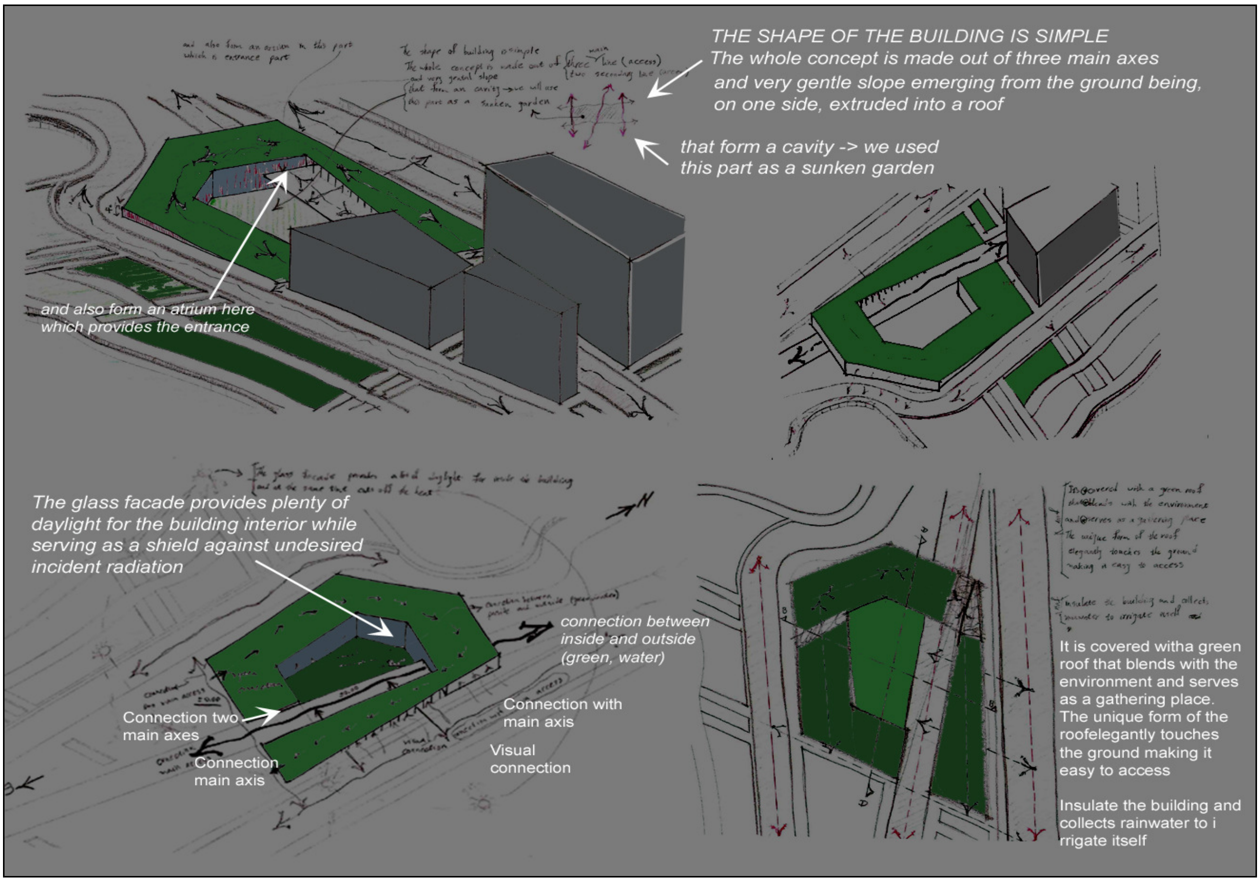
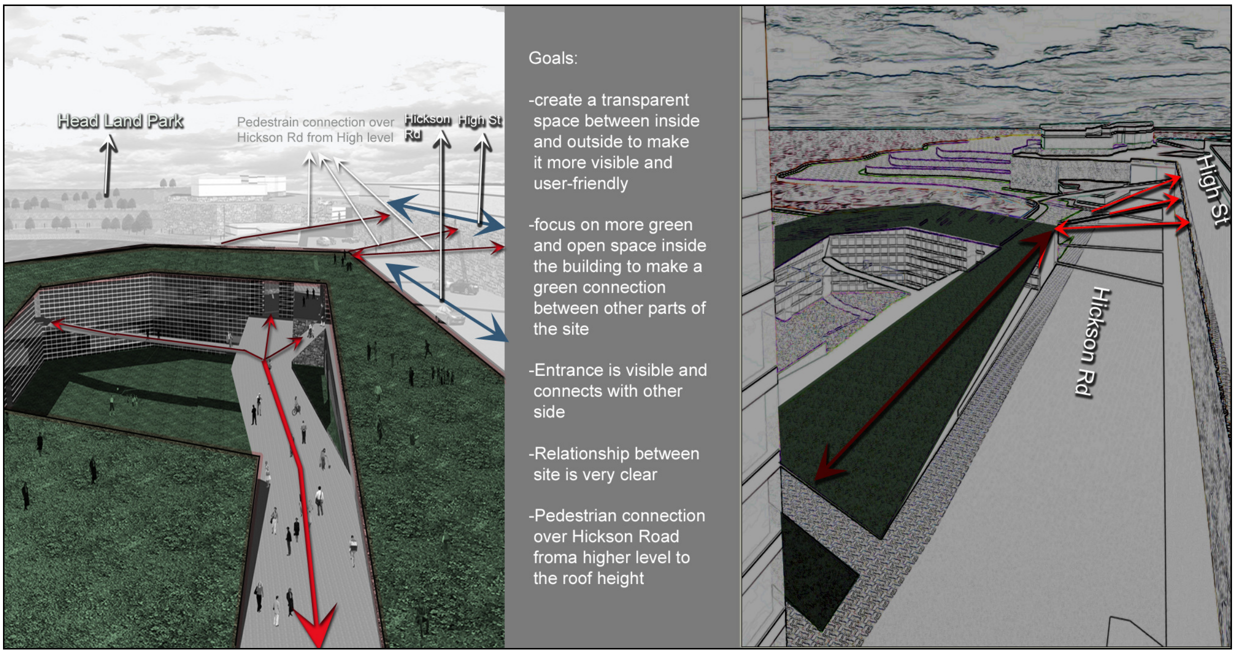


Figure 3.1 Concept



Goals:

-create a transparent space between inside and outside to make it more visible and user-friendly

-focus on more green and open space inside the building to make a green connection between other parts of the site

-Entrance is visible and connects with other side

-Relationship between site is very clear

-Pedestrian connection over Hickson Road froma higher level to the roof height

Figure 3.2 Design goals

3.1.2 An open Gateway, not an Obstacle

The architectural form of the exhibition building is derived from the surrounding urban morphology; two east/west and two north/south axes create the basic pattern (blue and red on Figure 3.3).

The main north/south axis and the green axis is intentionally left open in order to encourage the public to visit and explore the site. This makes it possible for someone exploring or wandering across the site to haphazardly find themselves in front of the art exhibition entrance. From there they may either continue exploring Barangaroo or enter and visit the exhibition.

Most importantly, the building will not be perceived as an obstacle. Instead, it is completely imbedded into the landscape. It can be walked through, walked over, walked into, to be appreciated if you have the time, or overseen if you are just busily hurrying to a meeting.

3.2 Architectural Balance

3.2.1 Creation of a mixed-use environment

This art exhibition centre aims to be harmonious with the surrounding area and sustainable for the future. It is a built volume connected by pedestrian walkways extensively linking the green areas. Also there was a need to create a mixed use environment so that people can use and enjoy the volume and the rich surrounding throughout the year.

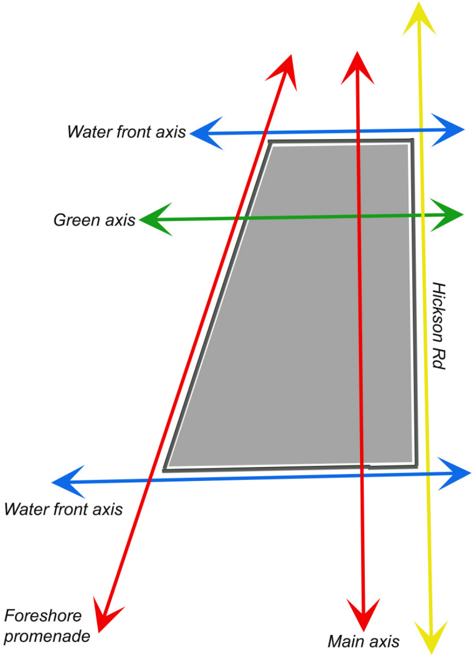


Figure 3.3 The Architectural Form

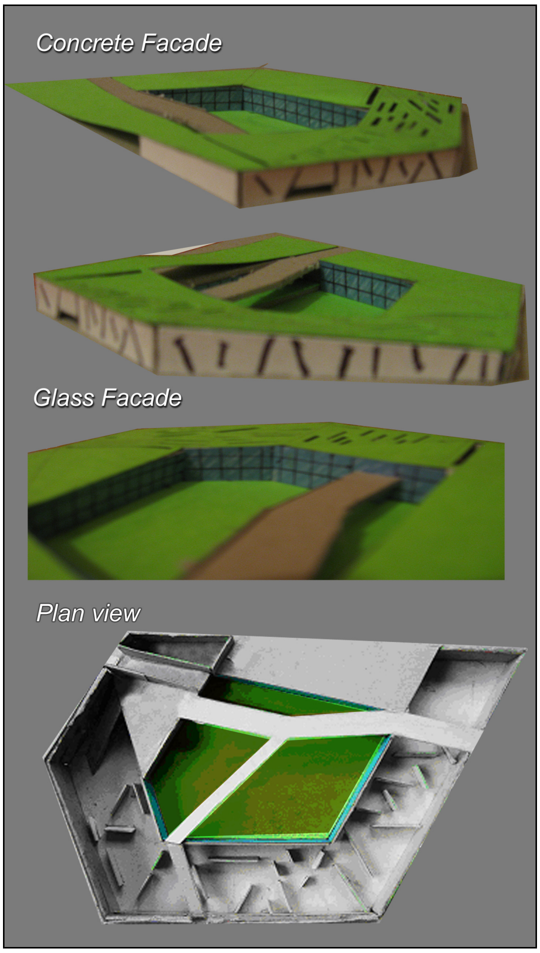


Figure 3.4 Facades and plan view

3.2.2 Use of the Building Footprint's dynamic shape

The external envelope is covered with treated concrete tiles at two different tiers on the north and west façade. Beyond the first tier, there are deeper slices cut into the building's façade. Their shape is inspired by the entire building footprint's dynamic shape as well as the skylights. The interior space has been divided taking the same dynamics into account by default but allowing for reconfiguration depending on the exhibition on show. This sustainable built volume maximizes user friendliness by being open and accessible on every level.

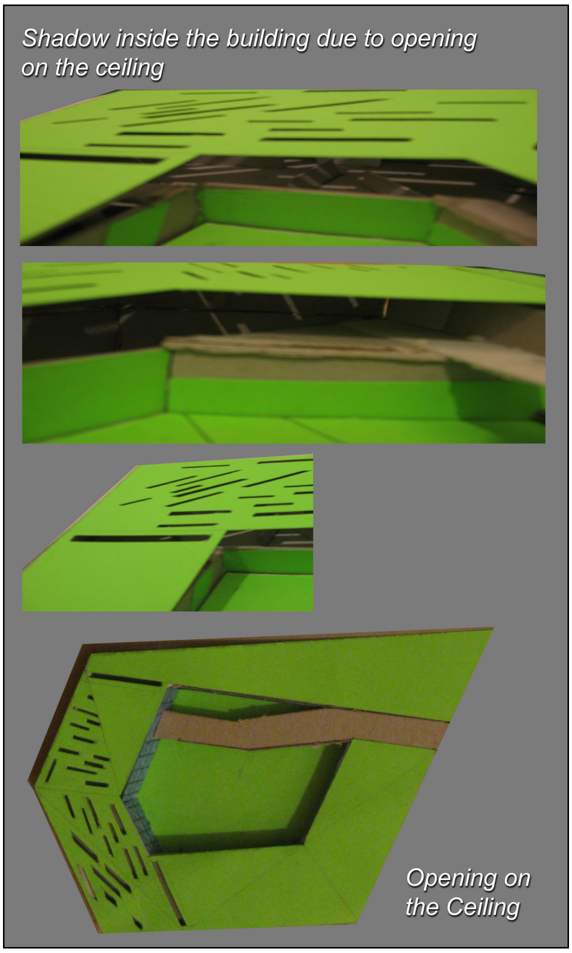


Figure 3.5 Ceiling openings and internal shadows

3.2.3 The Courtyard and Skylights

The interior green court is intended to be completely open to the gallery halls. It is reserved to customers making use of the gallery café or taking a break for some light and fresh air from visiting the gallery. The lighting of the interior space can be well controlled. The façade facing the interior court is glazed and provides daylight while improving internal thermal balance. The skylights give the building's exterior a more continued dynamic appearance across the otherwise large, unanimated surfaces. These openings create the internal slices of light in the lobby and main exhibition hall that should give a lasting and characteristic sensation when experiencing the inside space.

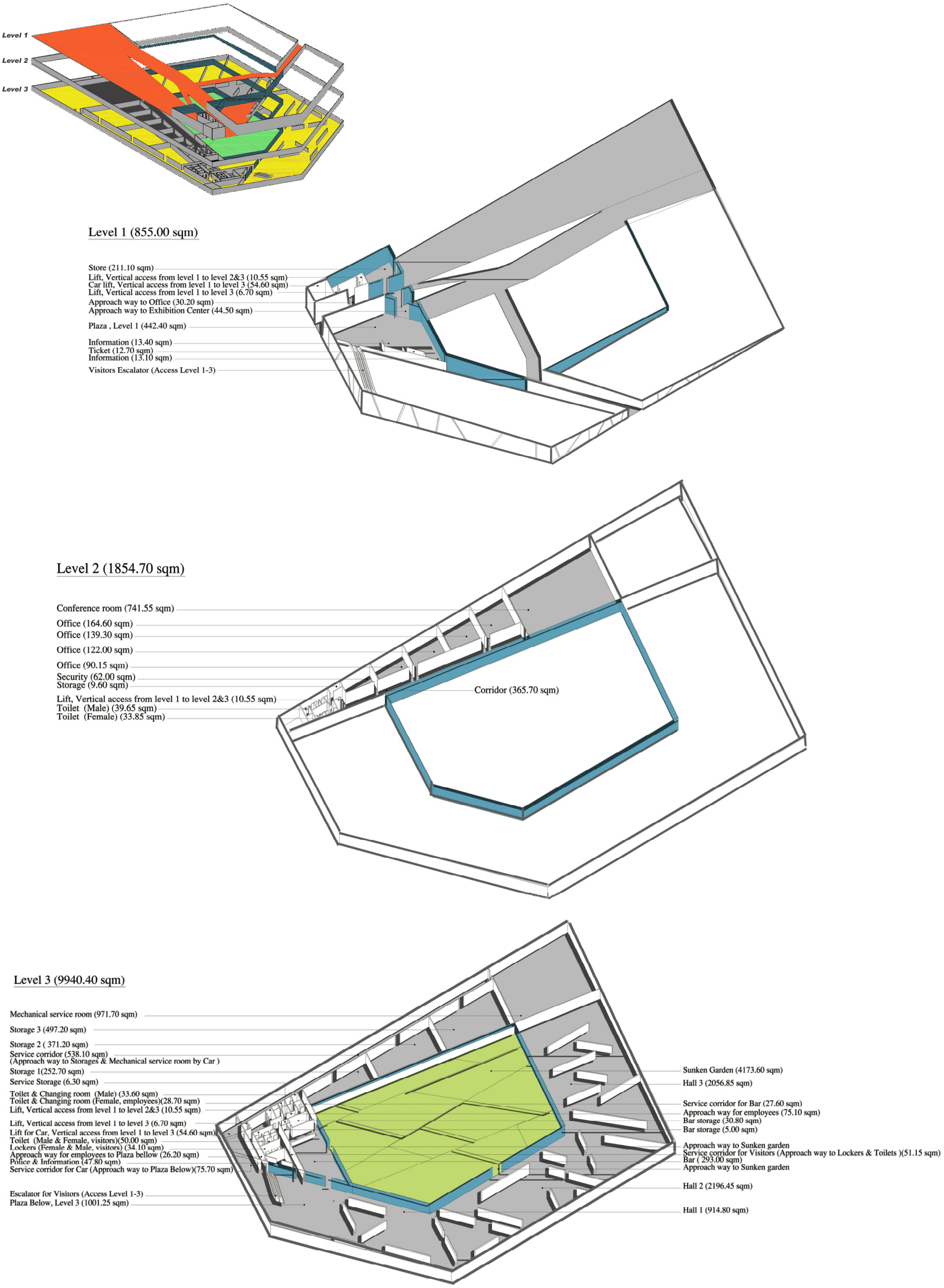
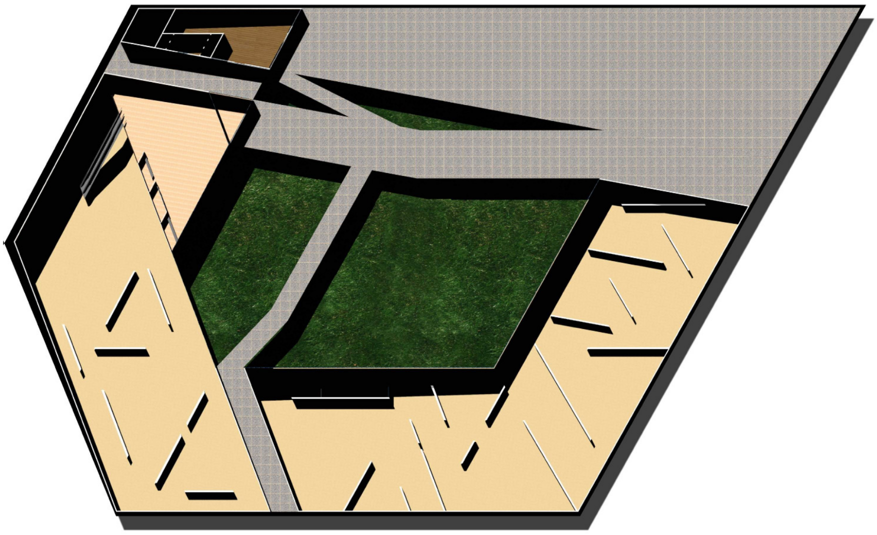
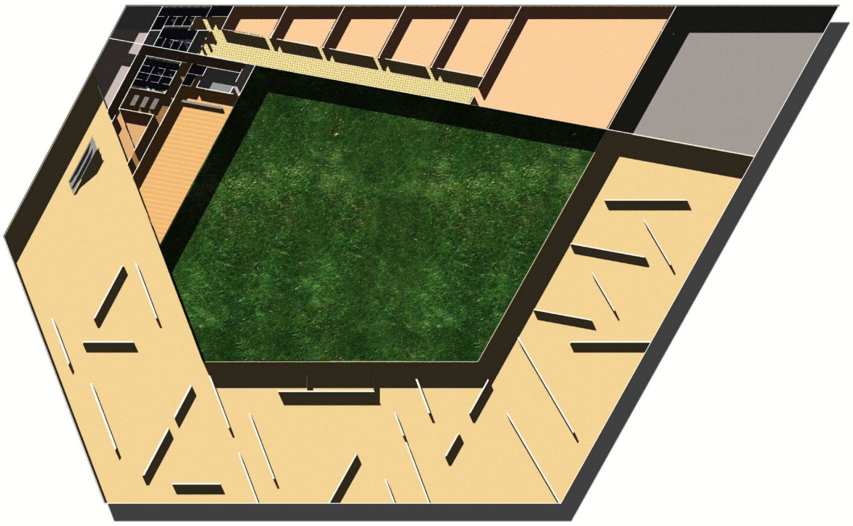


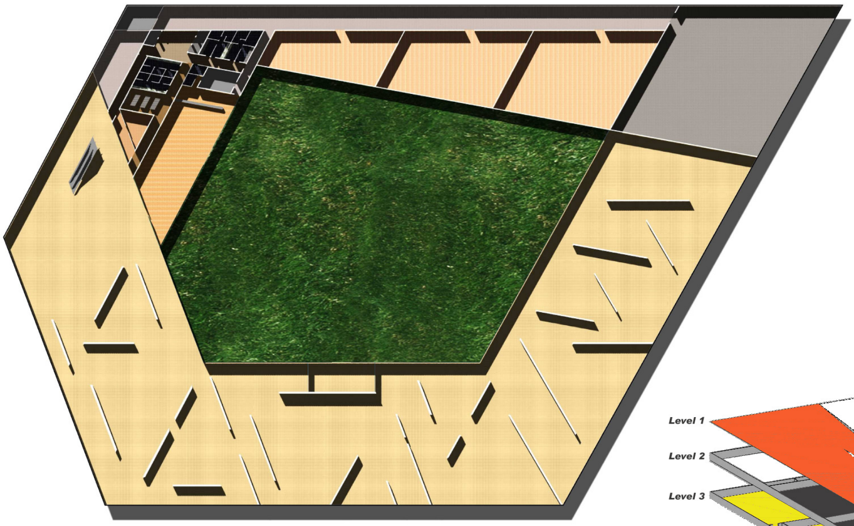
Figure 3.6 Axonometric floor plans of level 1, 2 and 3



Plan Level 1



Plan Level 2



Plan Level 3

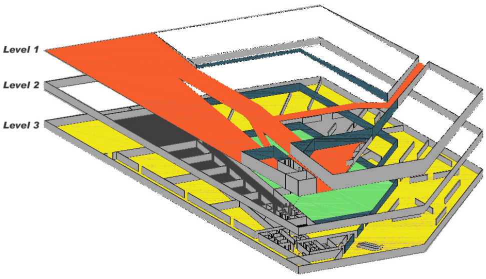


Figure 3.7 Floor plans, level 1, 2 & 3

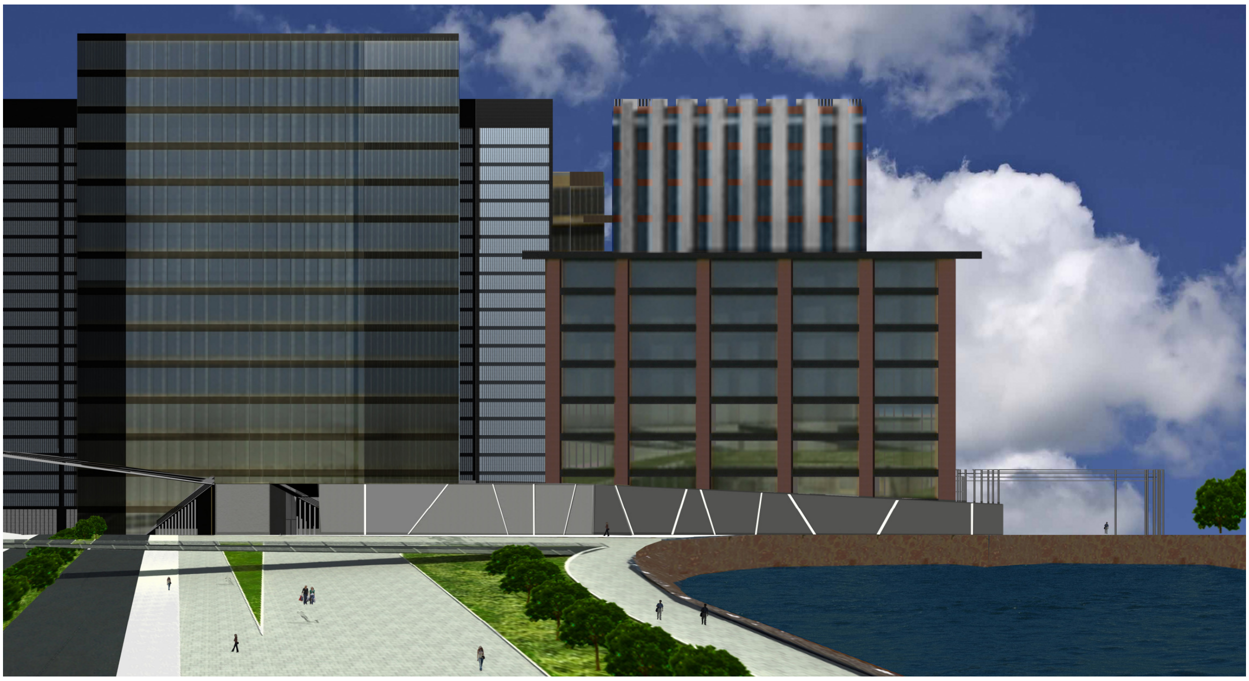


Figure 3.8 North elevation

Figure 3.9 West elevation

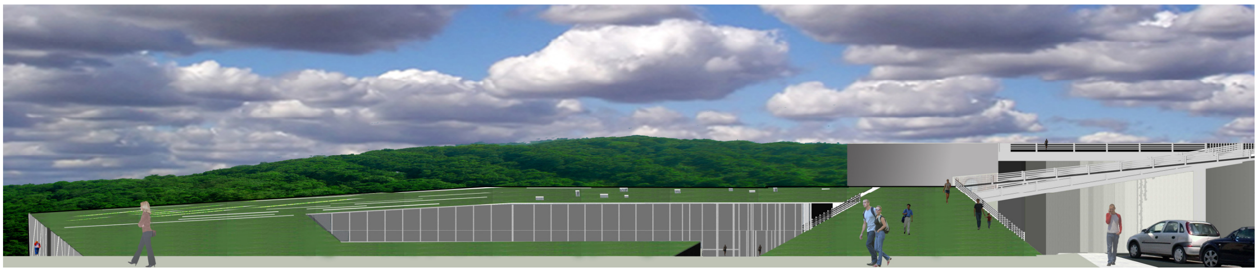


Figure 3.10 South elevation

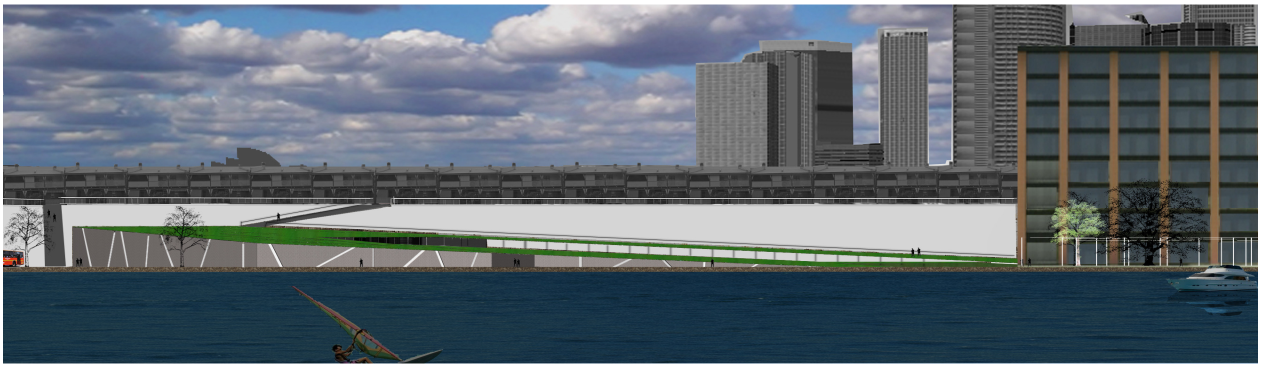


Figure 3.11 East elevation

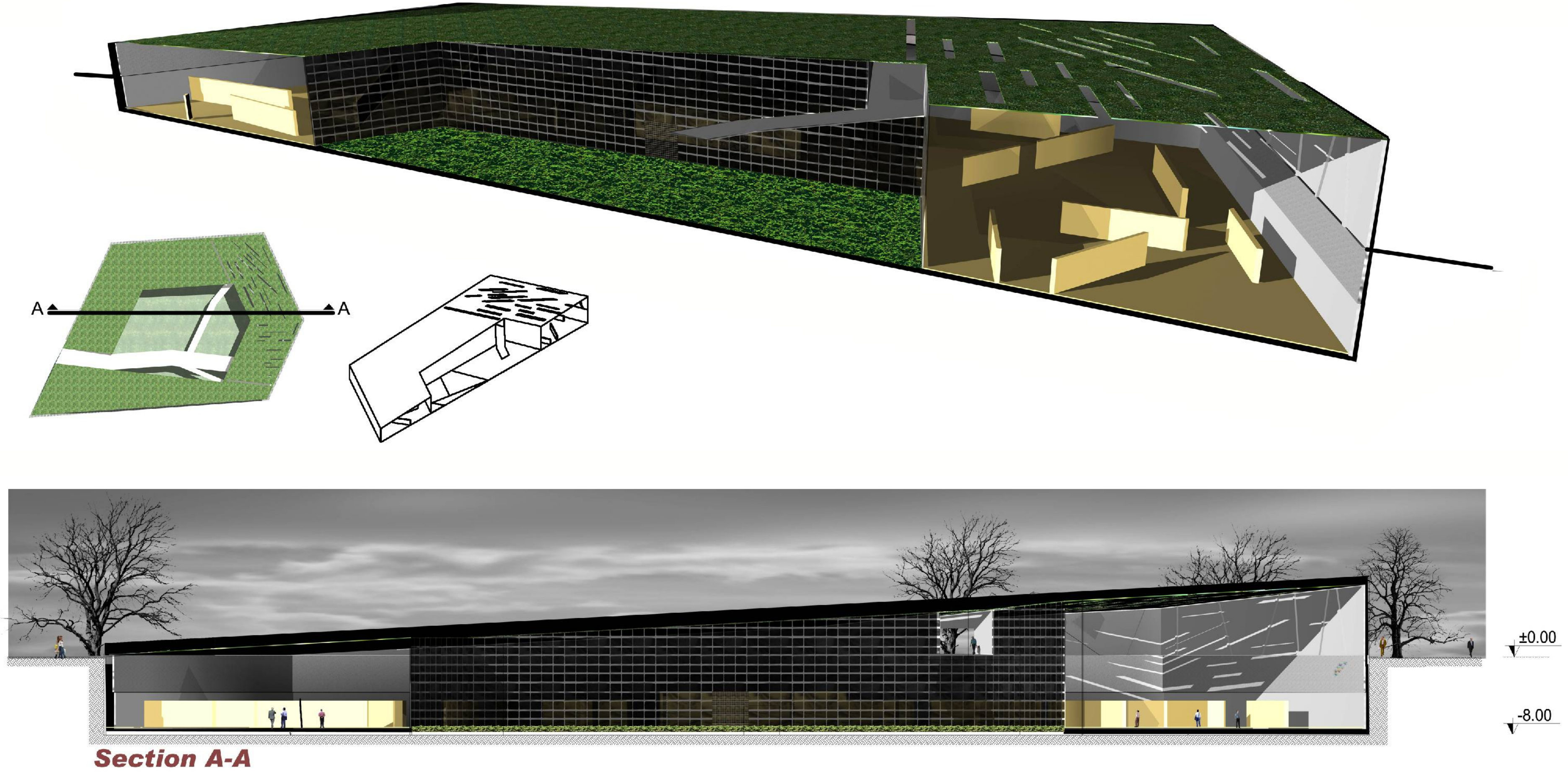


Figure 3.12 Section A-A

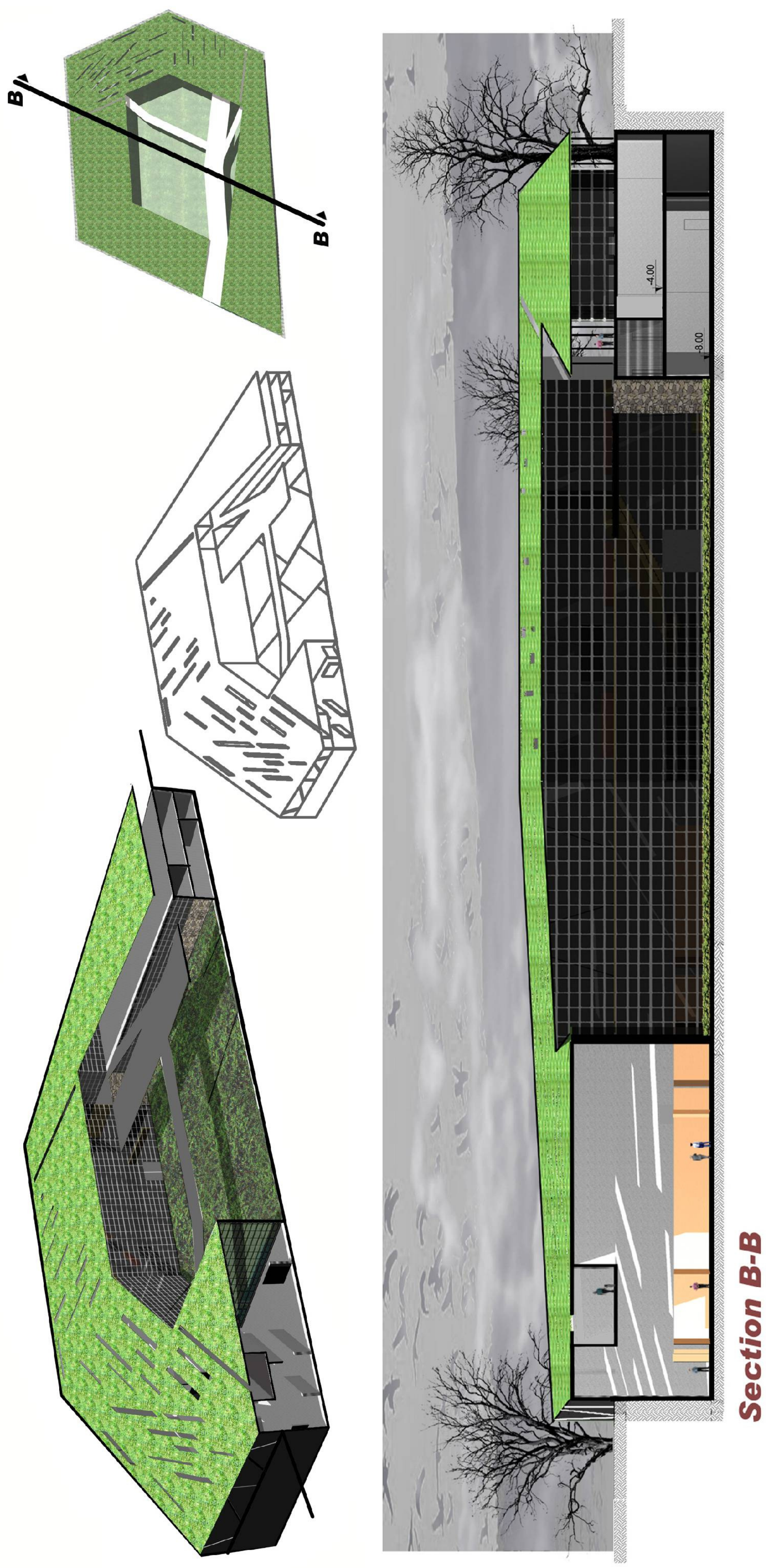
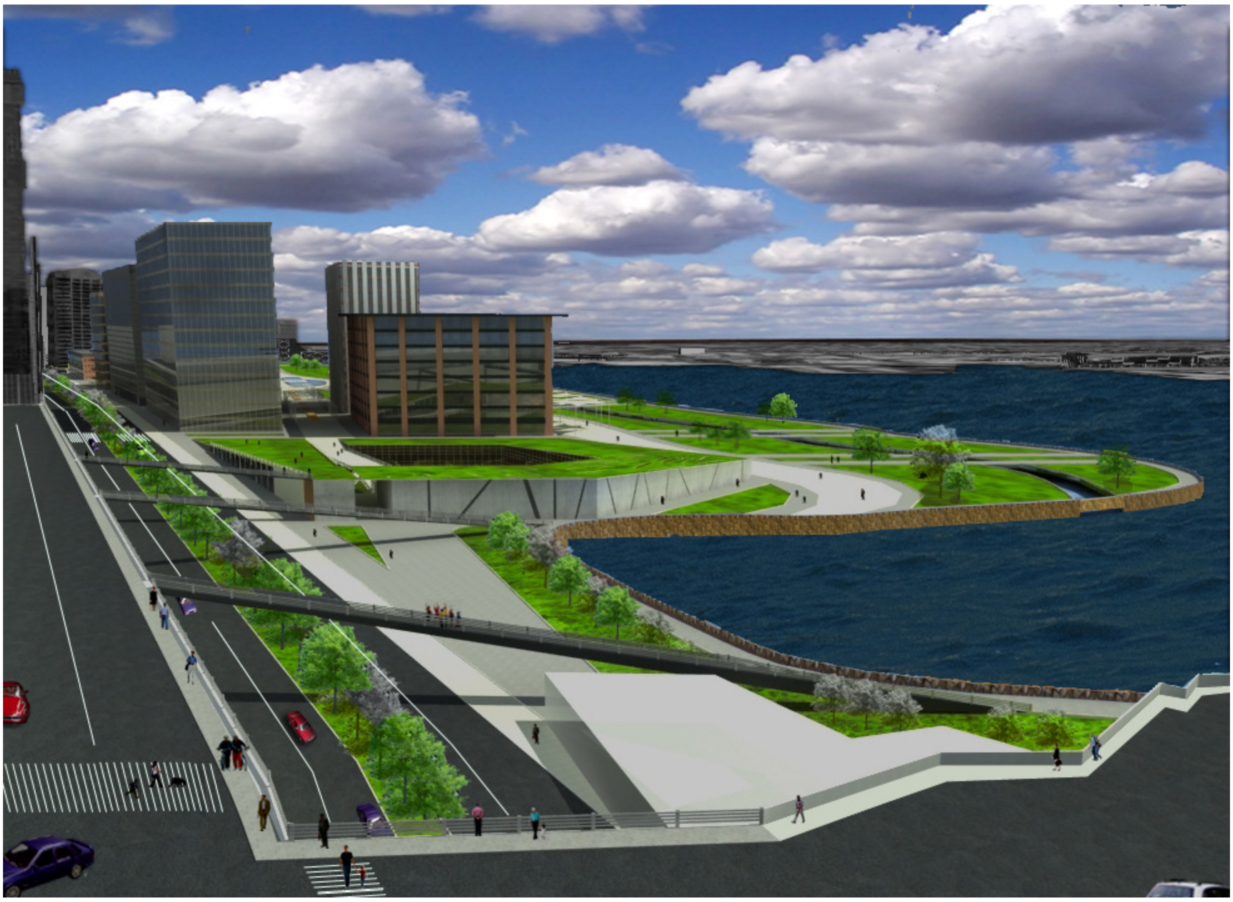
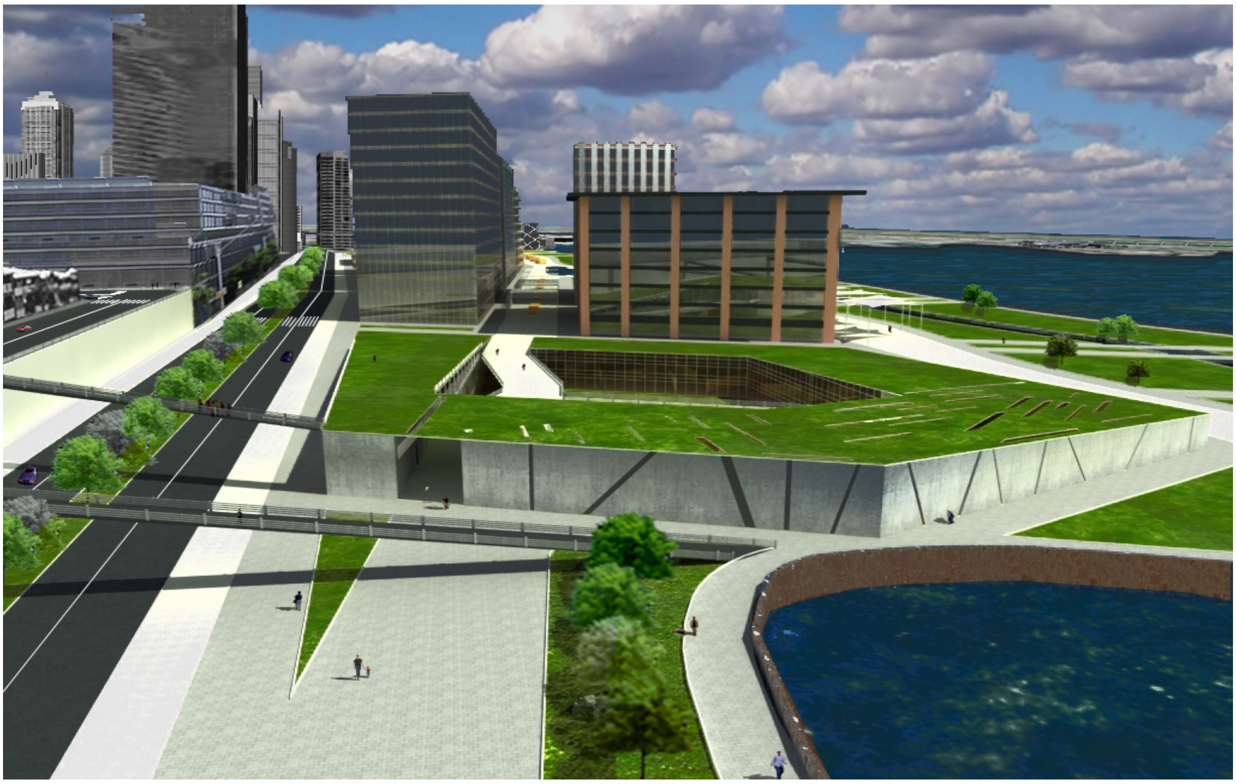
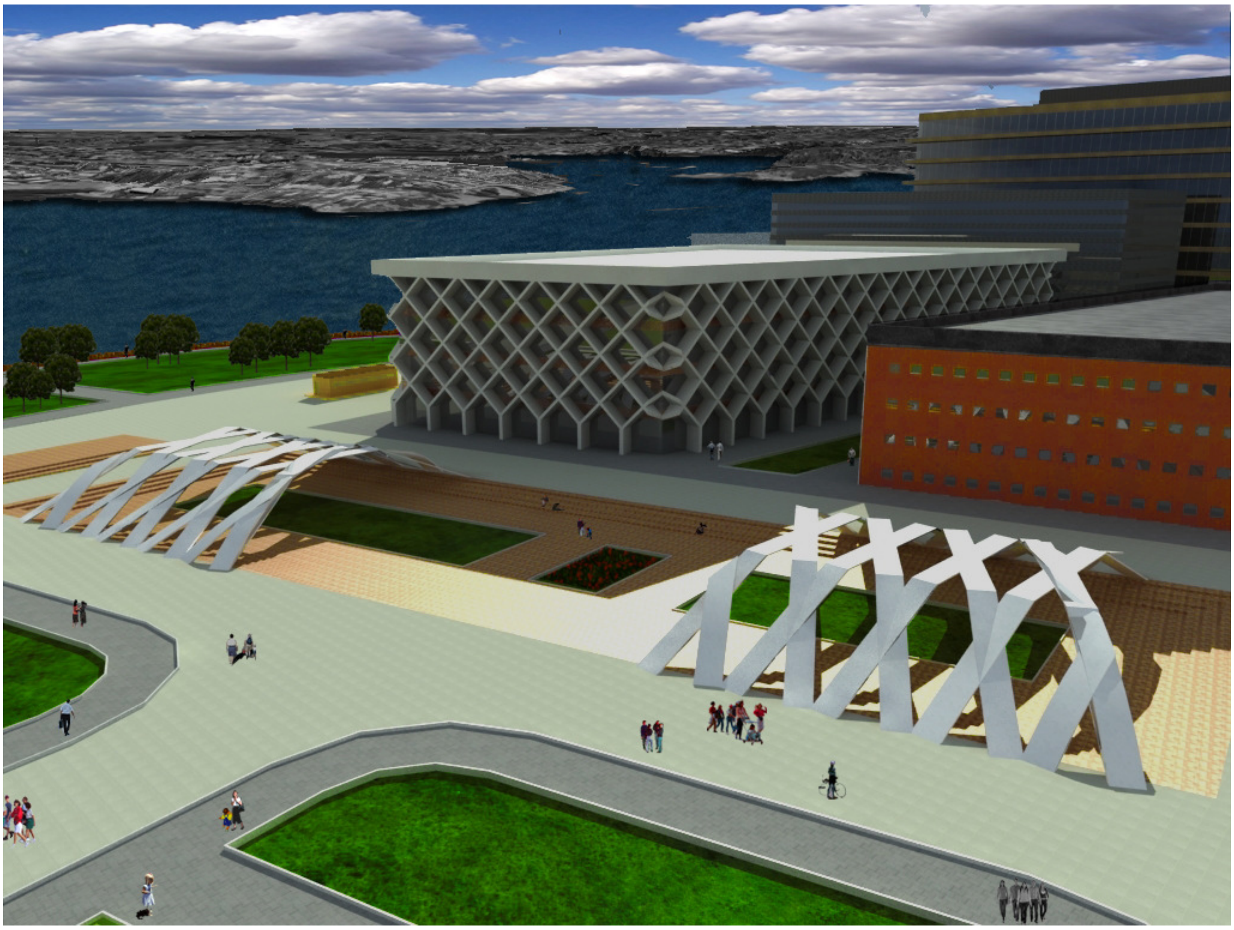


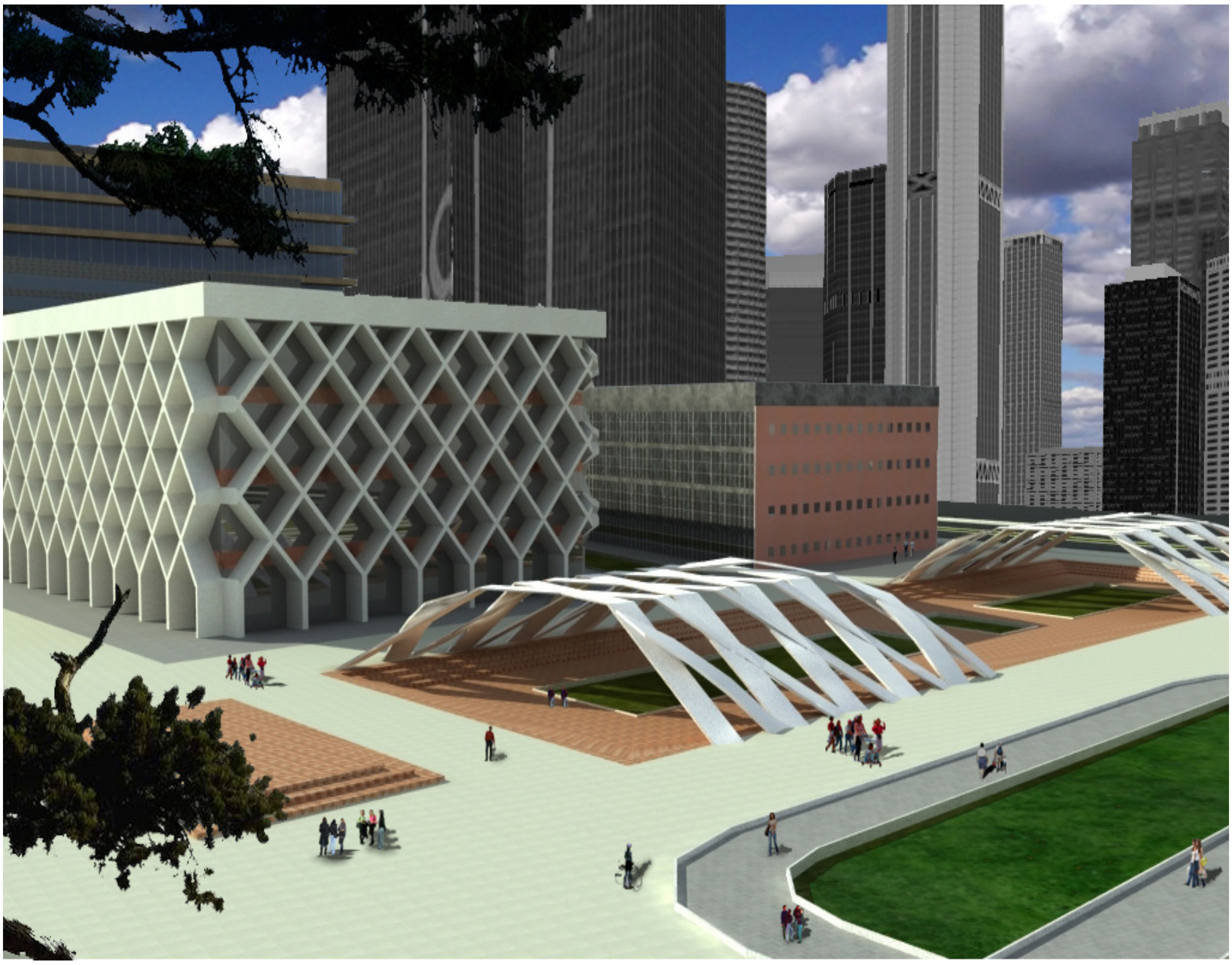
Figure 3.13 Section B-B

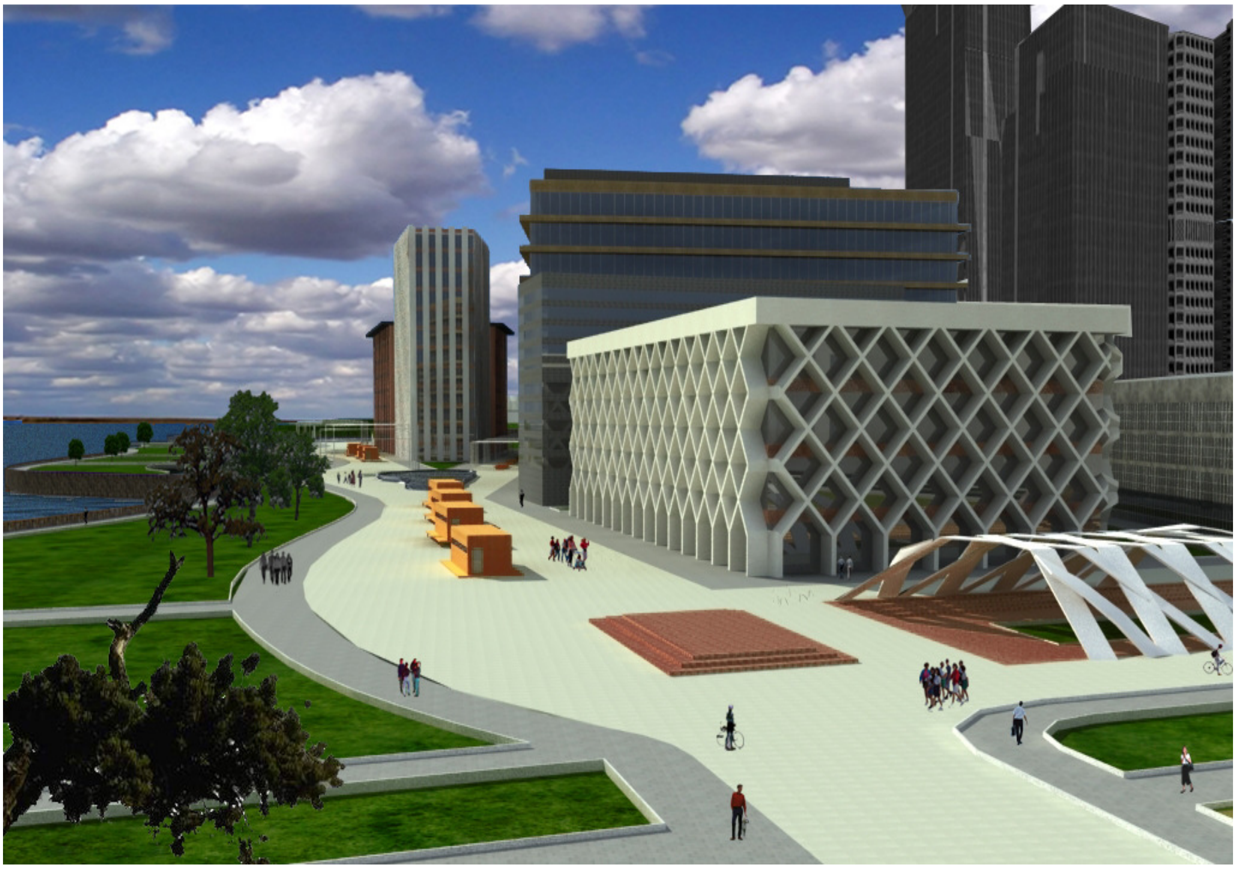
3.3 Renders

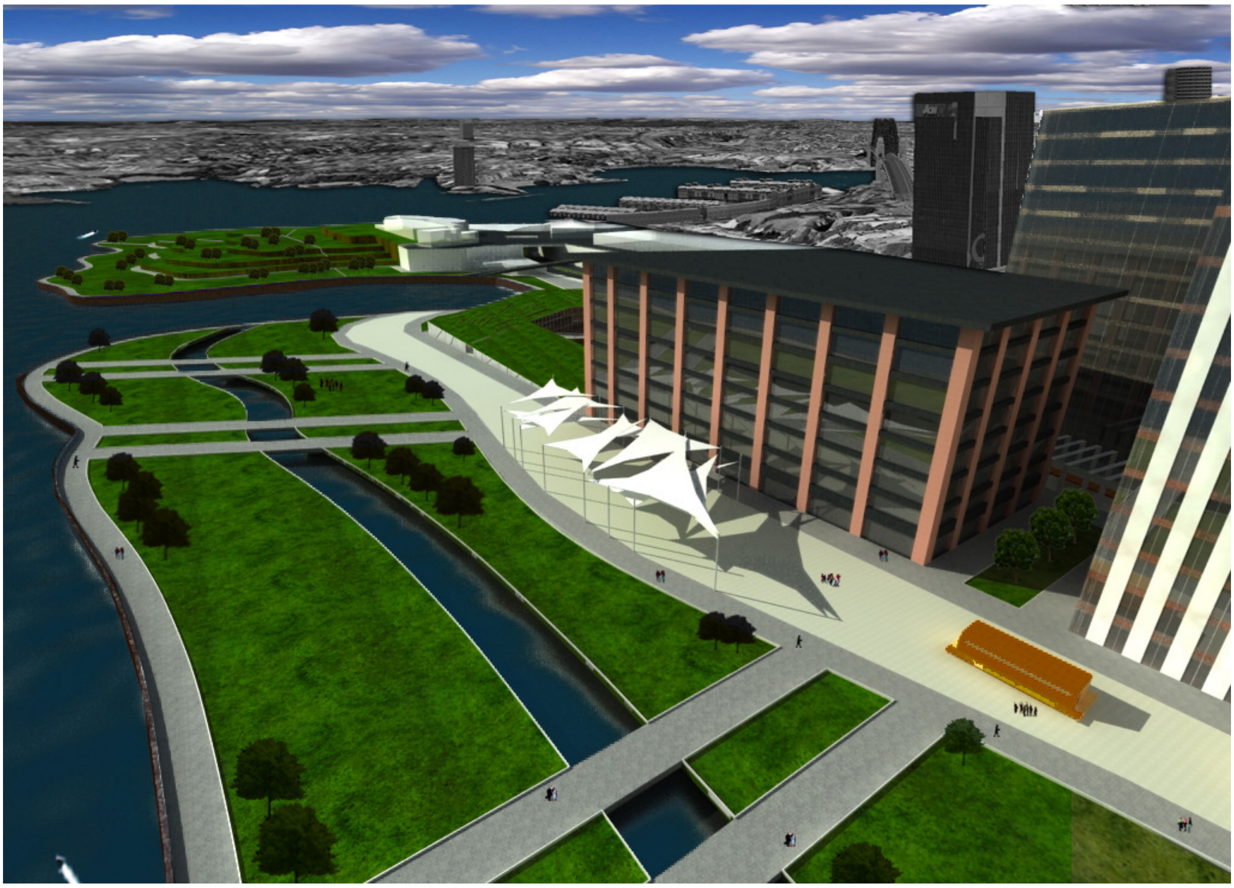


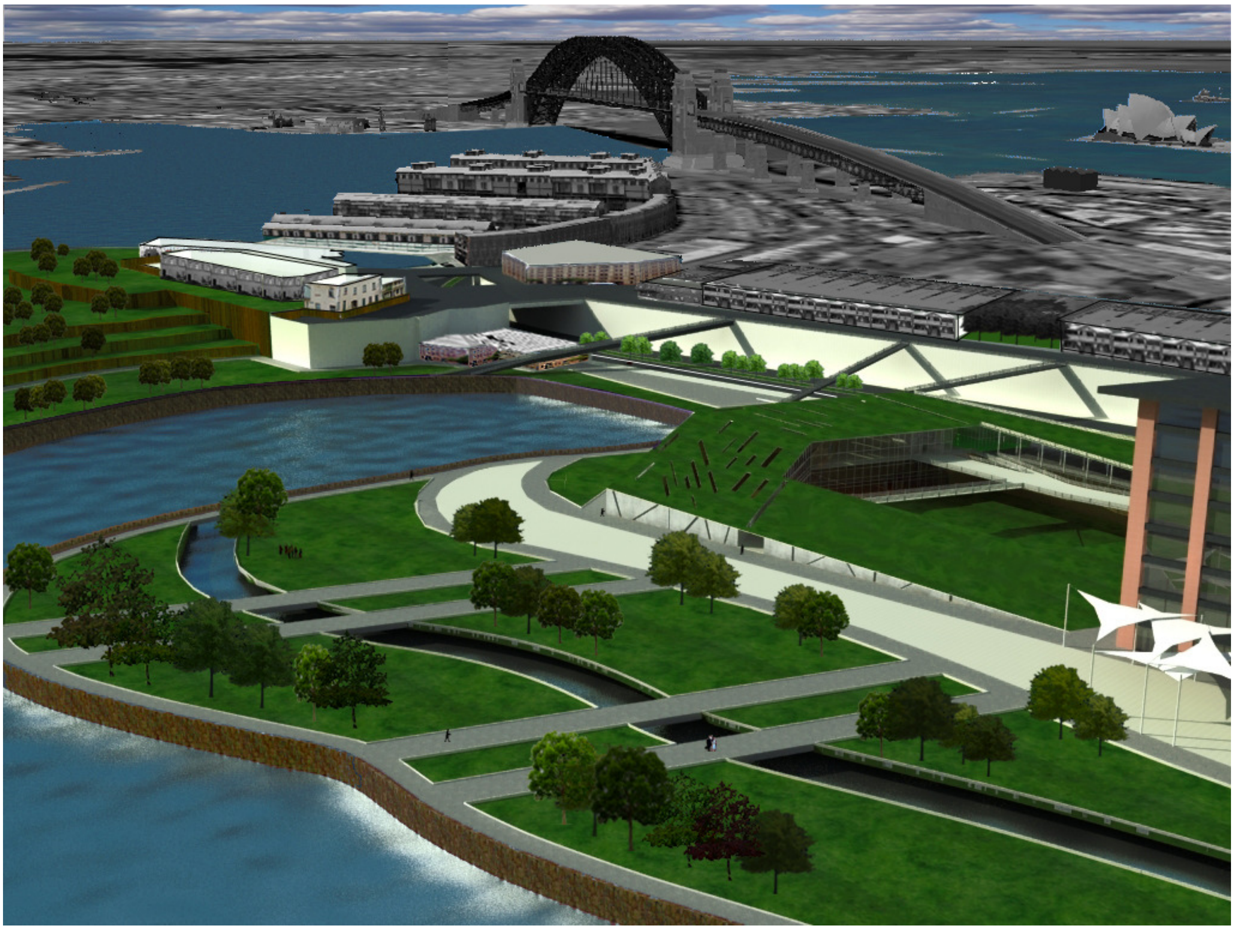


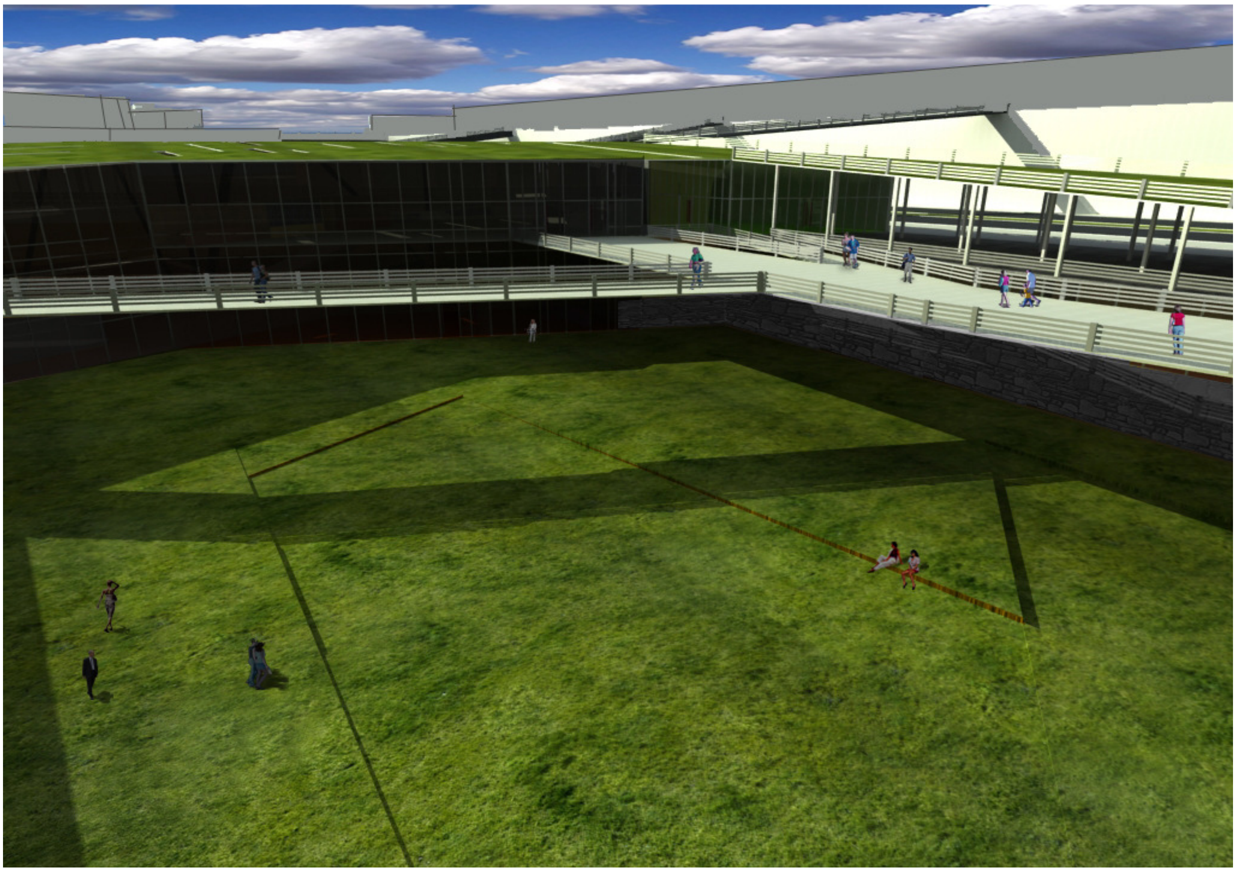


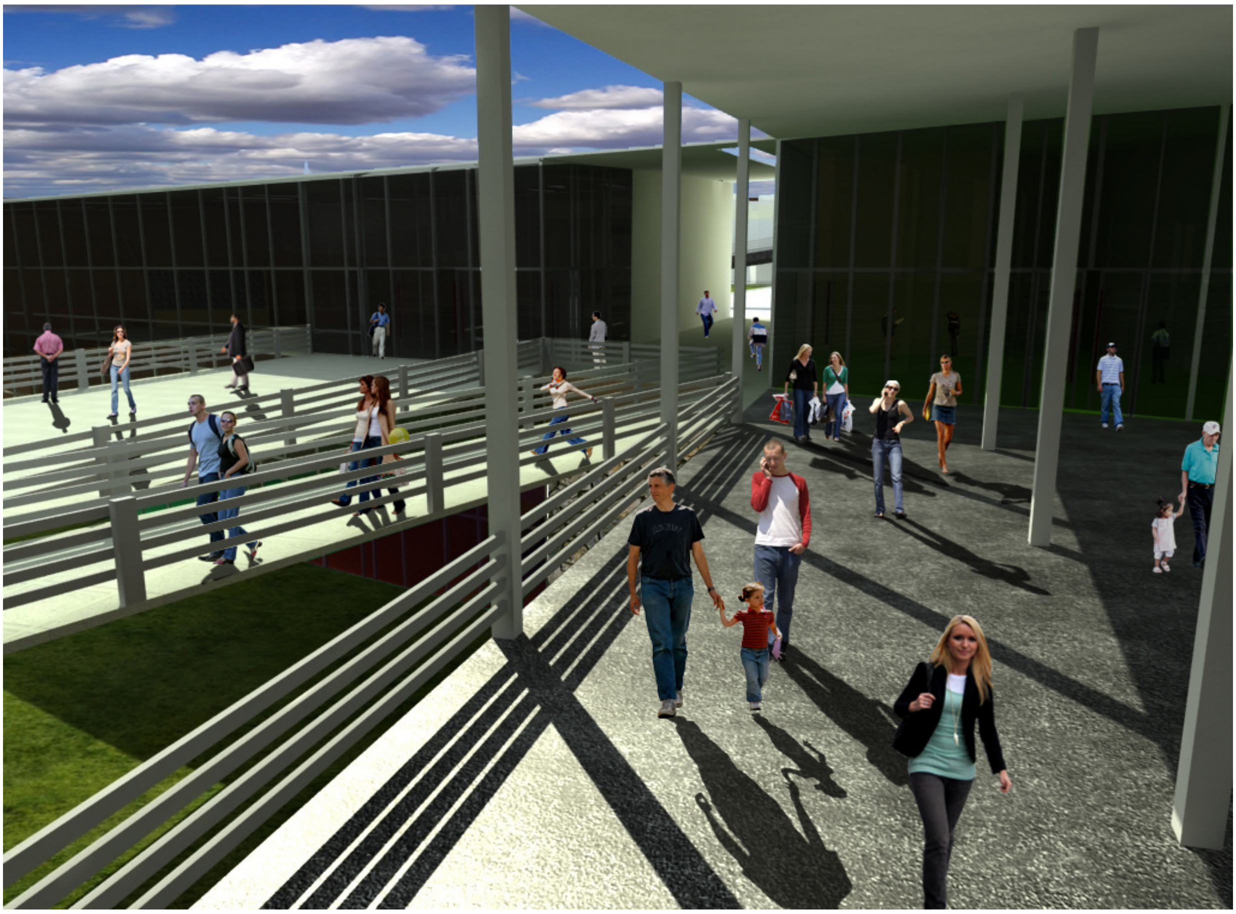


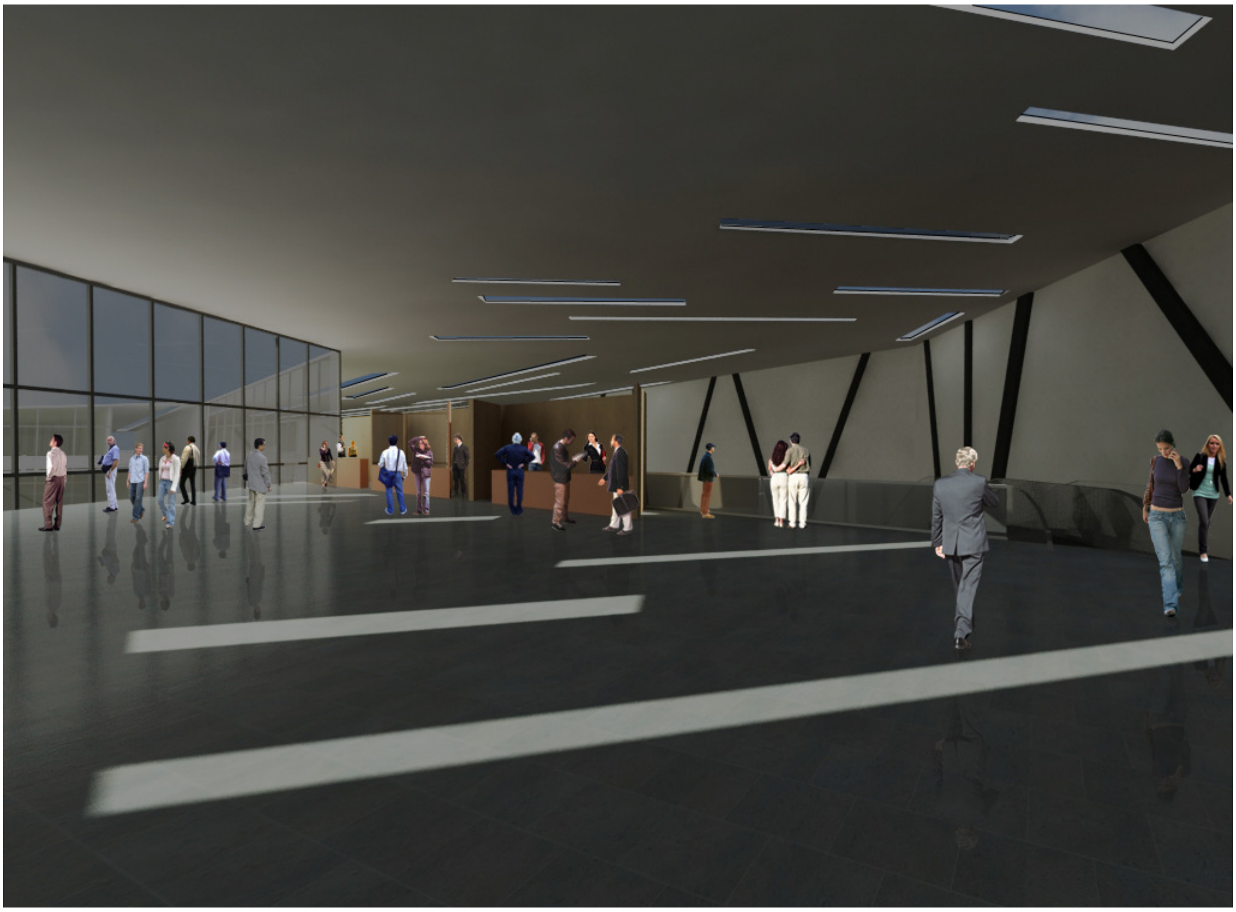


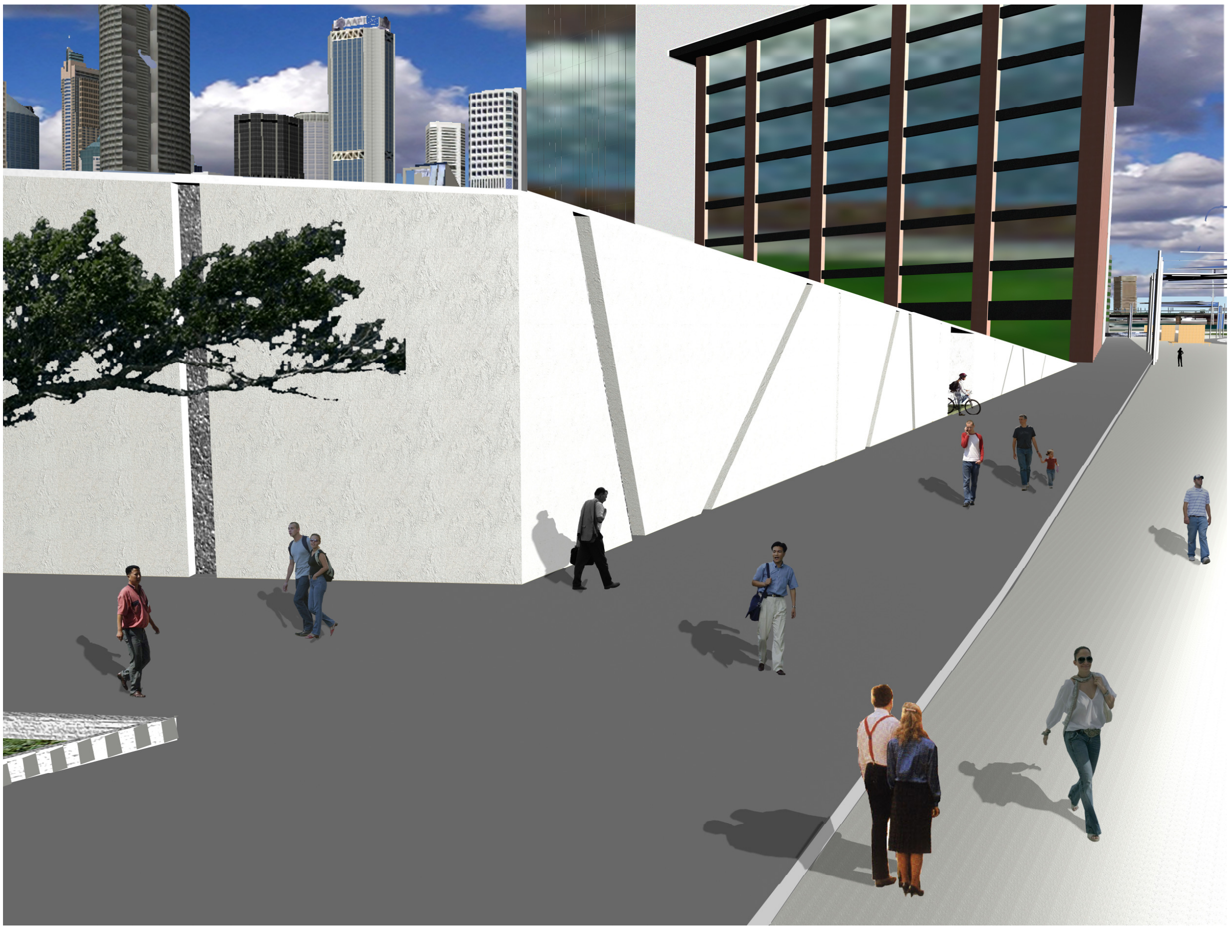












Chapter 4

Technological Design

This Section deals with the technologies used in our project. Beginning with the weather information of Sydney to the passive strategies we have used. Initial simulations and analysis have guided our technological design in an extensive way to add or subtract elements from architectural design with the sole purpose of tackling these issues early on in the design.

4.1 Vision Statement

We have mentioned in the earlier chapters that our design will mainly be guided by nature and predominantly the sun. The energy potential, which the nature places at our disposal on a daily basis, seems inexhaustible. Yet we continue to meet these demands almost exclusively with non-renewable energies generated primarily from fossil fuels. Additionally, the current scientific and economic reports predict the extinction of such fossil fuels in the not too distant future. Architecture and buildings play a key role within this context. Energy consumed in buildings all over the world is expended in the operation of buildings, that is, for heating, cooling, and lighting. We have chosen to build a massive building in Sydney, where the cooling loads soar a few factors above the heating load. This goes to show the significance of energy efficient designs and informed choices when it comes to energy savings in the building. Having said that, meeting these energy needs cannot just be reduced to isolated measures such as collectors or photovoltaic installations on the roof. Rather, a building must be understood as a complex configuration - a total energy concept that makes the best possible use of locally available natural resources such as solar energy. We should thereby understand that passive and active measures complement one another in the quest to conserve energy. From the orientation and division of the building to the integration of systems for the generation of warm water or power, all play an equally significant role. It goes without saying that we, who are involved in the design of this massive building, need to be involved at an early stage. It is important that we think of passive measures to reduce the energy loads. Passive use of solar radiation functions without the need for technical systems. The building itself makes direct use of solar energy by virtue of its placement, geometry, building materials and components. This is the simplest and, at the same time, the most effective form of sustainable architecture.

A carefully thought out design can adapt a building to the natural energy potential in order to utilize it efficiently. The clever selection of the site, placement, shape and orientation, deliberate window arrangement, considered selections of materials and wall structures are what give the building character. In paying attention to a few simple rules, solar architecture is thus the most effective and progressive form of gaining and conserving energy in buildings.

Therefore, without further ado, let us look into the physics involved and the technologies selected as a result of the building physics.

4.2 Physics and the Environment

The geographic co-ordinates for Sydney are 33° 51′ 35.9″ South, 151° 12′ 40″ East. At this latitude and longitude the weather is considered temperate with warm summers and mild winters. The summer months are very warm while the humidity profile is working to our benefit. The summer months, from the figures below, tells us that the temperatures soar up to a record 40˚C while the relative humidity stays around 40% during the peak hours. Due to the fact that relative humidity during the few yet existing peak hours seems a bit low we have the opportunity to employ evaporative cooling into our design. An-other point to be noted is that the relative humidity stalemates at a comfortable 50% to 60% the rest of the summer months. Now the incident solar radiation figures, both direct and diffuse, tell us that there is ample opportunity to utilize daylight. Having said that, however we also need to consider the fact that the tremendous amount of radiation might as well as over heat our buildings during the summer months. Special care and deliberation should be exercised when planning the balance of day lighting versus the cooling loads.

When directing our attention to the average monthly rainfall we see that there rainfall in fairly spread throughout the year in Sydney, but is slightly higher in the first half of the year. The forthcoming images depict the weather profile of Barangaroo Sydney very well.

Figure 4.1 shows a colour coded graph of the average temperature of Sydney on a weekly basis. The darkest colour - Blue depicts temperatures of around 0˚C, representing the lower limit of the colour spectrum. The colour spectrum then increases with increments of 5 until reaching the brightest colour - Yellow that portrays temperatures of around 45˚C. The X-Axis shows the number of weeks, 52 in total that makes up a year. The Y-Axis is the hour axis that ends at 24 which shows the number of hours each day. Both the X and Y axes increase in steps of 4.

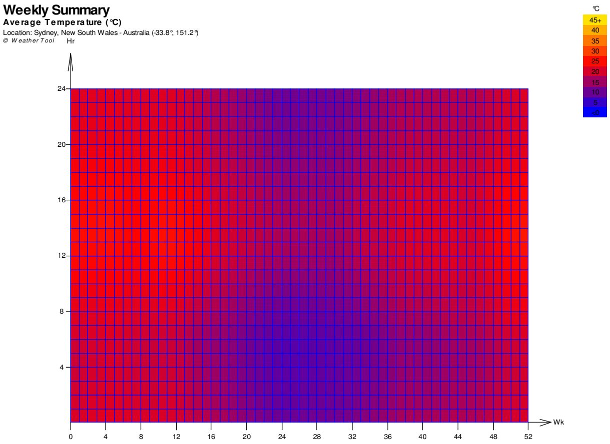


Figure.4.1 Average Temperature-Weekly Summary

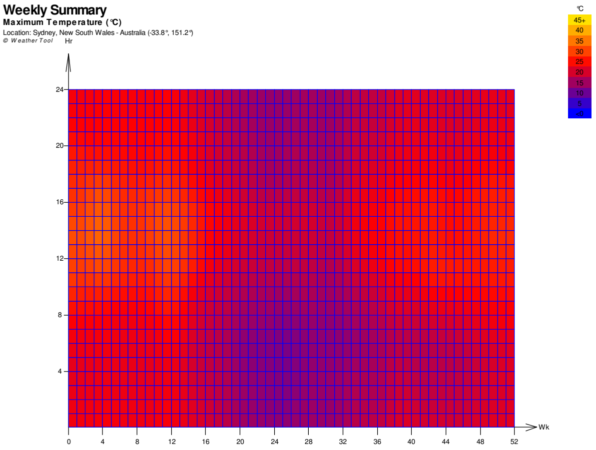


Figure.4.2 Maximum Temperature-Weekly Summary

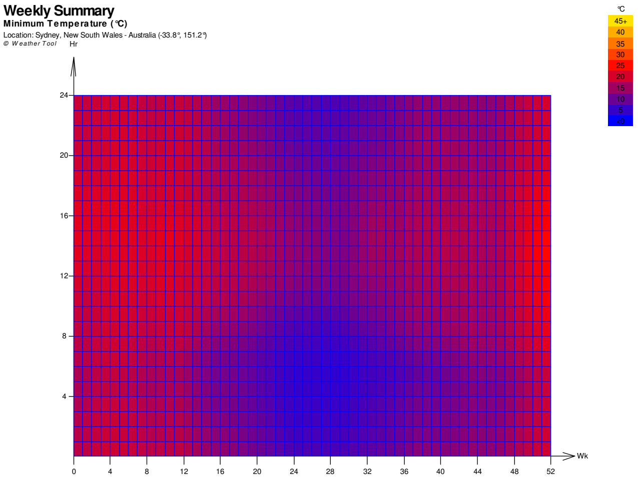


Figure.4.3 Minimum Temperature-Weekly Summary

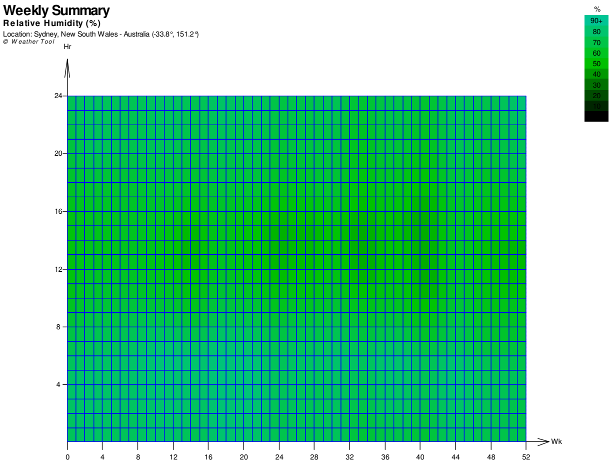


Figure.4.4 Relative Humidity-Weekly Summary

From the figure's 4.1, 4.2 and 4.3 we can immediately recognize the fact that weeks 1 through 20 and weeks 44 through 52, approximately from January through April and November through December are the months that require cooling and weeks 44 through 52 and weeks 20 through 32, approximately late June through August require some sort of heating. Figure 4.4 shows a colour coded graph of the relative humidity in Sydney on a weekly basis.

The darkest colour - dark Green depicts relative humidity of around 0% and above, representing the lower limit of the colour spectrum. The colour spectrum then increases with increments of 10% until reaching the brightest colour - Bright almost bluish Green that portrays Relative humidity of around 90%.

The figure 4.4 gives us an underlying idea of how our space should be treated in terms of relative humidity. When looked at closely Sydney nights, from midnight through 8 A.M, is very humid, close to 90% relative humidity. This is most likely since the site is in the vicinity of the Ocean. However, the relative humidity decreases considerably during the day to reach a comfortable 60% humidity. An exception is however, the months of December, January, February and March when the relative humidity drops to 50% during the hours of 10 A.M through 6 P.M. This gives us the opportunity to employ evaporative cooling into our design.

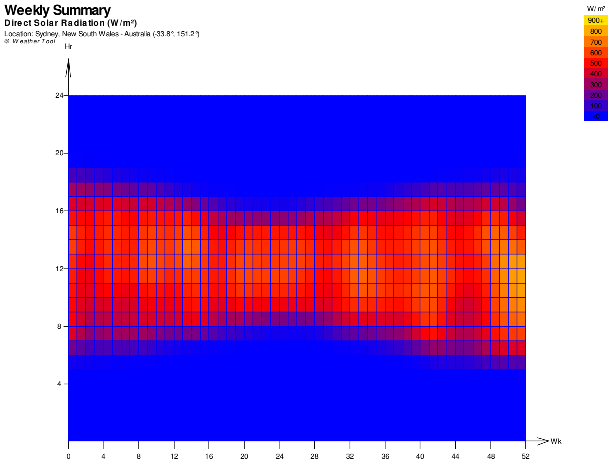


Figure.4.5 Direct Solar Radiation-Weekly Summary

Figure 4.5 shows the direct solar radiation Sydney receives on a weekly basis. Especially during the months October to December and January to March 700 W/m^2 to 800 W/m^2 of solar radiation is incident on Sydney from the hours of 8 A.M through 4 P.M. This particular behaviour gives us the opportunity to make use of the radiation towards day lighting, yet conversely requires us to think of the cooling loads in the summer as well.

In the following pages, the weather data is summarized based on the summer and winter peaks that occur on the 2nd of February and 27th of July respectively. The figures 4.6 and 4.7, in the next page, basically show the maximum, minimum and average monthly temperatures in Sydney. In addition to that the dotted green line shows the relative humidity while the solid green area shows the comfort zones for the particular months. The graphs on the bottom right hand corner show the daily details for the summer peak, 2nd of February and for the winter peak, 27th of July. The figures 4.6 and 4.7 also tell us that the months of January, February, March, April and December require us to provide Cooling to attain comfort conditions. While, the months May, June, July and August require us to provide some sort of heating.

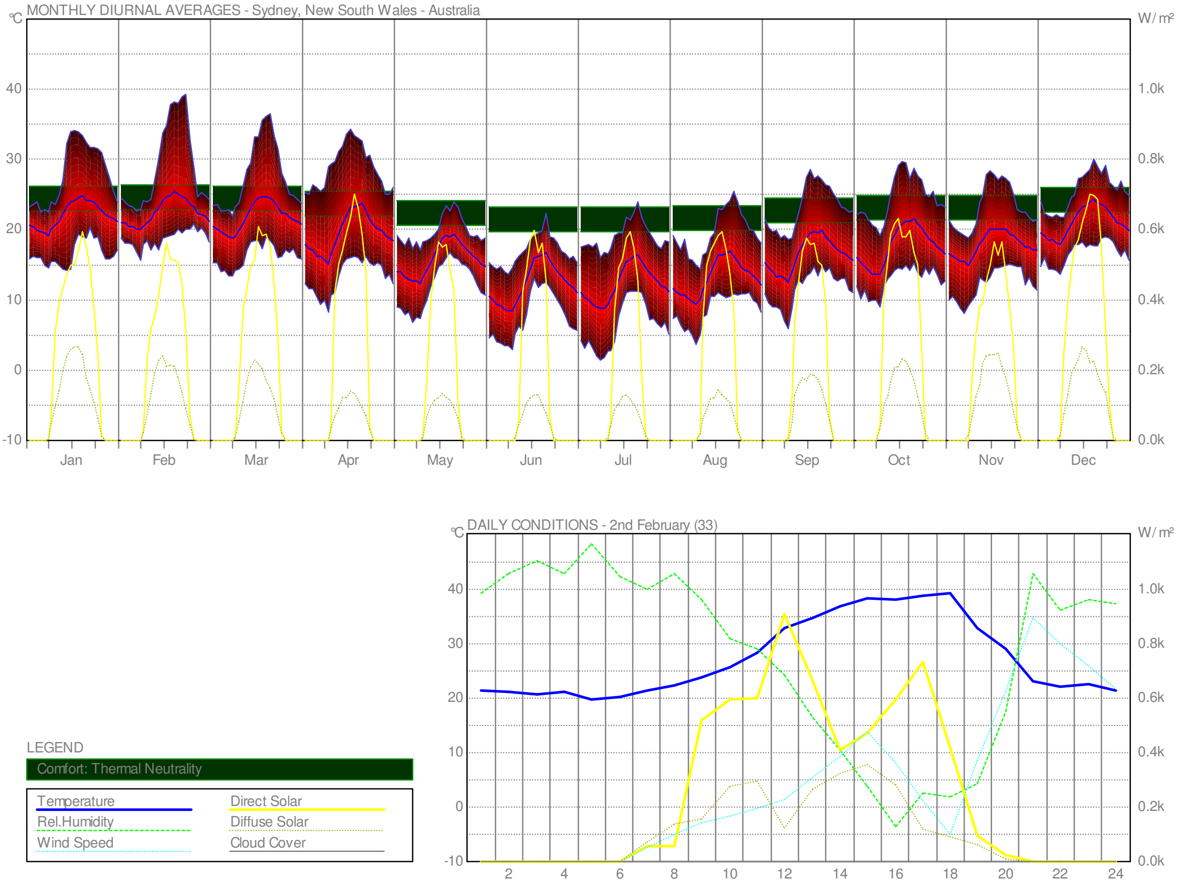


Figure.4.6 Monthly Diurnal Averages – Summer Peak

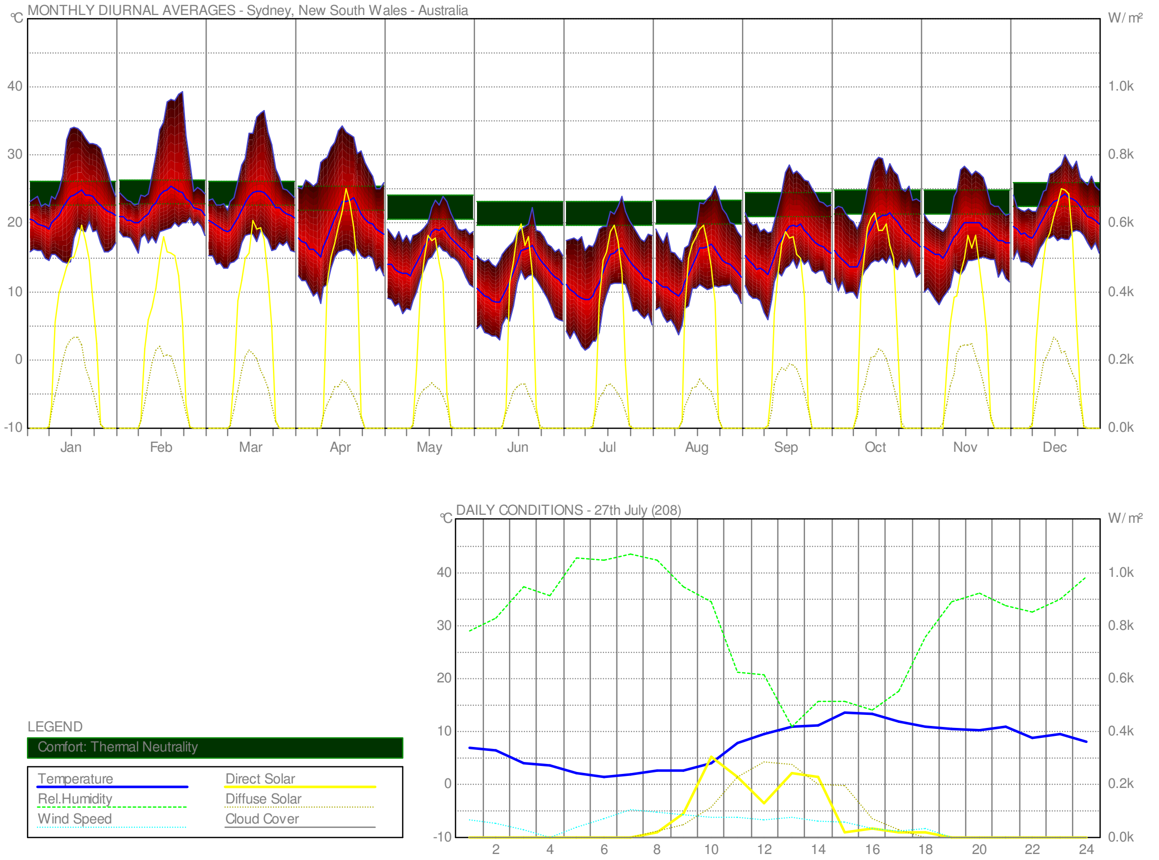


Figure.4.7 Monthly Diurnal Averages – Winter Peak

Based on the aforementioned weather conditions we then shift our focus to the Psychometric charts that show us a comfort band that we shall strive to attain through our designs. The figures 4.8 and 4.9 show us where the comfort zone lies for medium/low activity zones in Sydney for summer and winter respectively.

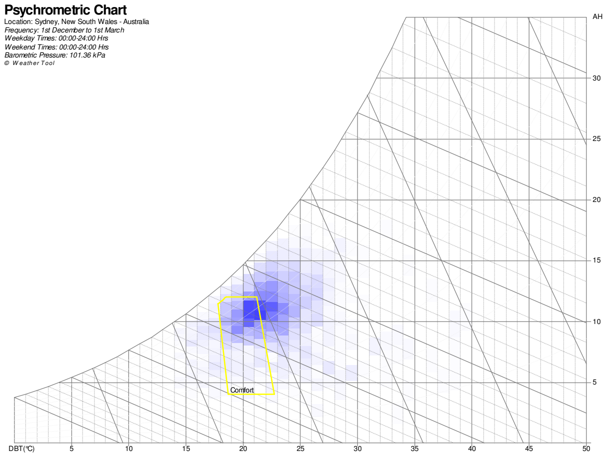


Figure.4.8 Summer Comfort Zone psychrometrics

From the summer comfort zone it is readily understandable the cumulative frequency of the temperature remains outside the comfort band while relative humidity remains inside the comfort band for the most part during summer. This also leads us to believe that during summer months we should mainly consider cooling our site with little or no humidification during the days. And if required, some dehumidification of incoming air during the mornings could be a welcome addition. The morning air tends to be cooler and can be further cooled for daytime use while simultaneously dehumidifying it could prove beneficial and energy conscious.

Again, from the winter comfort zone it is easily understood that the cumulative frequency for temperature falls short of the comfort zone.

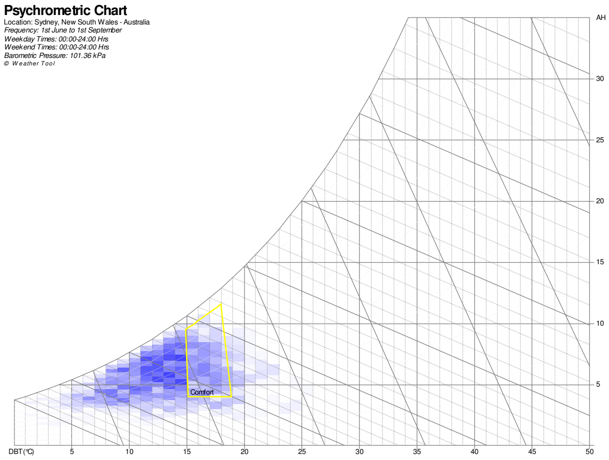


Figure.4.9 Winter Comfort Zone psychrometrics

The relative humidity on the other hand stays at a higher level of 60% to 70%. Therefore, in the winter, we conclude, that we are required to heat the incoming air while probably also not humidifying it since when air is heated without humidification the relative humidity decreases. If the relative humidity of the heated air drops below comfort levels we shall humidify it in hopes of attaining comfort. However, if we choose to heat the morning air, with considerably high relative humidity and low in temperature, we lower the relative humidity while increasing the temperature of incoming air as well.

To design in conformity with climate, the designer needs to understand the microclimate of the site, since all climatic experience of both people and buildings is at this level. This is the reason why; when we laid out our design we called upon the aforementioned Weather details to help us design with the climate on mind. In the subsequent sections we will discuss the methods and principles we have called upon from Building Physics that helped us move closer to energy efficiency. Right from the start we have used Ecotect to measure and improve environmental design factors early on. In almost all projects, decisions made in the first few weeks have the greatest overall impact on building performance. Where it is on site, its basic form and orientation, internal layout, external materials, window size and position Ecotect has helped us get most of this right from the very beginning, as can be seen from this section.

4.3 Insolation Analysis

Insolation on Facades

This section deals with the radiation incident on the facades of the proposed building. The proposed building, as can be seen, has already attained a shape and form. This attainment is a result of the urban fabric and also an explicit understanding of the orientation of the building with respect to the North-South directions.

The following results are the cumulative insolation over each grid over the summer. The results are in Watt Hours (Wh) that is the total amount of energy from the sun that is incident on each facade. Since Power (P) is denoted in Watts and the Time (T) in Hours, Energy (Wh) is the product of Power and Time. And, 1 Watt Hour corresponds to 3.6 Kilo Joules of energy. However amount of Watt Hours is incident on each grid, in this case denotes the total amount of solar energy incident on that grid all over the summer. It should be emphasized that these simulations are not a quantitative analysis but a rather qualitative one that helps us decide which part of the facade to cover and which part to leave open or the deliberate placement of windows for optimum sunlight in the winter and minimum during the summer.

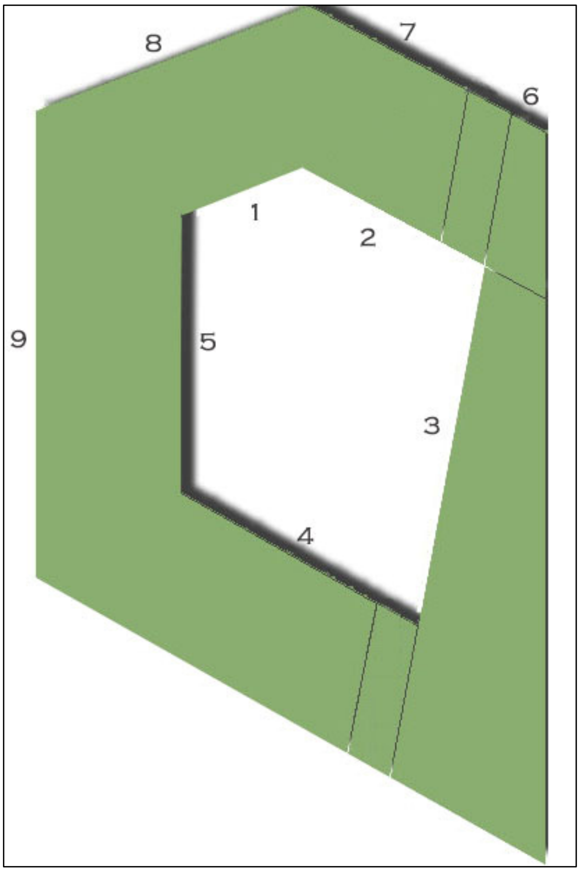


Figure.4.10 Each Facade number coincides with the simulation number.

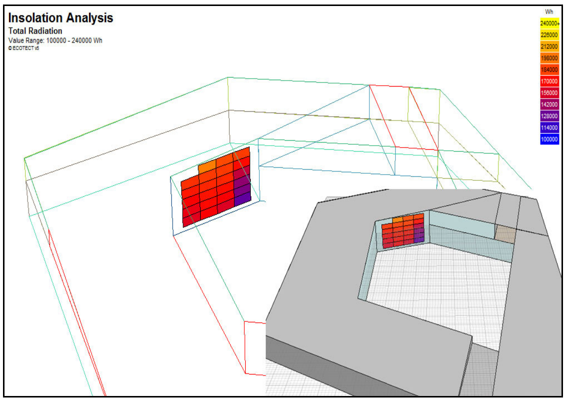


Figure.4.11 Insolation Summer, Facade 1

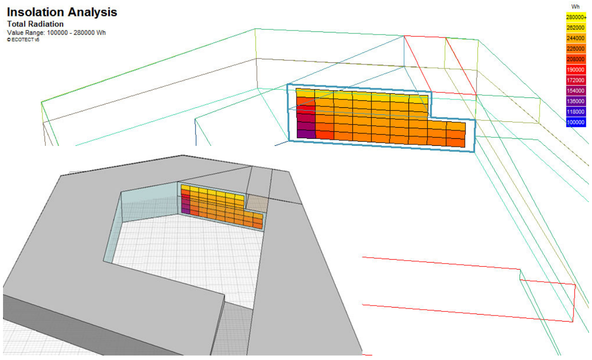


Figure.4.12 Insolation Summer, Facade 2

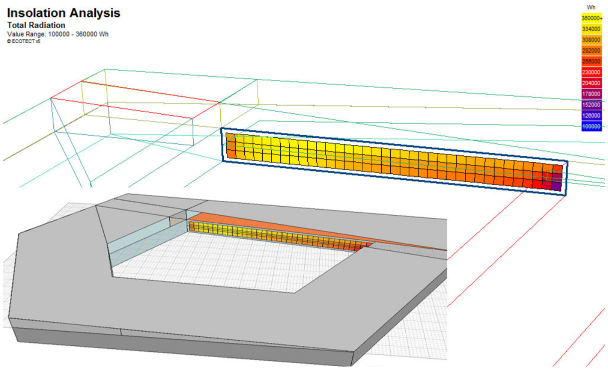


Figure.4.13 Insolation Summer, Facade 3

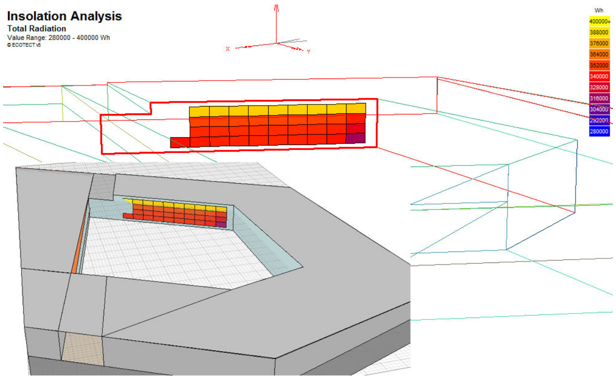


Figure.4.14 Insolation Summer, Facade 4

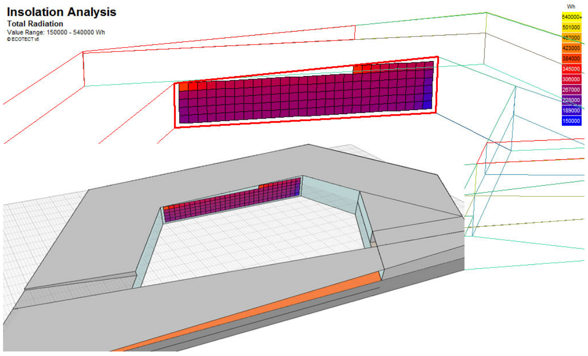


Figure.4.15 Insolation Summer, Facade 5

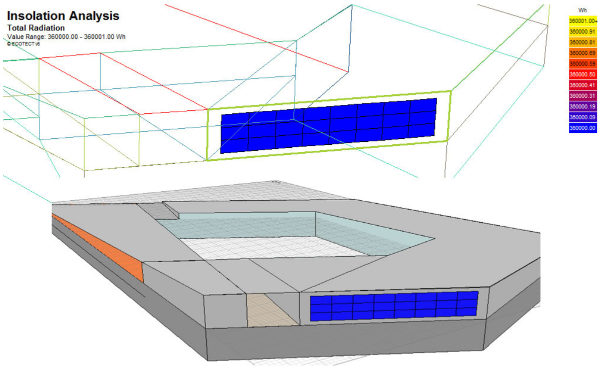


Figure.4.16 Insolation Summer, Facade 7

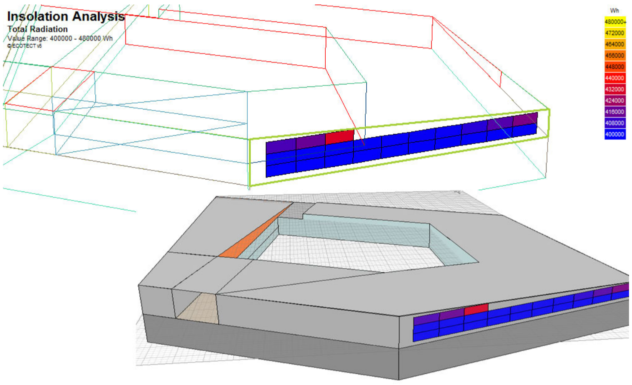


Figure.4.17 Insolation Summer, Facade 8

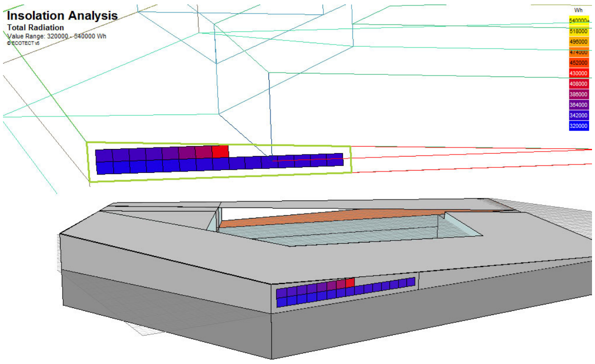


Figure.4.18 Insolation Summer, Facade 9

Figures 4.11 through 4.18 show grids that are colour coded, and this simulation is conducted more for qualitative reasons rather than quantitative ones. Our idea is that where ever we see bright yellow on the facades we want to somehow cover that part or atleast provide some form of technological solution like photovoltaic panels intermittently which can utilize the extra solar radiation as a gain.

It is clear that the facades 3,4,7,8 and 9 receive most of the peak solar radiation and hence requires design considerations and technological solutions to avoid any discomfort for the internal occupants. Facades 4 and 8 receive a staggering total summer insolation of 400000 watt hours. Comparatively facades 3, 7 and 9 each account for a total summer insolation in between 300000 and 360000 watt hours.

These analysis results will be invoked soon as we start thinking of the facade components, openings and cool and warm rooms. In addition, the sun has a slightly high azimuth angle during summer therefore it is in our best interest to prevent the intense radiation making its way inside the rooms. All choices that we make based on these simulations will be evident in the chapters that follow.

Daylight Penetration and load:

Another conclusion, a pretty self explanatory one based of common sense, and that can also be deduced from the Insolation Analysis is the fact that the north, south and south-east facades are the ones that receive the most incident solar radiation. This is a welcome addition in the winter however quite the contrary during summer.

We chose one of the most relevant rooms facing south side. One of those that receives the most radiation and ran simulations to choose the best type of glass or shading or the combination that would suit our needs.

First, we fitted the room with a normal double glazed window, ran the daylight analysis simulation on the room and calculated the heating and cooling load for the room. Once the results were documented we proceeded further. Identical steps were repeated for the same room but this time we fitted the room with an ultra high insulated glass produced by the company SOLERA and NANOGEL. Once each case was documented we weighed all the options and chose the best possible solution.

Before we discuss the results however, let us discuss the significance of day lighting and the allowable percentages that pertain to human comfort. The daylight factor (DF) is a very common method to measure the subjective day light quality in a room. It represents the ratio between indoor and outdoor illuminance levels, expressed in percent. The higher the Daylight Factor, the more natural light is available within a space. Ecotect uses the Building Research Establishment (BRE) Split-Flux method to calculate daylight factors. This method assumes that there are three separate components, ignoring direct sunlight, of the natural light that can reach any point within a building. The DF is simply the sum of each of these three components as seen in equation (I).

DF = SC + ERC + IRC ---------------- (I)

Where,

Sky Component (SC) = directly from the sky, through an opening such as a window. Externally Reflected Component (ERC) = Reflected of the ground, trees or other buildings.

Internally Reflected Component (IRC) = the inter-reflection of light arriving from infinite possible paths.

DF (%)	
≤ *2%*	*Room looks gloomy. Electric lighting needed most of the day.*
2% to 6 %	*Room appears predominantly day lit. Artificial lighting may be required. This value strikes a good balance between daylight & artificial light.*
≥ *6%*	*Room appears strongly day lit. Daytime electrical lighting is likely not needed, but there exists a potential for thermal problems due to overheating.*

Table 4.1 Day Lighting Levels.

One important point to note is that the day light factor values are generally calculated under an overcast sky to represent the worst case scenario to design for. The results are given in terms of percentages and convey a certain physical characteristic. Table 4.1 denotes the characteristics.

The following figures depict the day lighting levels over an analysis grid on the floor of the room. The Daylight Factor is easily discernible with the help of colour coded grids that refer to a certain percentage of daylight levels. These levels give us a lot of information on the amount of daylight received.

With checks made, we also look at the contribution to the cooling and or heating loads by the amount of radiation penetrating the room. Only then are we poised to make the decision for the right technology. Following are the results of each simulation and analysis.

Case 1: Double Glazed Glass

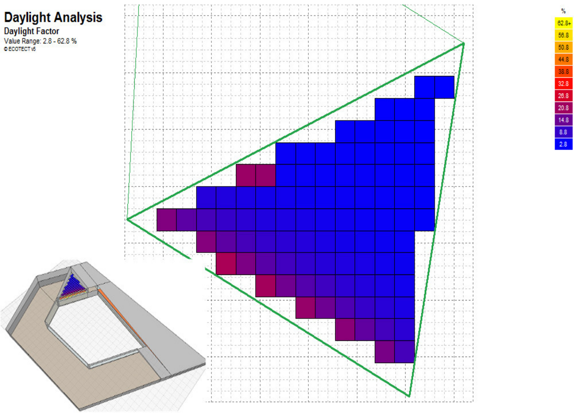


Figure.4.19 Daylight Factor – Double Glazed Glass

Figure 4.19 shows a colour coded graph of the daylight factor in the room, which happens to be a reception and ticketing area. The darkest colour – Blue depicts a Daylight Factor of 2.8%, representing the lower limit of the colour spectrum. The colour spectrum then increases with increments of 2% until reaching the brightest colour - Cardinal that portrays the Daylight Factor of 20.8%.

It is obvious that the double glazed glass will not be ideal alone in terms of daylight to attain comfort level. The majority of the floor is Blue in colour which reads a Daylight Factor between comfortable ranges of 2% to 6%. This is obviously way within allowable levels. The initial two to three metres of the floor receives a little excess day light with Daylight Factor ranging within 8.8% to 20.8% which may lead to thermal problems like overheating.

The subsequent table and graph shows the monthly loads for the reception and ticketing area.

The figure shows a bar chart of the monthly loads in the reception area when we use simple double glazed windows. The y-axis of the chart denotes watts and increases in steps of 180 thousand watts.

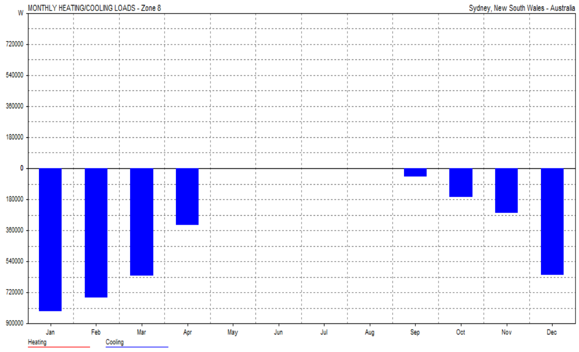


Figure.4.20 Monthly Loads – Double Glazed Glass

Loads			
Month	*Heating (Wh)*	*Cooling (Wh)*	*Total (Wh)*
Jan	*0*	*828144*	*828144*
Feb	*0*	*747850*	*747850*
Mar	*0*	*622717*	*622717*
Apr	*0*	*326614*	*326614*
May	*0*	*0*	*0*
June	*0*	*0*	*0*
July	*0*	*0*	*0*
Aug	*0*	*0*	*0*
Sep	*0*	*49601*	*49601*
Oct	*0*	*167960*	*167960*
Nov	*0*	*256676*	*256676*
Dec	*0*	*618445*	*618445*
Total	*0*	*36180007*	*36180007*
Per m^2	*0*	*7286*	*7286*

Table 4.2 Monthly Loads – Double Glazed Glass

One can easily understand that this room requires more cooling than any heating during the summer months. Also based on the table we can see that the heating load per m^2 is nonexistent. However, the cooling load per m^2 is around 7.2 Kw.

Case 2: SOLERA and NANOGEL

Before we discuss the Daylight factor and loads, let us take a look at SOLERA and NANOGEL.

A double glass insulating glazing unit provides the system with excellent thermal insulation of a U-value of U=0.63 $W/m^2.K$ and a reduced solar heat gain.

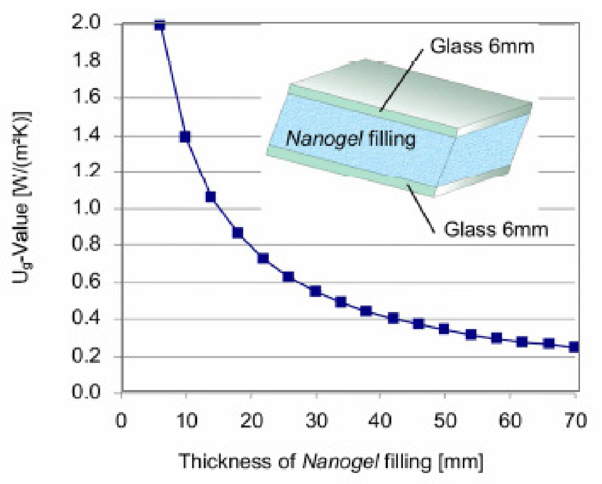


Figure.4.21 U values against NANOGEL thickness with Double Glazed Glass

NANOGEL aerogel is a lightweight, translucent thermal insulation material comprised of 97% air and 3% solids. Aerogel any of a group of extremely light and porous solid materials; the lightest is less than four times as dense as dry air. Aerogels are produced from certain gels by heating the gel under pressure, which causes the liquid in the gel to become supercritical (in a state between a liquid and a gas) and loose its surface tension. In this state, the liquid may be removed from the gel by applying additional heat, without disrupting the porous network formed by the gel's solid component. Silica-, melamine-, and carbon-based aerogels have been produced. Silica-based aerogels are among the lightest, and some, nicknamed "solid smoke" or "frozen smoke," are nearly transparent. Newer, lighter aerogels with relatively high insulating properties are being tested as substitutes for the chlorofluorocarbon foams used as refrigerator insulation and as replacements for the air between the panes of double-glazed windows.

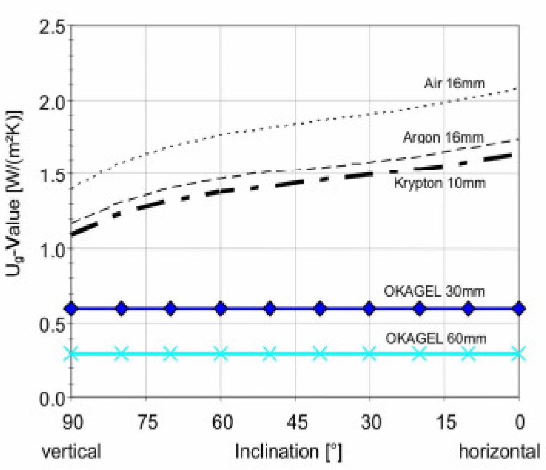


Figure.4.22 U values comparison – NANOGEL against other traditional alternatives in Double Glazed Glass

The unique properties of SOLERA + NANOGEL enable:

- Superior thermal efficiency
- Significantly reduced transmitted noise
- Exceptional glare reduction
- Good Durability
- Hydrophobic Surface

The translucent nanoporous granulate in the cavity results in a best possible even light distribution into the room, independent of the changing irradiation conditions together with glare protection. It can also be designed to have project specific light transmission and total solar transmittance. NANOGEL also exhibits a high light transmission of 75% per cm.

The glazed unit uses a toughened/tempered glass for the outer pane and laminated safety glass for the inner pane. Below are the results from simulations.

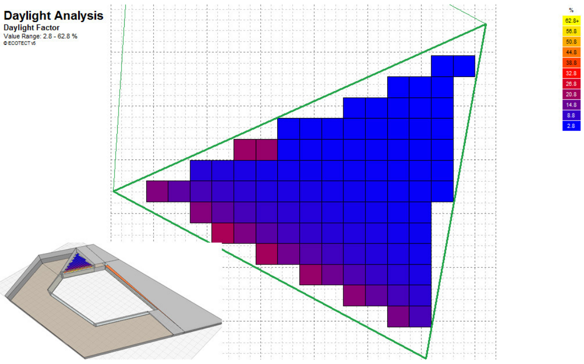


Figure.4.23 Daylight Factor – SOLERA +NANOGEL

Figure 4.23 shows a colour coded graph of the daylight factor in the room, which happens to be a reception and ticketing area. The darkest colour – Blue depicts a Daylight Factor of 2.8%, representing the lower limit of the colour spectrum. The colour spectrum then increases with increments of 2% until reaching the brightest colour - Cardinal that portrays the Daylight Factor of 20.8%. The majority of the floor is Blue in colour which reads a Daylight Factor between comfortable ranges of 2% to 6%. This is obviously way within allowable levels.

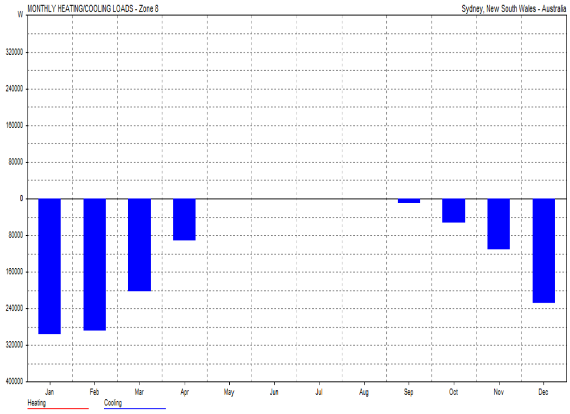


Figure.4.24 Monthly Loads – SOLERA +NANOGEL

Loads			
Month	*Heating (Wh)*	*Cooling (Wh)*	*Total (Wh)*
Jan	*0*	*295634*	*295634*
Feb	*0*	*287905*	*287905*
Mar	*0*	*201958*	*201958*
Apr	*0*	*91039*	*91039*
May	*0*	*0*	*0*
June	*0*	*0*	*0*
July	*0*	*0*	*0*
Aug	*0*	*0*	*0*
Sep	*0*	*9847*	*9847*
Oct	*0*	*52247*	*52247*
Nov	*0*	*110843*	*110843*
Dec	*0*	*228179*	*228179*
Total	*0*	*1277652*	*1277652*
Per m^2	*0*	*2573*	*2573*

Table 4.3 Monthly Loads – SOLERA +NANOGEL

The figure shows a bar chart of the monthly loads in the reception area when we use simple double glazed windows. The y-axis of the chart denotes watts and increases in steps of 80 thousand watts.

When compared to the results of using double glazed glass, SOLERA +NANOGEL definitely comes out superior. It is clear that this room requires very little cooling during the summer months and completely zero heating during the winter. Also based on the table we can see that the heating load per m^2 is nonexistent. However, the cooling load per m^2 is comparatively a smaller value of 2.5 Kw.

The use of NANOGEL as can be seen from comparison has drastically reduced the cooling load. This is due to the fact that solar heat gain coefficient of SOLERA + NANOGEL is considerably less than that of traditional double glazed glass and low thermal conductivity. When the whole picture is looked at, total energy for heating and cooling, is reduced from 7.2 KWh/m^2 to 2.5 KWh/m^2 with the use of NANOGEL.

4.3.1 Passive Measure 1

From the results from Analysis 2, it is evident that the balancing of energy performance with the transparency of the building is a major challenge in the design of our building. However, after running the checks on transparency and balancing it out with the energy performance, the double glazed window system with NANOGEL turn out to be a better choice.

The double glazed glass furthermore, comes in two types. First the Hard Coat (HC) – Low e and second Soft Coat - Low e glass. For this project we have chosen to use the Soft Coat (SC) - Low e glass. This glass has various advantages over normal double glazed units, and they are as follows:

- High visible light transmission.
- Ultra low emissivity's giving optimum summer and winter U-values.
- Up to 70% less UV transmission compared with standard clear glazing.
- Optical clarity with minimal colour haze.

SG Clima plus	*Thickness*
SC-Low e	*6 mm*
Nanogel	*25 mm*
SC-Low e	*6 mm*
U-Value	*0.63 W/m^2.K*

Table 4.4 Type of Glass used in the Unit – SOLERA +NANOGEL

4.4 Ventilation

The term ventilation is used for three totally different processes and it serves three different purposes:

- Supply of fresh air, to remove smells, CO_2 and other contaminants.
- Remove some internal heat when $T_o < T_i$.
- To promote heat dissipation from the skin, i.e. physiological cooling.

The possibility for natural ventilation was minimal or almost nonexistent in our case as the proposed building volume was a Modern art Exhibition Centre that has to maintain a stable environment when it comes to occupant comfort and also taking into account the artifacts health in display.

The use of HVAC (Heating, Cooling and Air Conditioning) refers to the indoor or automotive environmental comfort. The process of Mechanical Ventilating is the process of "changing" or replacing air in any space to control temperature or remove moisture, odours, smoke, heat, dust, airborne bacteria, carbon dioxide, and to replenish oxygen. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. It is one of the most important factors for maintaining acceptable indoor air quality in buildings.

4.4.1 Passive Measure 2

In addition to the earlier passive measure we are also using the ventilated facade. Primarily due to the fact that North West and North West facing facade along with the west facing facade in Barangaroo receives a large amount insolation daily and so we have decided to use ventilated facade.

In terms of thermal energy, these ventilated walls will reduce the amount of heat that the Exhibition building absorbs during the hot summer conditions. This is achieved due to partial reflection of solar radiation by the covering and the ventilated air gap. Further, the application of insulation behind makes possible considerable reduction in the costs of air conditioning. Vice versa, in winter, ventilated walls manage to retain heat, resulting in savings in terms of heating if any and in our case nil.

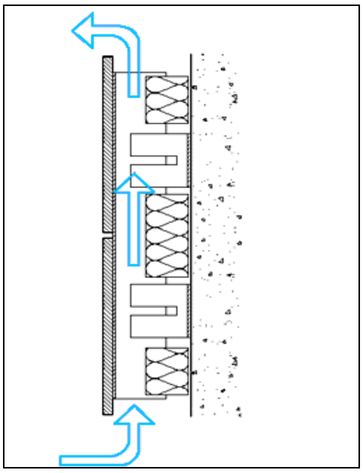


Figure.4.25 Ventilated Facade Concept

In addition, the ventilated walls tend to increase the reflection of external noise that occurs in the busy Barangaroo Foreshore area. The exterior surface including the air gap and insulating material ensures a certain level of acoustic absorption that will abate the sounds from the vehicles and or crowds of people right outside the building. Due to its cooling capabilities combined with sound mitigating characteristics the ventilated facades works very well for our Barangaroo Exhibition Centre.

4.5 Day lighting

Visual comfort is the main determinant of lighting requirements. Good lighting will provide a suitable intensity and direction of illumination on the task area, appropriate colour rendering, the absence of discomfort and in addition a satisfying variety in lighting quality and intensity from place to place and over time. There is an absolute necessity of lighting on human life, health and affairs in general, and specifically the significance of ample quality day lighting. An effective day lighting system will improve our luminous environments and, if properly detailed, save energy. From the environmental perspective, the definition of day lighting also includes the inherent ability to turnoff electric lighting when not needed in the daytime. Daylight is the light to which we are naturally adapted; it is the light against which we measure all other kinds of light, in which we try to view things if we want to know what they really look like. Historically, fine buildings have always exploited natural light and, after a brief interlude, the skilful use of daylight is once again being seen as a critical element in the design of buildings of high architectural quality.

The argument for day lighting in buildings therefore has three strands:

- It provides a healthier indoor climate.
- It conserves the earth's resources.
- Because it saves energy, it saves money.

4.5.1 Passive Measure 3

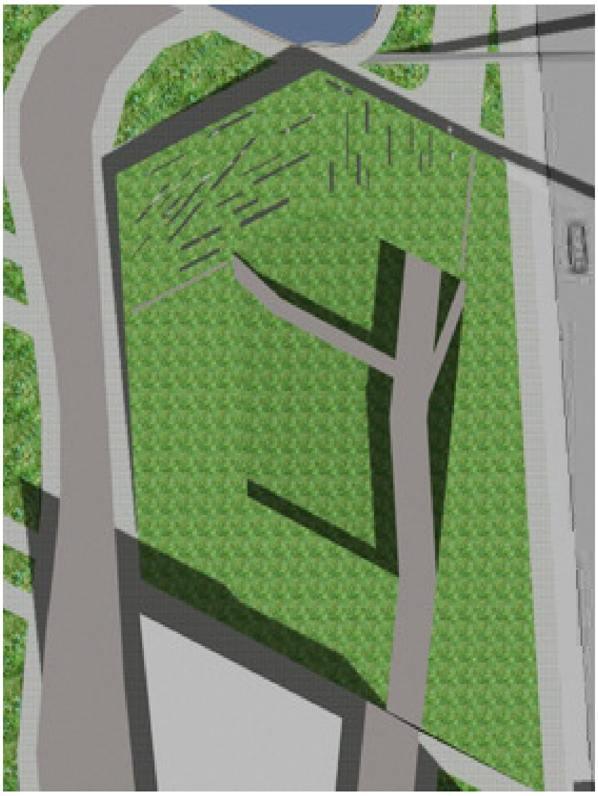


Figure.4.26 Day Light Penetration through Roof Opening's- Skylights.

The North part of the exhibition centre which has a low day light factor as compared to other sections of the centre ,which earlier also confirmed by the low insolation on the facade 1 confirms the need to intervene and add alternate natural sources to improve the visual comfort . This part of the exhibition centre also serves as the first entry point in to the display area and cafeteria which in our architectural point of view needed an additional element of drama and excitement. The slope of the roof and the sun path also adds in the effective function of the skylights in our case. Thus by adding numbers of skylights the play of natural light increases the experience to a whole new level inside the centre at the same time maintaining a preferred level of visual comfort.

4.6 Layer Composition

This section discusses the various layers and their U-Values throughout the building.

To put it simply, a U-Value is the measure of the rate of heat loss through a material. Thus in all aspects of building design one should strive for the lowest U-Values possible because, the lower the U-value, the less heat that is needlessly escaping. The calculation of U-values can be rather complex - it is measured as the amount of heat lost through a one square meter of the material for every degree difference in temperature either side of the material. It is indicated in units of Watts per Meter Squared per Degree Kelvin or [W/m^2K]. Note that Kelvin is used as the scale of temperature difference, but this is numerically equal to C^0.

The U-Value of the layers is calculated with the use of the formula (i):

$U = 1/[R_{Si} + \sum R_i + R_{Se}]$ --------------- (i)

Where, $R = [S/\lambda]$ & R_{Si} and R_{Se}. R_{Si} and R_{Se} are the Internal and External Surface resistance respectively. Both depend on the orientation of the wall.

Once the U-values were calculated they were checked against the standard. If insufficient, they were corrected otherwise left alone. The following tables to the right show the calculations along with the standard values it is checked against.

External Wall

Material	Thick (S)
Tiles	0.010
Air Gap	0.030
Plaster Board	0.010
Vapour Barrier	0.002
Woodwool	0.150
Air Gap	0.080
Polyisocyanurate Board	0.100
Plaster Board	0.010
Total	0.392

U_{Total} = 0.140 W/m^2.K

$U_{allowable}$=0.30 W/m^2.K

Table 4.5 U-value for the External Wall

Internal Floor

Material	Thick (S)
Floor Tiles	0.020
Cement Screed	0.040
Vapour Barrier	0.004
Polyurethane Board	0.080
Concrete	0.200
Air Gap	0.050
Plaster Board	0.010
Total	0.404

U_{Total} = 0.240 W/m^2.K

$U_{allowable}$=0.30 W/m2.K

Table 4.6 U-value for the Internal Floor

Roof

Material	Thick (S)
Sedum Blanket	0.100
Capping Sheet	0.005
Under layer	0.004
Vapour Barrier	0.002
Polyisocyanurate Board	0.120
Structural Steel Tray	0.010
Total	0.241

U_{Total} = 0.160 W/m^2.K

$U_{allowable}$=0.30 W/m^2.K

Table 4.7 U-value for the Roof.

4.7 Technologies

This section talks about the various technologies that are used among different sections of the building.

4.7.1 Photovoltaic Cells

Figure.4.27 Similar Photovoltaic's to be used on interior facades with most insolation.

The use of Photovoltaic cells to generate electricity is widely used across all facets of architectural design. Building Integrated Photovoltaic's (BIPV) are used to convert the solar energy to electricity, with the use of known physical phenomena called the `Photovoltaic Effect'.

The balance of aesthetics and functionality is the key when using photovoltaic cells. In our design we propose to use photovoltaic cells on the facades around the interior shell which are subjected to high insolation. We intend for the electricity generated by these photovoltaic's to be connected to the grid which can be used later. Additionally, the electricity from these photovoltaics will be used for lighting in the building which is equipped with Light Emitting Diode (LED) lights.

4.7.2 LED Lights

Light Emitting Diodes (LED) present many advantages over traditional light sources including lower energy consumption, longer life time, improved robustness, smaller size and faster switching. Typical indicator LED's are designed to operate with no more than 3060 milliwatts [mW] of electrical power. This is one of the key advantages of LED-based lighting, its high efficiency, as measured by its light output per unit power input.

The various advantages of LED lights are listed below:

- LED's produce more light per watt than incandescent light bulbs.
- LED's can emit light of an intended colour without the use of colour filters that traditional lighting methods require. This is more efficient and can lower initial costs.
- LED's can be very small, therefore can be installed anywhere in the building.
- They light up quickly, they achieve full brightness in microseconds.
- These lights can be very easily dimmed, and can be customized to the users visual comfort needs.
- Cool light. In contrast to most light sources, LED's radiate very less heat.
- Compared to Fluorescent lights lifetime of 10 thousand hours, LED's last 40 thousand hours.
- LED's are not toxic like other lights, since they do not contain Mercury.

With the barrage of advantages of LED lights there remains no choice but to use them. We recommend the use of Philips Lumileds in the building.

4.7.3 Green Roof

Besides being aesthetically pleasing, a green roof can provide numerous environmental, technical and owner benefits. We have proposed the extensive use of Green Roof in our project.

Ecological Benefits:

- Mitigates Urban Heat Island: Green roofs cool and humidify the surrounding air creating a microclimate which has beneficial effects within the immediate area.
- Natural Habitat for Animals and Plants: Green roofs create biodiversity, encouraging wildlife, such as birds, butterflies and insects, to remain within urban areas.
- Reduction of Dust and Smog Levels: Green roof vegetation helps to filter out dust and smog particles. Nitrates and other aerosol contaminants are absorbed out of the air and rainfall and bound within the soil.

Technical Benefits:

- Storm Water Retention: Depending on the design, a green roof can typically reduce storm water run-off by 50 to 90%. Additionally, the peak flow volume is greatly reduced and the peak flow period is delayed by as much as 4 hours, minimizing the impact on existing sewer systems.
- Additional Thermal Resistance: Green roofs can improve the thermal resistance of the roof assembly throughout the year, especially in summer months by helping to reduce cooling costs.
- Reduced noise levels: Typical extensive green roofs (80mm – 100mm growing media) reduce reflective sound by up to 3 dB and improve sound insulation by up to 8 dB. This is most effective with buildings near airports, factories or busy freeways.

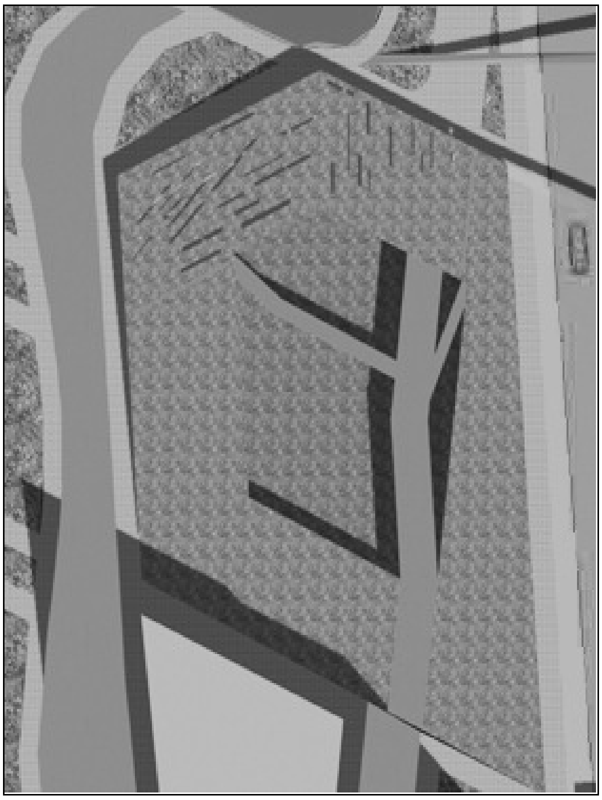


Figure.4.28 Sustainable Use of Green Roof in Barangaroo Exhibition Centre-Sydney.

Other Benefits in addition to the above can be listed as:

- Increased Life Expectancy of the Roof: A green roof, much like a PMR (Protected Membrane Roof) Assembly, protects the roof membrane from climatic extremes and physical abuse, thereby greatly increasing the life expectancy of the roof.
- Additional Usable Space: Converting or designing normally unused roof areas into green roofs simply makes sense. Increase your property value by reclaiming the

fifth elevation of a building and make it an amenity to be used by the buildings occupants.

- Building Incentives: More and more municipalities and other government agencies are providing incentives that can help off-set the cost of a green roof.

5.7.4 Solar Shading System

As one of the most important aspects of the building envelope, solar shading system prevent rooms from overheating in summer, but also optimizes the penetration of natural light and improves the comfort of the user.

The architectural concept of our building is to create a volume with a solid outer envelope and a soft inner envelope basically like a Shell with a harder outer skin and a softer inner. So to maintain this idea we need a shading system that doesn't disturb the core idea of architecture. And which can be used at needed times of intense insolation on the envelopes and where facades are just served by traditional double glazed units (like near the cafeteria on the basement level).

The Integrated Schüco Solar Shading system Schüco CTB (Concealed Toughened Blind) is an external shading device that is integrated in to the facade and is ideal in extreme weather conditions due to its high wind stability. The solar shading is constructed from micro aluminum louvre blades. Optimal Shading is possible and at the same time a high level of transparency provides outside views. Operated by using a 230 V motor, the awning can be concealed in the facade for a cohesive facade appearance.

Figure.5.29 Integrated Schüco Solar shading system by Schüco named Schüco CTB.

The extruded aluminum louvre blades can be perfectly incorporated in to the external design of the building as their outer surfaces can be anodized. Schüco CTB solar shading offers a well balanced design in which form, function and surface finish are in perfect harmony.

The main benefits of this system can be listed as:

- Fully integrated solar shading without a facade mounted fascia
- Guide rail integrated into the facade profile
- Complete protection from when the sun is at an angle of 20° protects rooms from heat.
- Wind stability up to 30 m/s guarantees solar shading even on windy, sunny days.
- Transparency of up to 35 % makes it possible to look outside at anytime
- Louvre blade shape directs diffuse light inside and ensures pleasant room lighting.

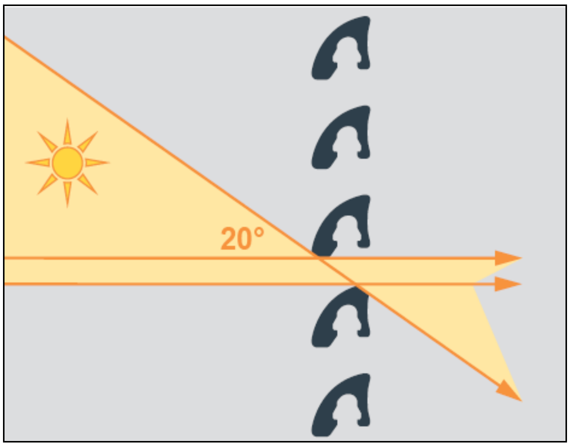


Figure.5.30 Shading from when the sun is at an angle of 20°

The Schüco CTB will be an effective way of providing a good reliable solar shading system.

One of the other alternate ideas discussed and thought of solar shading was the use of solar cooling vacuum tube collectors in row lined along the roof edges as potential shading system. The solar vacuum tube system along the roof can also harness the ample insolation it receives on a daily basis. This active strategy works to reduce the buildings carbon footprint since it utilizes solar energy which is clean, free and safe.
The choice in this case can be of Kingspan Thermomax Vacuum Tube Systems. These Thermomax collectors transform direct and diffuse solar radiation into useful heat. Each solar collector consists of a highly insulated manifold and a row of solar tubes. The vacuum inside each tube provides perfect insulation there-fore protects the system from outside influences such as cold and windy weather or high humidity.

The vacuum technology ensures the most effective transfer of energy into heat, giving extra performance in comparison to traditional flat plate collectors and providing heat not only on warm, sunny days, but also in cooler, windy or humid conditions.

The Thermomax vacuum tube collectors can also be made to work in tandem with solar desiccant cooling system in the Exhibition Centre to meet a majority of the cooling load as well.

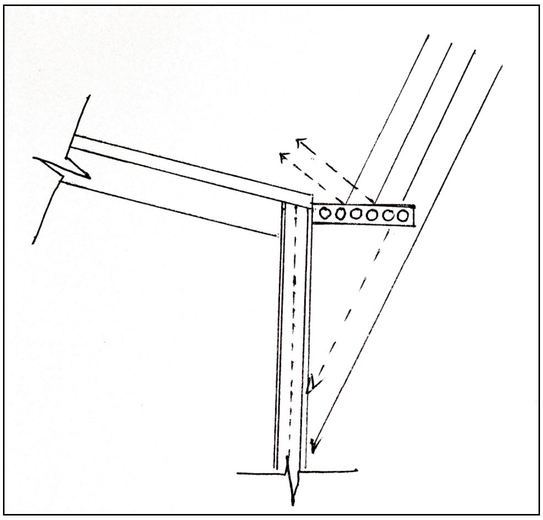


Figure.5.31 Shading with solar vacuum tube system.

4.8 Building Services

After deliberate thought and analysis, based on the summer cooling & winter heating loads, we have decided to use Solar Desiccant Cooling to be the primary system to meet the heating and cooling needs of the Exhibition centre.

Desiccant cooling is an important part of the diverse portfolio of Thermally Activated Technologies (TAT) designed for conversion of heat for the purpose of indoor air quality control. Thermally activated desiccant cooling incorporates a desiccant material that undergoes a cyclic process involving direct dehumidification of moist air and thermal regeneration. This type of cooling is a new and potentially clean technology that can be used to condition the internal environment of buildings without the use of harmful refrigerants. Unlike conventional air conditioning systems, which rely on electrical energy to drive the cooling cycle, desiccant cooling is an open heat driven cycle, which uses a desiccant wheel and thermal wheel in tandem to achieve both cooling and dehumidification. Because it is a heat driven cycle, there is the potential to use environmentally cleaner sources of energy such as gas, hot water, waste heat or any heat source, in our case solar thermal energy, able to elevate the air temperature to a level adequate for reactivation. Desiccant materials, which absorb moisture can be dried or regenerated by adding heat supplied by the solar Photovoltaic Cells on the interior facades of the building. In this proposed system, a wheel that contains a desiccant turns slowly to pick up humidity from incoming air and discharge that humidity to the outdoors or vice versa depending on what want. Below we can see a schematic of the Solar-Assisted Desiccant Cooling that we propose to use.

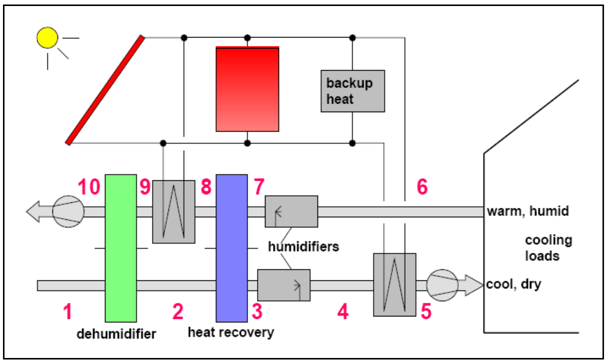


Figure.4.32 Schematic Solar Assisted Cooling.

In this case, the compression machine is used as a heat pump between the supply and the return air streams. It operates by lowering the temperature of the supply air and delivering the condensation heat to the regeneration air. Therefore, a direct evaporator and direct condenser without additional water circuits are used. The advantage of this system is the high heat-recovery rate that can be achieved since the heat pump provides both cooling of the supply air and heating of the regeneration air. The heat pump has to work at a higher compression rate due to the higher temperature difference compared to a machine using ambient air for condensation. Although the supply-air cooler can always provide cooling, it is necessary also to install a humidifier on the supply air side. Since ample solar radiation is available in Sydney this allows the plant to be operated as a conventional solar desiccant cooling system. In the figures 4.29 and 4.30 we can see the cooling and dehumidification process or vice versa with the Solar Assisted Cooling system.

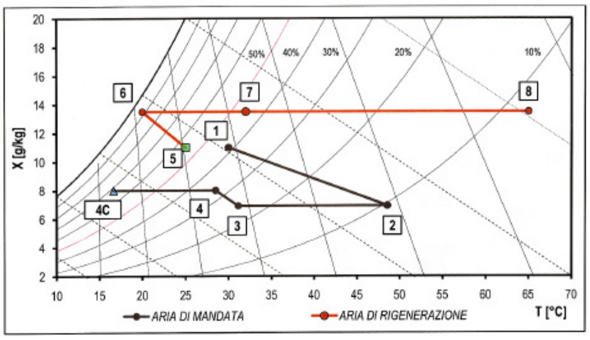
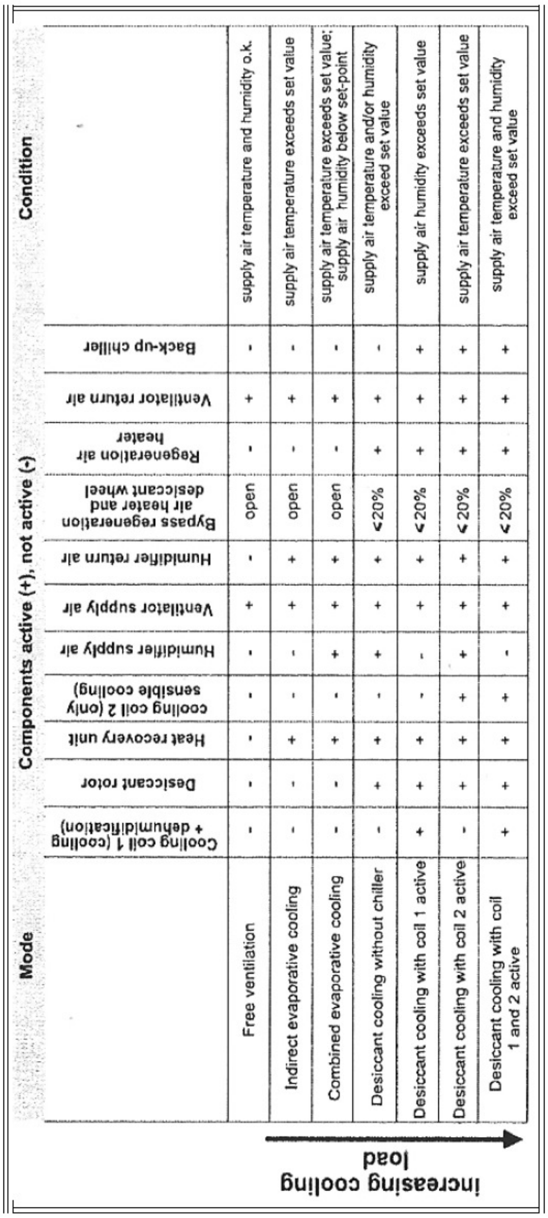


Figure.4.33 Schematic Solar Assisted Cooling plotted on the psychrometric chart.

The process in which air is conditioned is pretty self explanatory from the figures 4.32 & 4.33. The operation of such a solar assisted desiccant cooling system needs to be specified for the conditioning of incoming air during different times of the day and different days of the year. For instance the desiccant device can work in concert with the evaporative cooling device but needs to be specified when. So in the upcoming table we illustrate the operation scheme of a desiccant cooling unit driven with heat coming from solar collector and a compression chiller that provides chilled water for the cooling coils.



Mode	Components active (+), not active (-)											Condition
	Cooling coil 1 (cooling + dehumidification)	Desiccant rotor	Heat recovery unit	Cooling coil 2 (only sensible cooling)	Humidifier supply air	Ventilator supply air	Humidifier return air	Bypass regeneration air heater and desiccant wheel	Regeneration air heater	Ventilator return air	Back-up chiller	
Free ventilation	-	-	-	-	-	+	-	open	-	+	-	supply air temperature and humidity o.k.
Indirect evaporative cooling	-	-	+	-	-	+	+	open	-	+	-	supply air temperature exceeds set value
Combined evaporative cooling	-	-	+	-	+	+	+	open	-	+	-	supply air temperature exceeds set value; supply air humidity below set-point
Desiccant cooling without chiller	-	+	+	-	+	+	+	<20%	+	+	-	supply air temperature and/or humidity exceed set value
Desiccant cooling with coil 1 active	+	+	+	-	-	+	+	<20%	+	+	+	supply air humidity exceeds set value
Desiccant cooling with coil 2 active	-	+	+	+	+	+	+	<20%	+	+	+	supply air temperature exceeds set value
Desiccant cooling with coil 1 and 2 active	+	+	+	+	-	+	+	<20%	+	+	+	supply air temperature and humidity exceed set value

Table 4.8 Operation Scheme of a Desiccant Cooling unit

Although the Solar desiccant cooling system is proposed, it may not meet the peak cooling loads during the summer. While there still arises a need for an auxiliary system. Therefore an auxiliary natural gas driven chiller will meet the remainder of the load. We have chosen to build a massive building in Sydney, with a floor area of close to 13,000 m^2, where the cooling loads soar many factors above the heating load.

However, In figures 4.8 and 4.9 we have also shown the comfort zones on the Psychometric chart for the Barangaroo location. It was our goal to steer the indoor air temperature and humidity to this comfort zone. After careful planning and consultations we have come to the conclusion that the proposed Solar-Assisted Desiccant Cooling system along with the traditional Gas Driven Chiller working in concert, will meet the daily needs for thermal comfort in the building.

Chapter 5

Structural Design

5.1 Introduction

We have chosen steel frame structure based on the fact we need a light weight structure, compared to the reinforced concrete.

Due to the shape of building, the building has been divided into seven structurally sound parts by providing the required dilatations between them. For the purpose of covering the big span for the exhibition center, we used single-span half step-up truss system. The continuity of the columns and the structure are kept as regular as possible.

5.2 The Steel Frame Advantages and Disadvantages

Advantages;

1. Steel frames are extremely strong and durable, able to withstand extreme natural occurrences such as hurricanes and earthquakes.
2. Due to the ease of working with steel, the time of construction is reduced.
3. Steel frame buildings offer significant advantages with increased strength, durability, and stability.
4. Steel creates longer lasting structures that require little maintenance.
5. Due to the lower self-weight, the steel-framed building can reduce the vertical load and earth-quake effect which are transferred from the structure to the foundation.
6. Steel frames are precise and predictable (excellent quality control)

Disadvantages;

1. The cost of making steel is very high and much more expensive than masonry or concrete.

2. The Steel Frame needs fire protection as a result of lower resistance of fire: the beam, column, bracing and the trapezoidal metal sheeting should be covered by fire resisting dope. In addition to this, the cost of fire protection is approximately 30% of the total cost of a steel structure.
3. Insulation is a large-scale difficulty with steel buildings. Steel buildings require the insulation as steel on its own is not a very good insulator.

5.3 Design Assumptions

In conformity with steel-frame construction with truss roof system, it is assumed that resistance to lateral wind loads is provided by a system of localized cross-bracing, and the main steel frame is designed to support gravity loads only. The connections are designed to transmit vertical shear, and to be capable of transferring a horizontal tying force to preserve the integrity of the structure in the event of accidental damage. With these assumptions, the frame is classified as 'simple', and the internal forces and moments are determined using a global analysis which assumes the members to be effectively pin-connected.

5.4 Truss Geometry, Loading, Analysis

All the design choices, calculations and choice methods have been thoroughly calculated by hand. The most common use of trusses in buildings are 32 m span. The design of single-span roof trusses at 6-m centers has been assumed. The roof purlins are used to provide the lateral restraints. The purlins are positioned at node points and are assumed to provide lateral restraint to the top boom at 4-m centres.For the purposes of the analysis, it is assumed that all the joints in the truss are pinned.

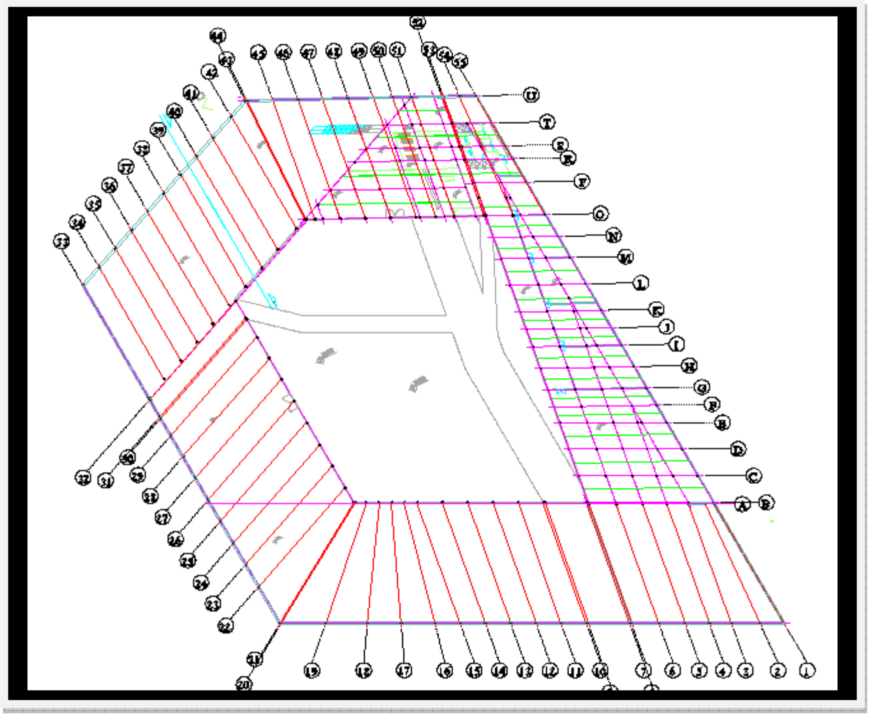


Figure 5.1: Structural Plan

5.4.1 Variable Actions

It is assumed that the roof is accessible with occupancy, giving a characteristic imposed load of $4\ kN/m^2$ by considering snow load as well. “Snowfall was last reported in Sydney City area in 1836.”

Determine wind speeds and design wind pressure in Sydney

Wind speed;$V_{sit,\beta} = V_R . M_d . (M_{z,cat} . M_s . M_t)$

$V_{sit,\beta} = 48{,}3\ m/sn$

Design wind pressure;

p=(0,5. $p_{air} . [V_{des,Q}] . C_{fig.} C_{dyn}$ $C_{fig.}$=$C_{p,e.} K_{a.} K_{c.} K_{l.} K_p = 0{,}8.0{,}8.1.1.1 = 0{,}64$ p=$0{,}895 \frac{kN}{m^2}$

5.4.2 Permanent Actions

Table 5.1 Load Calculation of Green Roof

	kN/m^2
Vegetation Growth Medium(Lighter Soil Medium) Drainage Composite -Drainage -Aeration -Water Storage -Root Barrier(To retard plan growth)	1,1
Insulation(Extruded Polystyrene)	-
Membrane Protection and Root Barrier	-
Roofing Membrane	-
Concrete With Reinforcement(6mm)	1,44
Corrugated Steel	0,1
C Profile	-
Plasterboard	0,1
Service	0,3
Total	3,04 kN/m^2

Table 5.2 Load Calculation of Floor

	kN/m^2
Pavement	0,1
Adhesive Mortar	-
Concrete Screed	0,9
Expanded Polystrene	-
Concrete with Reinforcement	1,4
Corrugated Steel	0,1
Mineral Wool Insulation	-
C profile	-
Plasterboard	0,1
Service	0,3
Total	2, 9 kN/m^2

5.4.3 Design Action

It is assumed that the roof loading is applied at the nodes on the top chord of truss. The design loads are derived as follows;

		Roof	Floor
Variable Actions	;	4x 1,5=6 $\mathrm{kN/m^2}$	4x1,5= 6 $\mathrm{kN/m^2}$
Permanent Actions	;	3,04x1,35 = 4,1 $\mathrm{kN/m^2}$	2,9x1,35=3,9 $\mathrm{kN/m^2}$
Total	;	10,1 $\mathrm{kN/m^2}$	9,9 $\mathrm{kN/m^2}$

The forces applied to each node will be 10,1x6x4=242,4 kN

Wind Uplift

Since there is full wind coming uplift on the truss, the service loading will not be present. 3,04-0,3=3,01 kN/m^2

Wind Uplift ; 3,01x4x6x1,5=108,36 kN

Restraining permanent action ; 3,01x4x6x1=72,74 kN

Total Uplift =35,6 kN

5.4.4 Member Forces

As a general rule the spacing should be between 5m and 10m for the economic range of truss spans. The spacing between two truss systems has been chosen 6m.The shorter side of truss depth is 1m and the longer side is assumed 3.85m with a span-to-depth ratio between 10 and 20 depending on the intensity of the applied loads.

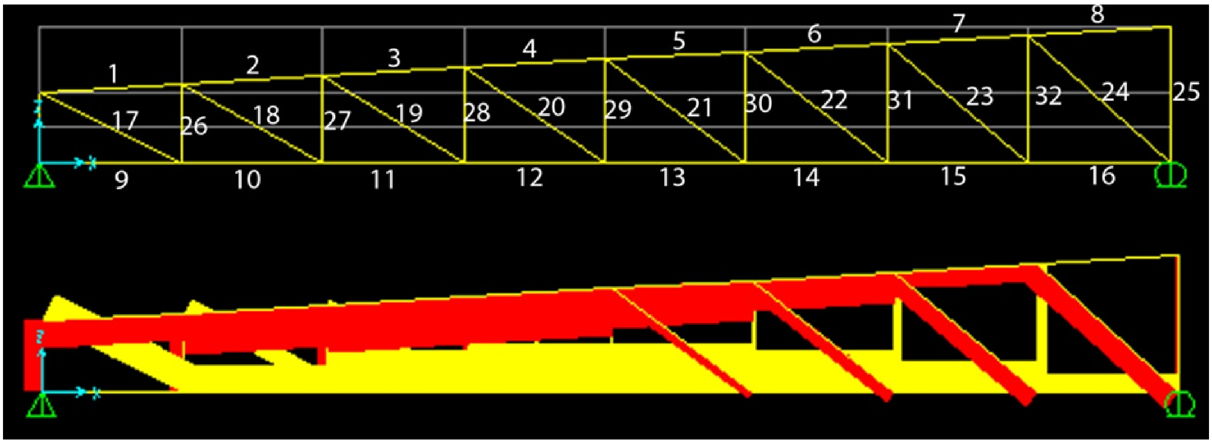


Figure 5.2: Truss Member Force Diagram

Table 5.3 Truss Member Forces (compression negative)

	Force(Kn)			Force(Kn)	
Member	**Vertical**	**Wind**	**Member**	**Vertical**	**Wind**
1	-1523	223	17	1700	-249
2	-2471	347	18	1006	-141
3	-2824	397	19	413	-58
4	-2774	390	20	-59	8
5	-2411	339	21	-449	63
6	-1797	253	22	-780	109
7	-981	138	23	-1066	150
8	0	0	24	-1320	186
9	0	0	25	-126	17
10	1587	-223	26	-794	111
11	2467	-347	27	-490	68
12	2819	-397	28	-216	30
13	2770	-290	29	33	-4
14	2407	-338	30	265	-37
15	1794	-252	31	483	-67
16	979	-138	32	689	-96

5.4.5 Design Using Double-angles

Design assumption allows for bolted splice at mid-span.

5.4.5.1 Top Chord

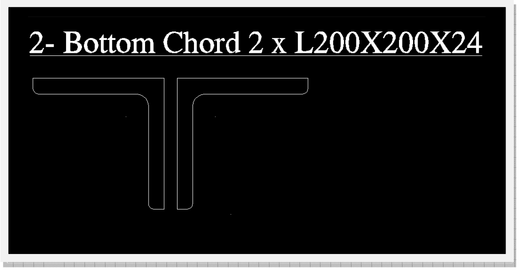


Figure 5.3: Top Chord 2XL200x200x24

Design Forces compression; 2705 kN

Tension caused by wind reversal; 397 kN

Length between restraints; 4,0m both axes

b=420 mm

h=200 mm

t=24 mm

i_z=60,6 mm(radius of gyration)

A=18120 mm^2

Material Properties

$t \leq 40mm$

$f_y = 275N/mm^2$

$f_u = 430N/mm^2$

Section Classification

$\varepsilon = \sqrt{(235/f_y)}$ $\varepsilon = \sqrt{(235/275)}$=0,924

c/t_f=8,75 15 ε = 13,86

The flanges satisfy the requirements for class 3 element.

h/t_w=200/48=4,16 15 ε> h/t_w

13,86>4,16

The stem is a class 3 element.

Section in compression

N_{sd}=2705 kN

The buckling length,L=4000 mm

λ_z=l/i_z=66

λ_1=93, 9x0,924=86,7

$\bar{\lambda}=\lambda_z/\lambda_1\ .\beta_A^{0,5}$=0,761

Buckling curve,c

χ =0,699

The design buckling resistance of a compression member shall be taken as;

N_{sd}= χ. $\beta_A^{0,5}$.A. f_y/γ_{m_1}=3317 kN$\geq$ N_{sd}=2705 kN satisfactory√

Section in tension

Under wind uplift max.tension on top chord ; 397 kN

$N_{Rd}=A.f_y/\gamma_{m_0}$=18120x275x$10^{-3}$/1,05=4745kN$\geq$ N_{sd}=397kN satisfactory√

5.4.5.2 Bottom Chord

Design forces for bottom chord;

Tension ; 2701 kN

Compression; 390 kN

There will be bolted splice at the point of max force.

Resistance of M27 bolts,grade 4,6

A_s=460mm^2

f_{ub}=400N/mm^2

γ_{M_b}=1,35

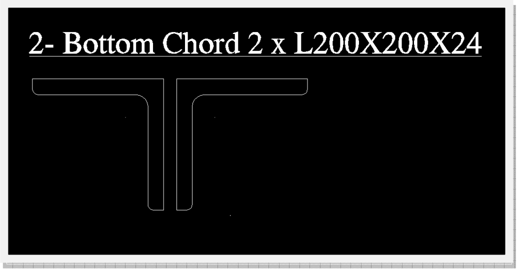


Figure 5..4: Bottom Chord 2XL200x200x24

Shear resistance per shear plane

$$F_{V,Rd} = \frac{0{,}6.\, f_{ub}.A_s}{\gamma_{M_b}}$$

$F_{V,Rd}$=81,7 kN

d_o=27+3=30mm

e_1 =60 mm for plates

$e_1/3.\,d_o$=0,666 for plates 0,555 for section

$$\frac{p_1}{3.\,d_0} - \frac{1}{4} = 0{,}583$$

f_{ub}/f_u=400/430=0,930

α=0,555(the smallest one)

Bearing Resistance

$$F_{b,Rd} = \frac{2{,}5.f_u.d.\,t}{\gamma_{M_b}} = 477\ kN$$

477Kn for stem,238 kN for flange

For bolts in four each shear;

$F_{v,sd} \leq 4x81{,}7$

$\leq$326,8kN

The resistance of the bolts is provided by four each shear.

Number of bolts required = $N_{sd}/F_{v,sdmax}$

=2701/326,8=9 bolts

9 bolts are used to provide the required resistance.

To carry the shear resistance of the bolts in bearing

Minimum plate thickness;

$$\frac{F_{v,Rd}\cdot\gamma_{M_b}}{2{,}5.\alpha.f_{ud}} = 6{,}84\ \mathrm{mm}$$

20 mm splice plates between back to back profile have been placed.

Limiting stress to limit deformations;

0,85.(430+275)/1,35=444 $\mathrm{N/mm^2}$

Maximum bearing stress(in stem)

$$\frac{2819}{9}\mathrm{x}\frac{10^3}{27\mathrm{x}40} = 290\mathrm{N/mm^2} \leq 444\ \mathrm{N/mm^2}$$

Check tension resistance of member

The checks required for the tension resistance of the member are as follows;

-the resistance of the whole section ($N_{pl,Rd}$), and

-the resistance of the section where bolts are located

Resistance of the whole section;

$$N_{pl,Rd} = \frac{A.f_y}{\gamma_{M_0}} = \frac{18120\mathrm{x}275}{1{,}05\mathrm{x}10^3} = 4745\ \mathrm{kN}$$

-Resistance at bolt holes at any section allowing four 30mm diameter.

A_{net}=A minus area of all bolt holes

A_{net}=18120-30x(2x20)=16920 $\mathrm{mm^2}$

γ_{M_2}=1, 25

$$N_{u,Rd} = \frac{0{,}9.A_{net}.f_{ud}}{\gamma_{M_2}} = \frac{0{,}9\mathrm{x}16920\mathrm{x}430}{1{,}25\mathrm{x}10^3} = 5238\ \mathrm{kN} \geq 2701\mathrm{kN}\surd\ \text{satisfactory}$$

Section in compression

N_{Sd}=397 kN

$N_{b,Rd}=\chi\cdot\beta_A\cdot A.f_y/\gamma_{m_1}$

The buckling length = 4000 mm

λ_z=l /i_z=66 λ_y=l /i_y=4000/39=102

λ_1=93, 9x0,924=86,7

$\bar{\lambda}_z=\lambda_z/\lambda_1\ .\beta_A^{0,5}$=0,761 $\bar{\lambda}_y=\lambda_y/\lambda_1\ .\beta_A^{0,5}$=1,17

Buckling curve,c,

$\bar{\lambda}_{eff,z}$=0,5+0,7x0,761=1,03

$\bar{\lambda}_{eff,y}$=0,35+0,7x1,17=1,17

χ_{min}=0,45

$$N_{b,Rd} = \chi.\ \beta_A.A.f_y/\gamma_{m_1}$$

$$= 0{,}45x1x18120x275/1{,}05/10^3\ =\ 2135kN \geq 397kN\ \surd\ \text{satisfactory}$$

5.4.5.3 Diagonal Brace Members

The critical member is that adjacent to the support.

Design forces for diagonal brace member;

Tension ; 1700 kN

Compression; 1265 kN

b=420 mm

h=200 mm

t=20 mm

i_z=61,12 mm(radius of gyration)

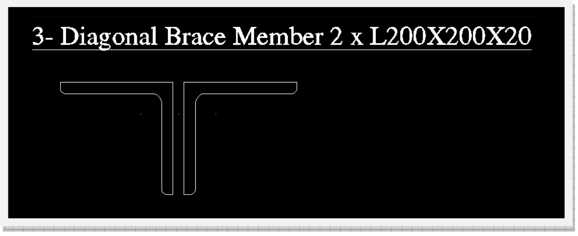


Figure 5.5: Diagonal Brace Member 2XL200x200x20

A=15270 mm^2

The connections between top and bottom chord are provided by 20 mm gusset plate. There will be bolted splice at the point of max force.

M27 bolts, grade 4,6

A_s=460mm^2

f_{ub}=444 N/mm^2

γ_{m_b}=1,35

$$F_{v,Rd} = \frac{0{,}6.f_{ub}.A_s}{\gamma_{M_b}} = 81{,}7kN \qquad (\text{Shear resistance})$$

d_o=27+3=30mm

e_1=50mm for section = 60mm for plate

e_1/d_o=0,555 for section=0,667 for plate

$$\frac{p_1}{3d_o} - \frac{1}{4} = 0{,}583$$

$$\frac{f_{ub}}{f_u} = \frac{400}{430} = 0{,}930(< 1{,}0)$$

α=0,555 for section=0,667 for plates=40 mm

$$F_{b,Rd} = \frac{2{,}5.\alpha.f_u.d.t}{\gamma_{M_b}} = 447 \text{ kN for stem },238 \text{ kN for flange}$$

For bolts in four shear;

$$F_{v,sd} \leq 4x81{,}7 = 326{,}8 \text{ kN}$$

Number of bolts required; 1775/326, 8=6 bolts

Minimum plate thickness;

$$\frac{F_{v,Rd}.\gamma_{M_b}}{2{,}5.\alpha.f_u} = 6{,}84 \text{ mm} < 20mm\ gusset\ plate$$

Limiting stress=0,85(430+275)/1,35=444 N/mm^2

Max bearing stress(in stem);

$$\frac{1775}{6}x\frac{10^3}{27x30} = 365N/mm^2 \leq 444\ N/mm^2$$

<u>Section in Tension</u>

$$N_{t,Rd} = N_{pl,Rd} = A.\frac{f_y}{\gamma_{M_0}} = \frac{15270x275}{1{,}05x10^3} = 4000kN \geq N_{sd} = 1700kN$$

<u>Section in Compression</u>

$N_{sd} = 1320\ kN$

Section Classification; class 3

$\varepsilon = \sqrt{(235/f_y)}$ $\varepsilon = \sqrt{(235/275)}$=0,924

h/t_w=150/42=3,57 15 ε = 13,86

The flanges satisfy the requirements for class 3 element.

The buckling length = 5000 mm, $\beta_A^{0,5} = 1$

λ_z=l /i_z=5000/61,12=81,8 λ_y=l /i_y=5000/39,2=127

λ_1=93, 9x0,924=86,7

$\bar{\lambda}_z$=$\lambda_z/\lambda_1\ .\beta_A^{0,5}$=0,94 $\bar{\lambda}_y$=$\lambda_y/\lambda_1\ .\beta_A^{0,5}$=1,46

Buckling curve,c,

$\bar{\lambda}_{eff,z}$=0,5+0,7x0,94=1,16

$\bar{\lambda}_{eff,y}$=0,35+0,7x1,46=1,37

χ_{min}=0,36, $\gamma_{M_1} = 1{,}05$

$N_{b,Rd}$=$\chi.\beta_A.A.f_y/\gamma_{m_0} = 0{,}36x1x15270x275/1{,}05/10^3 = 1439kN \geq 1265kN\sqrt{}$ satisfactory

5.4.5.4 Vertical Brace Members

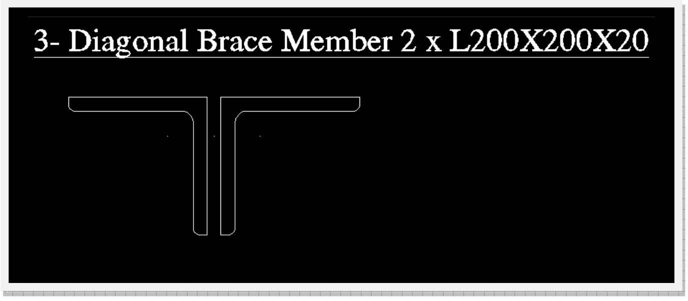


Figure 5.6: Vertical Brace Member

Design forces for vertical brace members;

Maximum Tension ; 660 kN

Maximum Compression; 760 kN

b=320 mm

h=150 mm

t=15 mm

i_z=45,7 mm(radius of gyration)

A=8600 mm^2

<u>Section in compression</u>

$N_{sd} = 760\ \mathrm{kN}$

Section Classification; class 3

The buckling length = 3600 mm, $\beta_A^{0,5} = 1$

$\lambda_z = l / i_z = 3600/45{,}7 = 78{,}7$ $\lambda_y = l / i_y = 3600/29{,}3 = 122{,}8$

$\lambda_1 = 93{,}9 \times 0{,}924 = 86{,}7$

$\bar{\lambda}_z = \lambda_z / \lambda_1 \cdot \beta_A^{0,5} = 0{,}9$ $\bar{\lambda}_y = \lambda_y / \lambda_1 \cdot \beta_A^{0,5} = 1{,}42$

Buckling curve,c,

$\bar{\lambda}_{eff,z} = 0{,}5 + 0{,}7 \times 0{,}9 = 1{,}13$

$\bar{\lambda}_{eff,y} = 0{,}35 + 0{,}7 \times 1{,}42 = 1{,}34$

$\chi_{min} = 0{,}36$, $\gamma_{M_0} = 1{,}05$

<u>Section in tension</u>

$N_{b,Rd} = \chi \cdot \beta_A \cdot A \cdot f_y / \gamma_{m_0} \quad = 0{,}36 \times 1 \times 8600 \times 275/1{,}05/10^3 = 810\ \mathrm{kN} \geq 660\mathrm{kN}\ \surd$ satisfactory

5.4.6 Column Design

We assume that the connection between columns and end of truss system are connected as a nominally pinned connection. The pinned connection is capable of transmitting the calculated design forces, without developing significant moments.

5.4.6.1 Selection of column

Steel truss members weight have been added to permanent values.

Loading;	Variable Action	Cumulative	Permanent Action	Cumulative
Roof	384 kN		331 kN	
		384 kN		331 kN

Partial Safety Factors for Loading

Permanent Action

$\gamma_{G,sup} = 1{,}35$

Variable Action

$\gamma_{G,sup} = 1{,}50$

Section Properties

305x305x198 universal column has been chosen.

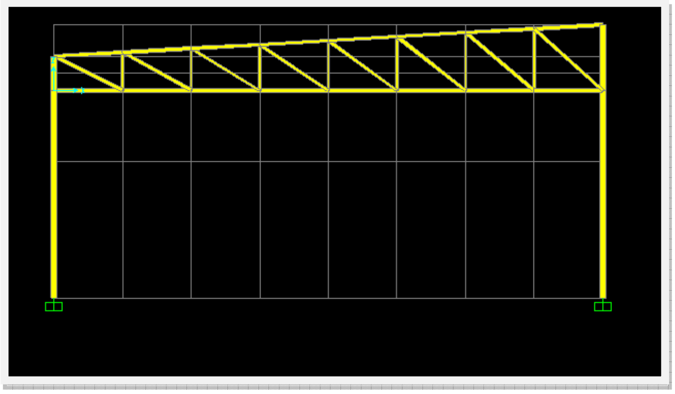


Figure 5.7: 305x305x198UC Universal Columns

h =406,4 mm b=403 mm

t_w=26,6 mm t_f=42,9 mm

d/t_w=10,9 mm c/ t_f=4,7 mm

A=433cm^2 I_y=1225x$10^6\mathrm{mm}^4$

I_w=15500x$10^9\mathrm{mm}^6$ I_z=468,5x$10^6\mathrm{mm}^4$

I_t=23430x$10^3\mathrm{mm}^4$ $W_{pl,y}$=6999x$10^3\mathrm{mm}^3$

$W_{el,y}$=6031x$10^3 mm^3$

i_z=104 mm

i_y=168 mm

$i_z = \left(\frac{I_z.I_W}{W_{pl,y}^2}\right)^{0,25}$ =110 mm

$a_{LT} = \left(\frac{I_W}{I_t}\right)^{0,5}$ =813 mm

Classification of Cross Section

The section is designed to withstand to small moments in addition to axial force. The section is always in compression.

$\varepsilon = \sqrt{(235/f_y)}$ $\varepsilon = \sqrt{(235/275)}$=0,924

Flange	Web
10ε=10x0,924=9,24	33ε =33x0,924=30,5
c/t_f=4,7	d/t_w=10,9
c/t_f<10ε	33ε > d/t_w

In accordance with the limiting value of c/t_f and d/t_w ,the classification of cross section is a class 1 section.

Design Value of Actions

The column supports the load from the roof.

G_k=292 kN

Q_k=384 kN

=$\Sigma\gamma_{Gj}.G_{kj} + \gamma_{Qi}.G_{Qi}$

=1,35x331+1,5x384

=1023 kN

The effect of unbalanced loading on either side of the column must be taken into account.

h/2+100mm=406,4/2+100=303 mm

$M_{y,sd}=1023x303/10^3$ =310 kNm

Resistance of Cross-section

For a class 1 section without bolt holes, the reduced design plastic moment, allowing for the axial force is;

$$M_{Ny,d}=\frac{M_{ply,Rd}.(1-n)}{(1-0,5a)}$$

Where,

n=$N_{Sd}/N_{pl,Rd}$

a=(A-2xbxt_f)/A

$M_{ply,Rd}=W_{pl}.f_y/\Upsilon_{Mb}$

=6999x10^3x275/1,05/10^6

=1833 kN

Applied force;1023 kN

For a member subject to axial compression,the design plastic resistance of the cross section is;

$N_{pl,Rd}$=A. f_y/Υ_{Ma}

=43300x275/1,05/10^3=11340 kN

n=1023/11340=0,1 , a=(43300-2x403x42,9)/43300=0,2

$$M_{Ny,d}=\frac{M_{ply,Rd}.(1-n)}{(1-0,5a)}=1833.\frac{1-0,1}{1-0,5x0,2}=1833kNm>M_{sd}=254kNm$$

Buckling Resistance of The Member

A class 1 member subject to axial compression is checked for the following modes of failure;

-Flexural buckling

-Lateral torsinal buckling

$$M_{Ny,d}=\frac{N_{sd}}{\chi_{min}.A.f_y/\Upsilon_{M1}}+\frac{k_y.M_{y,sd}}{W_{ply}.f_y/\Upsilon_{M1}}\leq 1,0$$

Applied axial force,

$N_{sd}=1023kN$

χ_{min} is of χ_y,where χ_y is the reduction factor for y-y axes.

λ_y=l /i_y=16000/168=95,2

λ_1=93, 9x0,924=86,7

$\bar{\lambda}_z=\lambda_z/\lambda_1 .\beta_A^{0,5}$=95,2/86,8x$1^{0,5}$=1,1 buckling curve a

χ_y=0,596

To calculate ky

$$M_{Ny,d}=1-\frac{\mu_y.N_{sd}}{\chi_y.A.f_y}\quad \text{but } k_y\leq 1,5$$

$\mu_y=\bar{\lambda}_y(\beta_{\mu y}-4)-(W_{ply}-W_{ely})/W_{ely}$ $\mu_y \leq$0,9

$\Psi=1,0$, $\beta_{\mu y}$(Moment factor)=1,3

μ_y=1,1x(2x1,3-4)+(6999x10^3-6031x10^3)/(6031x10^3) = -1,37

$M_{Ny,d}=1—1,37x1023x10^3 0,596x43300x275=$

1,2≤1,5

$M_{Ny,d}$=0,354≤1,00 is satisfied for flexural buckling.

Lateral Torsional Buckling

$$\frac{N_{sd}}{\chi_z.A.f_y/\Upsilon_{M1}}+\frac{k_{Lt}.M_{y,Rd}}{\chi_{Lt}.A.W_{ply}/\Upsilon_{M1}}\leq 1,0$$

Applied axial force; N_{sd}=1023 kN

Applied moment ; $M_{y,Rd}$=310kNm

$$k_{LT} = 1 - \frac{\mu_{LT}.N_{sd}}{\chi_z.A.f_y} \qquad k_{LT} \leq 1{,}0$$

μ_{LT}=0,15.$\bar{\lambda}_z$. $\beta_{\mu,LT}$-0,15

=0,14 $\leq$ 0,9

λ_y=l /i_z=16000/104=153

λ_1 =86,7

$\bar{\lambda}_z=\lambda_z/\lambda_1\ .\beta_A^{0,5}$=153/86,7x$1^{0,5}$=1,76

χ_z=0,253

k_{LT} =0,99≤1

For a nominally pin-ended I section with end-moment loading only the value of λ_{LT} can be obtained from;

$$\lambda_{LT} = \frac{{}^{L}/_{i_{LT}}}{C_1^{0,5}.\left[\left(1+\frac{(L/a_{LT})^2}{25{,}66}\right)\right]^{0,25}} = \frac{{}^{16000}/_{110}}{1^{0,5}.\left[\left(1+\frac{(16000/813)^2}{25{,}66}\right)\right]^{0,25}} = 72{,}6 \text{ using curve a}$$

$\bar{\lambda}_{LT}=\lambda_{LT}/\lambda_1\ .\beta_A^{0,5}$=72,6/86,8x$1^{0,5}$=1,1 buckling curve a

χ_{LT}=0,77

$$\frac{N_{sd}}{\chi_z.A.f_y/\gamma_{M1}} + \frac{k_{Lt}.M_{y,Rd}}{\chi_{Lt}.A.W_{ply}/\gamma_{M1}} \leq\ 1{,}0$$

0,574 $\leq$ 1,0 is satisfied for lateral buckling.

5.4.7 Bracing design

According to the design actions obtained from frame imperfections and wind loading on bracing system,2LX200X200X24 steel profile has been used. These forces are distributed equally between each bracing system. The cross-braced system has been used in each of the two end-walls into seven sound parts. As the longitudinal bracing is provided by external shear walls, interior parts of structures are supported by cross-braced system in each of the two ends.

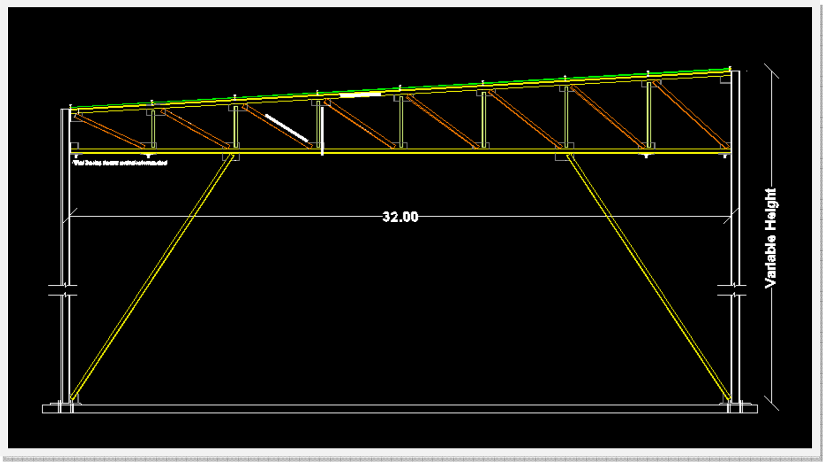


Figure 5.8: 2XL200x200x24 Equal angle steel profiles for transverse bracing

In accordance with the design load obtained from sap2000, 2LX200X200X24 steel profile is used for bracing.

Section Classification

$\varepsilon = \sqrt{(235/f_y)}$ $\varepsilon = \sqrt{(235/275)}$=0,924

c/t_f=8,75 15 ε = 13,86

The flanges satisfy the requirements for class 3 element.

h/t_w=200/48=4,16 15 ε> h/t_w

13,86>4,16

The stem is a class 3 element.

Resistance of cross-section

$N_{c,Rd} = A.\, f_y/\gamma_{M0}$=18120x275/1/$10^3$=4983kN >360kN

Buckling resistance

λ_1 =86,7

λ_y=l /i_z=14500/60,6=240

$\bar{\lambda}_z$=$\lambda_z/\lambda_1\ .\beta_A^{0,5}$=240/86,7x$1^{0,5}$=2,76

$N_{b,Rd}$= $\chi.\ \beta_A.A.f_y/\gamma_{M1}$=0,12x1x18120x275/1,05/$10^3$=570kN >260 kN

Figure 3.8 shows roof trusses in place in a building with the purlins providing lateral support to the top chord, and a lower chord bracing system providing lateral support to the bottom chord.

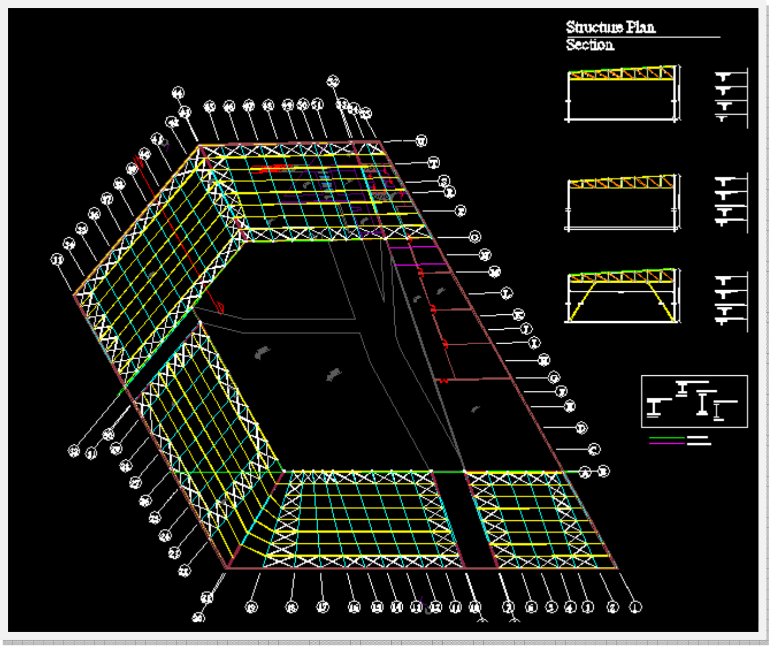


Figure 5.9: The purlins and bracing systems.

5.5 Two Storey Steel Frame Structure Analysis

The design choices, calculations and choice methods have been thoroughly calculated by hand. The frame is classified as 'simple' and internal forces and moments are determined using a global analysis which assumes the members to be effectively pin-connected. The connections are designed to transmit vertical shear, and to be capable of transferring a horizontal tying force to preserve the integrity of the structure.

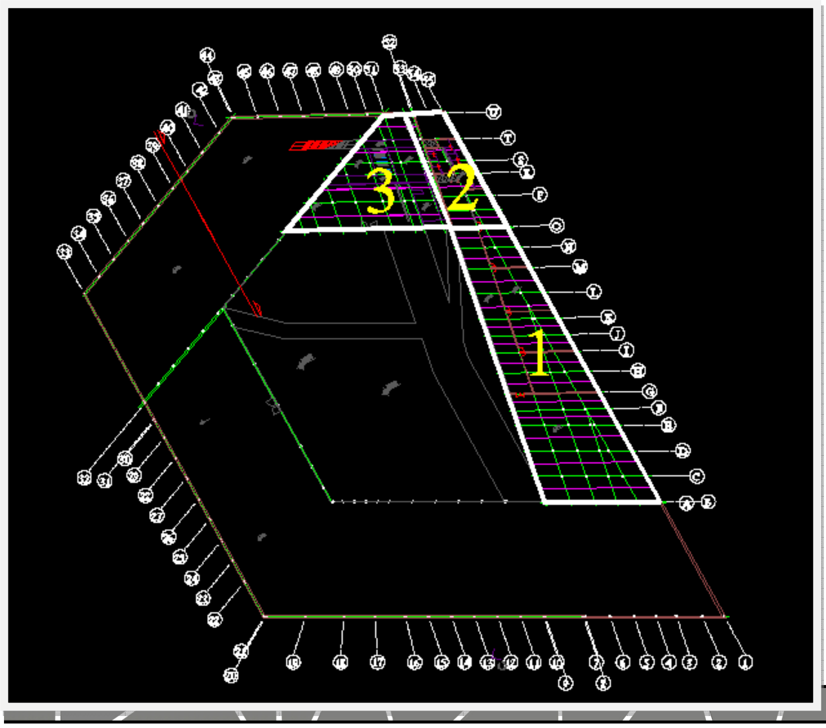


Figure 5.10: Two store braced frame structure blocks

5.5.1 Selection of the Beams

5.5.1.1 The Secondary Beam

The secondary beam is supported at both ends and is fully restrained along its length.

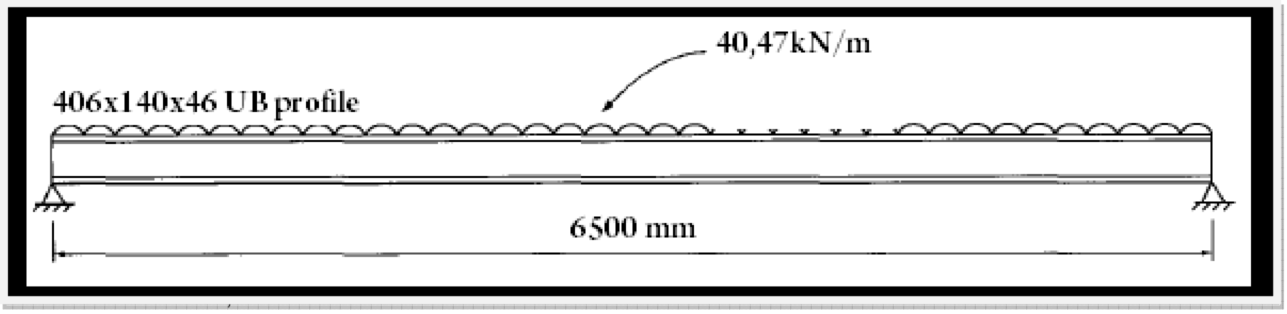


Figure 5.11: The secondary beam 406x140x46UB

Variable action ; Q_k=4x4kN/m=16kN/m

Permanent action ; G_k=3,04x4kN/m=12,20kN/m

Partial Safety Factor

Variable action ; $\gamma_{Q_{sup}}$=1,50

Permanent action ; $\gamma_{G_{sup}}$=1,35

Design Values

$F_d=\gamma_{G_{sup}}.G_k + \gamma_{Q_{sup}}.Q_k$

=1,35x12,2+1,5x16

=40,47 kN

Design Moment

$$M_{sd} = F_d.\frac{L^2}{8} = \frac{40{,}47x6{,}5^2}{8} = 213{,}7\ kNm$$

Design Shear Force

$$V_{sd} = F_d \cdot \frac{L}{2} = \frac{40{,}47x6{,}5}{2} = 131{,}5\ \mathrm{kN}$$

The section size is determined in accordance with $W_{pl,required}$, $M_{sd} \leq M_{c,Rd}$ flange thickness less than 40mm.

$$W_{pl} = \frac{M_{c,Rd}}{f_y} . \gamma_{Mo} = \frac{213{,}7}{275} . 1{,}05 = 815{,}9\ \mathrm{cm}^3$$

We chose 406x140x46 UB profile.

Classification of Cross Section

As a simply supported beam ,the section to develop plastic resistance has been chosen.

Flange buckling ;

$\varepsilon = \sqrt{(235/f_y)}$ $\varepsilon = \sqrt{(235/275)}$=0,924

c/t_f=6,36 11 ε = 10,16 6,36≤10,16

The flanges satisfy the requirements for class 2 element.

Web buckling ;

d/t_w=52,1 , 83 ε =76,7

52,1≤76,7

The stem is a class 2 element.

Deflection Check

The calculated deflection for an unit load of 1 kN/m

$$\delta = \frac{5}{384} x \frac{F_L.L^3}{E.I_y} = \frac{5}{384} x \frac{10^3.6{,}5.\ 6500^3}{210000.15690.10^4} = 0{,}705$$

δ_1 is the deflection due to permanent action

δ_2 is the deflection caused by variable action, which should be less than L/300

δ_{max} is the total deflection caused by permanent and variable action, which should be less than L/250

		Deflection Limit
δ_1 permanent action	0,705x12,20=8,6 mm	L/300=21,6 mm
δ_1 variable action	0,705x16=11,28 mm	L/250=26 mm
Total	19,88 mm	

Shear on Web

$V_{sd} < V_{pl,Rd}$

The design plastic shear resistance of the web is given by;

$$V_{pl,Rd} = A_v.\frac{f_{y/\sqrt{3}}}{Y_{Mo}} =.\frac{1,04x402,3x6,9x275}{\sqrt{3}x1,05x10^3} > V_{sd} = 127\ kN$$

Local shear check on the web of the beams, where it is connected to column.

$$A_v.\frac{f_{y/\sqrt{3}}}{Y_{Mo}}$$

$$A_v = t_w.d$$

$$V_{pl,Rd} = \frac{6,9x250x275}{\sqrt{3}x1,05x10^3} = 260,8\ kN > V_{sd} = 131,5\ kN$$

5.5.1.2 The Primary Beam

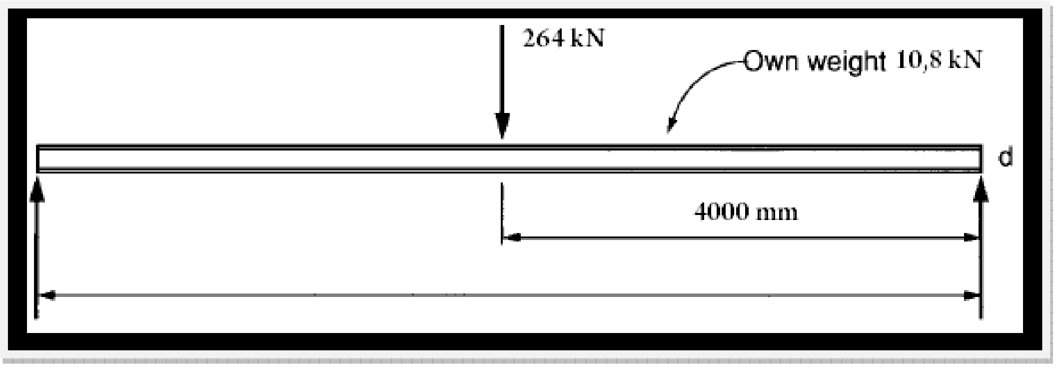


Figure 5.12: The primary beam 533x210x122UB

Characteristic Values

The point loads are taken as the end reactions from beam B1.

Variable actions at point load ; $Q_{k,1} = 4x4x6{,}5 = 104\ kN$

Permanent action at point load ; $G_{k,1} = 3{,}07x4x6{,}5 = 79{,}8\ kN$

For self-weight of primary beam = 8 kN

Partial Safety Factor

Variable action ; $Y_{Q_{sup}}$ =1, 50

Permanent action ; $Y_{G_{sup}}$ =1,35

Design Values

$F_d = Y_{G_{sup}}.G_k + Y_{Q_{sup}}.Q_k$

=1,35x79,8+1,5x104

=264 kN

Self-weight

$F_{d2} = 1{,}35x8$

$= 10{,}8\ kN$

Reactions

$V_{sd} = F_{d1} + F_{d2}/2$

$= 264 + 10{,}8/2$

$= 137{,}4$ kN (at supports)

$$M_{sd} = \frac{F_{d1.}L}{4} + \frac{F_{d2}.L^2}{8}$$

$$= \frac{264X8}{4} + \frac{(10{,}8/8).\ 8^2}{8}$$

$$= 538{,}8\ kN$$

$W_{pl.required} = 2057\ cm^3$

The beam is unrestrained between the point loads, the design resistance ($M_{c,Rd}$) of the section will be reduced by lateral torsional buckling.

533x210x122 UB section is chosen.

Design Buckling Resistant Moment

$M_{b,Rd} = \chi_{LT}.\beta_w.W_{pl,y}.f_y/\gamma_{M1}$

$a_{LT} = 114{,}2\ \mathrm{cm}$

$i_{LT} = 5{,}27$

$$\lambda_{LT} = \frac{L/i_{LT}}{C_1^{0,5}.\left[(1+\frac{(L/a_{LT})^2}{25{,}66})\right]^{0,25}} = \frac{400/527}{1^{0,5}.\left[(1+\frac{(400/114{,}2)^2}{25{,}66})\right]^{0,25}} = 68{,}8 \text{ using curve a}$$

$\lambda_1 = 93{,}9\varepsilon = 86{,}8$

$\bar{\lambda}_z = \lambda_z/\lambda_1\ .\beta_A^{0,5}$=68,8/86,8x$1^{0,5}$=0,79

$\chi_{LT} = 0{,}80$

The design buckling resistance moment

$M_{b,Rd} = 0{,}80x1x3196x275/1{,}05/10^3$

$=669$kNm > 538,8kNm satisfactory√

Shear on Web

The effect of shear will be checked for where there are point loads.

$V_{sd} = 264\ \mathrm{kN}$

The design shear resistance for a rolled I section is;

$$V_{pl,Rd} = \frac{1{,}04.t_w.b.f_y/\sqrt{3}}{\gamma_{Mo}} = \frac{1{,}04x544{,}5x12{,}7x(275/\sqrt{3})}{1{,}05x10^3} = 1097\mathrm{kN} > V_{sd} = 264\ \mathrm{kN}$$

$V_{sd} < V_{pl,Rd}$,so there is no reduction in moment resistance due to shear in the web is sufficient.

Deflection Check

The point –load-deflection is carefully considered by calculating the deflection from unit load and then multiplying by the applied loads.

The serviceability loads are used for deflection check.

Maximum deflection;

δ_1 for variable actions=0,067x104=6,97 <L/300=32mm

δ_2 for permanent actions=0,067x79,8=5,34

$\delta_1 + \delta_2$ =12,31mm<L/250=26,6mm

5.5.1.3 Selection of Column

We designed the column subject to loads from the roofs and first floor.

Loading for Column(kN)

	Variable(kN)	Cumulative(kN)	Permanent(kN)	Cumulative(kN)
Roof(2x)	52		39,9	
	52		39,9	
	104		79,9	
	104		79,8	
		2x312		2x239,4
First Floor	52		37,7	
	52		37,7	
	104		75,4	
	104		75,4	
		312		226,2
Total		936 kN		705 kN

Partial Safety Factor

Variable action ; $Y_{Q_{sup}}$ =1,35

Permanent action ; $Y_{G_{sup}}$ =1,50

Section properties

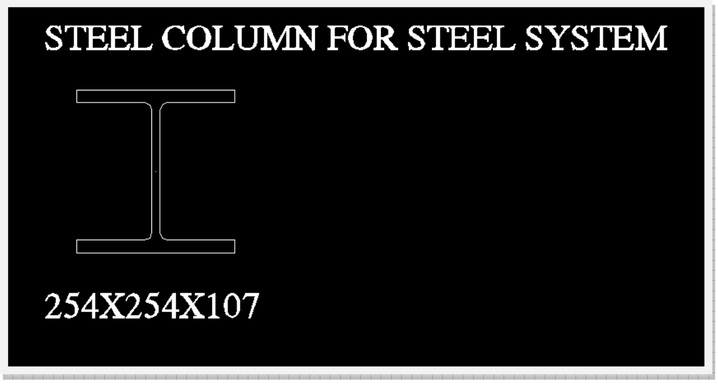


Figure 5,13: The column 254x254x107UC

h =267 mm b=259 mm

t_w=12,8 mm t_f=20,5 mm

d/t_w=15,6 mm c/ t_f=6,31 mm

A=13600mm^2 I_y=175x10^6mm^4

I_w=898x10^9mm^6 I_z=59x10^6mm^4

I_t=172x10^3mm^4 $W_{p,ly}$=1484x10^3mm^3

$W_{el,y}$=1313x10^3mm^3 Fe 430 UC

i_y=113 mm i_z=65,9 mm

Classification of Cross-section

The column is designed to withstand small moments together with axial force.

$p_y = 275\ N/mm^2$

$\varepsilon = \sqrt{(235/f_y)}$ $\varepsilon = \sqrt{(235/275)}$=0,924

c/t_f=6,31 10ε = 9,24 6,31≤9,24

The flanges satisfy the requirements for class 1 element.

Web buckling;

d/t_w=15,6 , 33 ε =30,5

15,6≤30,5

The stem is a class 1 element.

Design Value of The Action

N_{sd}=$\Sigma Y_{G_j}.G_{kj} + Y_{Q_i}.Q_{ki}$

=1,35x705+1,5x936

=2356kN

The effect of unbalanced loading on either side of the column mu =h/2+100mm=233,5mm

st be taken into account;

All moments of end of beams connected to column are in balance each other.

Resistance of Cross-section

Applied axial force ;

N_{sd}=2356 kN

$$N_{pl,Rd} = \frac{A.f_y}{\Upsilon_{m1}} = \frac{13600x275}{1,05x10^3} = 3562kN \geq 2356kN \text{ satisfactory}\surd$$

Buckling Resistance of The Member

Flexural Buckling

A class 1 member subject to moment about the major axis only, should satisfy the following;

$$\frac{N_{sd}}{\chi_{min}.A.f_y/\Upsilon_{M_1}} \leq 1,0$$

The buckling length = 4000 mm, $\beta_A^{0,5} = 1$

λ_z=l /i_z=4000/65,9=60,7 λ_y=l /i_y=4000/113=36

λ_1=93, 9x0,924=86,8

$\bar{\lambda}_z$=λ_z/λ_1 .$\beta_A^{0,5}$=6,07/86,8x$1^{0,5}$=0,69 use buckling $\bar{\lambda}_y$=λ_y/λ_1 .$\beta_A^{0,5}$=36/86,8x$1^{0,5}$=0,41 use buckling, a

$$\frac{N_{sd}}{\chi_{min}.A.f_y/\Upsilon_{M_1}} = \frac{2356x10^3}{0,85x13600x275/1,05} = 0,78 \leq 1,0 \text{ satisfactory for flexural buckling}$$

Lateral Torsional Buckling

$$\frac{N_{sd}}{\chi_z . A . f_y / \gamma_{M_1}} = \frac{2356x10^3}{0,85x13600x275/1,05} = 0,78 \leq 1,0 \text{ satisfactory for lateral torsional buckling}$$

5.6 Structural Integrity

Tying Forces

The beams and their connection should be designed to resist tie forces, so that they will limit the progressive spread of damage in the event of an accident. These forces are defined as;

0,5.w_f. s_t. L_S for internal beam

0,5.w_f. s_t. L_S for edge beam

The forces should not be less than 75kN for floors or 40kN for roofs

For the floors; 1,35x2,9+1,5x4=9,9kN/m^2

For the roof ; 1,35x3,04+1,5x4=10,1kN/m^2

Column Tie Forces

The columns must be restrained at the periphery of the structure.The restraints should be capable of resisting a tie force of not less than 1% of the axial force in the column.

The area supported by external column=8x4=32m^2

The column load at roof level

$w_f$xarea=10,1x32=323,2kN

The restraint force=3,23kN

Column load at 1st floor

2xRoof	2x323,2 kN
1st floor	316,8 kN
Edge beams	237 kN

Cladding	230 kN
Total	1430,2 kN

1% of the total axial force=14,3 kN

Roof Tie Forces

Edge beam=0,25x10,1x8x6,5=131,3 kN

Secondary beam=0,5x10,1x4x6,5=131,3 kN

Main Beam = 0,5x10,1x8x6,5=262,6 kN

All of tie forces are greater than 40kN and 1%of the column load(3,13kN)

Floor Tie Forces

Edge beam=0,25x9,9x8x6,5=131,3 kN

Secondary beam=0,5x9,9x4x6,5=128,7 kN

Main Beam = 0,5x9,9x8x6,5=257,4 kN

Both the calculated tie forces are greater than 40kN AND %1 of the column load(11,07kN)

5.7 Frame Imperfection

Appropriate allowances should be made to cover the effects of practical imperfections, including residual stresses and geometrical imperfections such as lack of verticality, lack of straightness, lack of fit and the unavoidable minor eccentricities present in practical connection. The effects of imperfections shall be allowed for in frame analysis by means of an equivalent geometric imperfection in the form of an initial sway imperfection determined from;

Roof;10,1 kN/m^2

Floor;9,9 kN/m^2

The design load for the weight of columns and beam casings,0,3 kN/m^2,for the floor and roof.

The cladding has a characteristic 0,8kN/m^2 and design load of 1,0 kN/m^2.

The area of building=1570m^2

The perimeter of the building is 200m

The weight of the cladding 4,8x200=960 kN/m^2

Total Design Loads on Each Floor(kN)

Roof(2x)	2x10,4x1570	32656
First Floor	10,2x1570+2x960	17934
Total		50590

To obtain the equivalent horizontal forces for checking the frame, the total floor load is multiplied by the imperfection angle ϕ which is obtained from;

$$\phi = k_c . k_s . \phi_o$$

$$\mathrm{k_c} = (0{,}5 + \frac{1}{\mathrm{n_c}})^{0{,}5} = (0{,}5 + \frac{1}{6})^{0{,}5} = 0{,}81$$ The value for transverse imperfection

$$\mathrm{k_c} = (0{,}5 + \frac{1}{\mathrm{n_c}})^{0{,}5} = (0{,}5 + \frac{1}{15})^{0{,}5} = 0{,}75$$ The value for longitudinal imperfection

The value of $\mathrm{n_s}$ in both direction is the same 2,

$$\mathrm{k_c} = (0{,}2 + 1/2)^{0{,}5} = 0{,}84$$

The final imperfections will be;

Transverse 0,8x0,84x1/200=1/298

Longitudinal 0,75x0,84x1/200=1/317

Equivalent horizontal forces at each floor(kN)

	Design Load	Transverse	Longitudinal
Roof(2x)	16328	54,8	103
First Floor	10,2x1570+2x960	60,1	56,6

Wind Loading on Bracing System

$q_p = 0{,}895\ \mathrm{kN/m^2}$

The force on each of the transverse braced bays;

$$= q_p . C_f . \mathrm{length}/2 = 0{,}895 \mathrm{x} 0{,}8 \mathrm{x} 80/2 = 28{,}6\ \mathrm{kN/m}$$

The total force to be resisted by the longitudinal bracing

$$= 0{,}895 \mathrm{x} 0{,}8 \mathrm{x} 30 = 21{,}5\ \mathrm{kN/m}$$

The force in the transverse bracing resulting from wind acting on the end-bays is determined by multiplying the total force on the longitudinal bracing by ratio of the half the width of the building by its length.

Multiplying factor; 30/(2x80) =0,1875

Design Actions on Transverse Bracing

	Wind on front elevation	Resultant couple from wind on ends	Transverse Imperfection	Longitudinal Imperfection	Design Action
Roof	57,2	8,06	27,4	8,58	101,2
1st Floor	114,2	16,13	30,05	4,72	165,3

As the structure is more than one storey high, in each direction two system of bracing is required. Two braced bays have been built into the rear elevation.

As the longitudinal bracing is provided on two elevation,Plan bracing will be provided by the floors acting as a diaphragms.

5.8 Beam to Beam Connection

Initial Design Information

The connection between the secondary (406x140x46 UB) and primary beam(533X210X122 UB) is designed.For a secondary beam the design ultimate reaction is;

V_{sd}=131,5 kN

The connection is pinned so that the significant moments in the primary beam doesn't occur.The connection has been designated as (Category A; Bearing Type) shear connection using a partial depth flexible end-plate.It can result in increased erection effort.

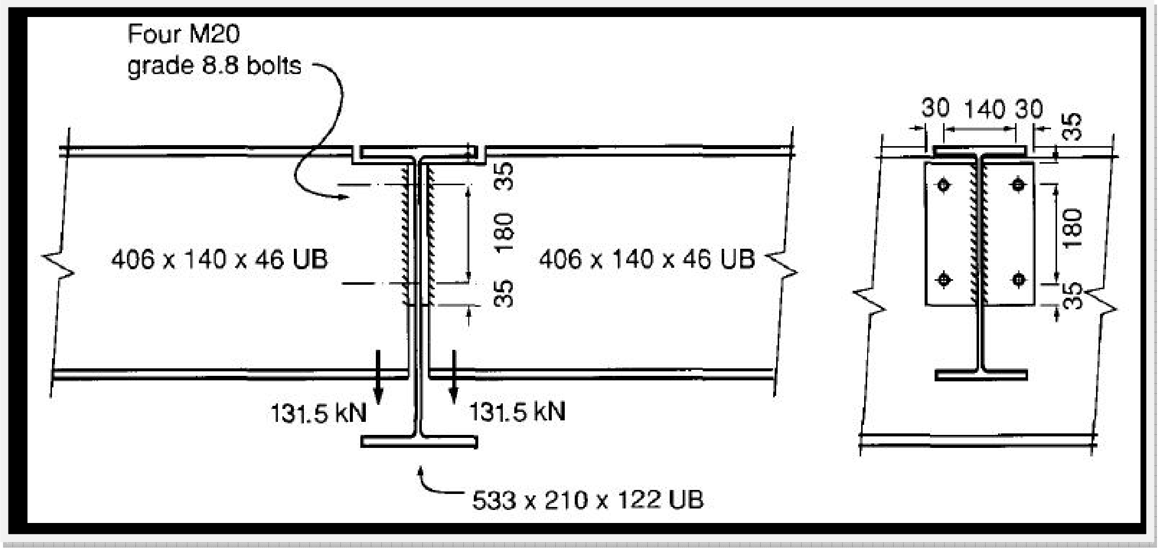


Figure 5.14: Beam to beam connection detail (dimensions mm)

The proposed end plate 200mm(wide)x250mm(deep)x8mm(thick).The four-bolt connections will be sufficient.The end distance=35mm,the bolt pitch is 180mm

Minumum end distance,e_1=1,2.d_o=1,2x22=26,4mm<35mm

Normal edge distance, e_2=1,5.d_o=1,5x22=33mm>30mm

Shear Resistance of Bolt Group

The force on each shear plane individually;

Shear per bolt=131,5/4=32,9kN

Shear resistance of bolt= $F_{V,Rd}$=0,6xf_{ub}xA_s/γ_{Mb} where;

γ_{Mb} is the material factor=1,35

f_{ub} is the ultimate tensile strength of the bolt=800 N/mm^2

A_s is the tensile stress area of the bolt=245mm^2

$F_{v,Rd}$=0,6x800x245/1,35/1000=87,1kN/plane>32,9kN satisfactory√

Check Shear Resistance of The End-plate

In accordance with the presence of fasteners, the reduced shear resistance can be ignored if;

A_{vnet}/A_v=0,824

f_y/f_u=275/430=0,640≤0,824

Design-Plastic Shear Resistance

$$V_{pl,Rd} = \frac{A_v . f_y}{\sqrt{3} . Y_{Mo}}$$

f_y=275N/mm^2

$Y_{Mo} = 1,05$ A_v=2x8x250=4000mm^2

$V_{pl,Rd} = 604,8kN > 131,5kN$ the plates are adequate in shear.

Design End-plate Weld

The end-plate is connected to the beam web by two full depth fillet webs;

Fillet weld shear strength, $f_{vw,d} = f_u/(\beta_w x Y_{Mw} x \sqrt{3})$

where, f_u=430 N/mm^2

β_w =0,85

Y_{Mw}=1,35

$$f_{vw,d} = \frac{430}{0,85x1,35x\sqrt{3}} = 216N/mm^2$$

Total length of weld=250x2=500mm

Resistance required/mm =131,5x10^3/500=263 N/mm

Design resistance, $F_{vw,Rd}$=$f_{vw,d}.a$

-throat thickness required,a≥263/210=1,21mm

-leg lengths required=a/0,7=1,73mm

-use of 6mm fillet weld as practical minimum

Shear Resistance of Secondary Beam Web

Influence of notch to the top flange

For restrained beams in grade Fe430 steel,the stability of the web is not to be checked if provided;

$V_{sd} \cdot (t_p + c) < M_{c,Rd(reduced)}$

Check Bearing Resistance of Supporting Beam

The bearing resistance of the secondary beam end-plates.

The actual bearing stress;

$$f_{b,sd} = 2xV_{sd}/(4xdxt_w) = 2x131,5x10^3/(4x20x12,7) = 258,8\ N/mm^2$$

The four M20, grade 8,8 bolts and a 200x250x8 mm grade Fe430 end-plate welded to the beam with a full-length 6 mm fillet weld(eachside).

5.9 Beam to Column Connection

Initial Design Information

The connection between the main beam 533x210x122UB and an external column 254x254x107UC at the first-floor level. The connections is nominally pinned.The rotation of the beam can occur without significant moments. The connection is designed as a ‘Category A;Bearing type’shear connection.

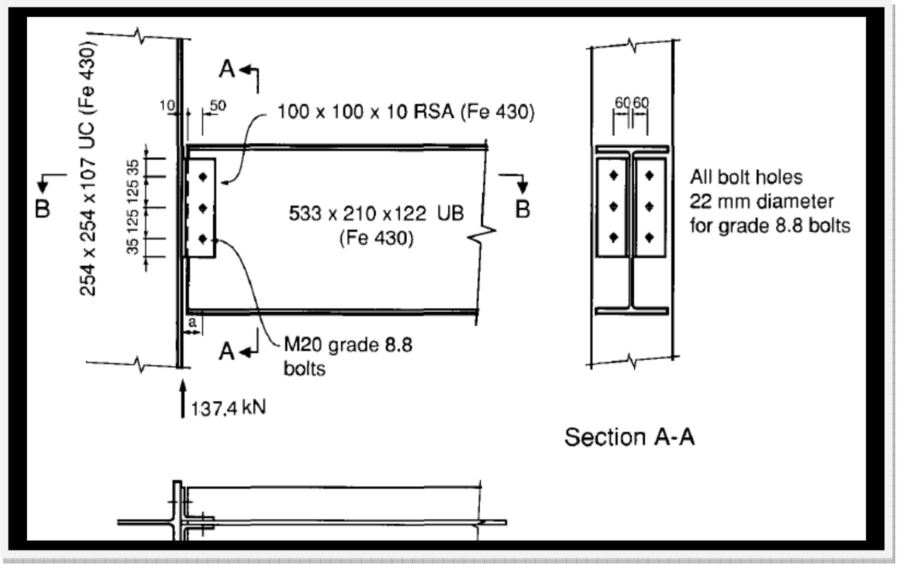


Figure 5.15: Beam to beam connection detail (dimensions mm)

Check Adequacy of Bolts to The Beam Web

The design shear force is the vector sum of vertical and horizontal components.

$$F_{v,sd} = (F_v{}^2 + F_m{}^2)^{0,5}$$

Where F_v is the vertical shear component per beam web bolt;

$F_v = V_{sd}/3 = 137,4/3 = 45,8kN$

F_m is the horizontal shear component per beam web bolt;

$F_v = V_{sd}.a/F_v = Z_b$ $Z_b = n(n+1)p/6 = 250$ a=60mm

$F_v = 33kN$

$F_{v,sd} = 56,4kN$

Shear resistance of bolt per shear plane;

$F_{v,Rd} = 0,6. f_{ub}.A_s/\gamma_{Mb}$

$\gamma_{Mb} = 1,5$

$f_{ub} = 800\ N/mm^2$

$A_s = 245mm^2$

$F_{v,Rd} = 87,1kN$ per shear plane

For double shear,bolt resistance

=2x87,1

=174,2kN>110kN satisfactory√

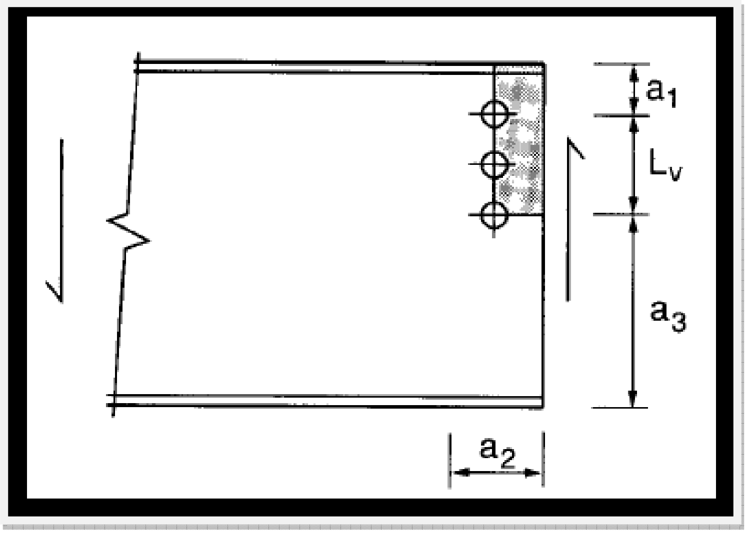


Figure 5,16; Block shear failure of web

$V_{eff} = (f_y/\sqrt{3}).A_{v,eff}/\Upsilon_{Mo}$

$\Upsilon_{Mo} = 1{,}05$

$A_{v,eff} = t.L_{v,eff}$

$L_{v,eff} = L_v + L_1 + L_2$

$L_v = 250mm$

$L_1 = 70mm$<5d

$L_2 = (a_2 - k.d_{o,t})(f_u/f_y)$,k=61

$L_3 = L_v + a_1 + a_2$

$= 250 + 70 + 216{,}7$

$= 536{,}7\text{mm, should not be greater than} (L_v + a_1 + a_3 + n.d_{o,v}).({}^{f_u}/_{f_y}) = 736mm$

$L_{v,eff} = 250 + 70 + 61 = 381\text{mm}$

$$V_{eff,Rd} = \frac{\left(\frac{275}{\sqrt{3}}\right)x12{,}7x381}{1{,}05x10^3} = 731\text{kN} > 269{,}4\ kN \quad satisfactory\surd$$

Check Bearing Resistance of The Bolts

$$F_{b,Rd} = \frac{2,5.\alpha.f_u.d.t}{\gamma_{Mb}}$$

$\gamma_{Mb} = 1,35$

t=12,7mm

d=20mm ,α is the lesser of $\left(\frac{e_1}{3do}\right), \left(\frac{e_1}{3\,d_o} - \frac{1}{4}\right), \left(\frac{f_{ub}}{f_u}\right)$ or 1,0

p_1 is the bolt pitch=125mm

e_1 is the distance of a bolt from a free edge in the direction of the applied load. e_1=85,4mm

$$f_{b,Rd} = \frac{2,5x1x430}{1,35} = 796\ N/mm^2$$

$$\text{Limiting stress} \le \frac{0,85(f_u + f_y)}{1,35}$$

$$\le \frac{0,85(430 + 275)}{1,35} = 443,9 N/mm^2$$

$$F_{b,Rd} = (\text{limiting stress}).d.t$$

$= 443,9x20x12,7/10^3$

$= 112,75kN > F_{v,sd}\ (56,4kN)$

Chapter 6

Conclusion

Barangaroo has been designed such that the urban environment will encourage the flourishing of a sustainable life style that has recently become a global trend. This opportunity has been taken to renew Barangaroo completely as a vibrant commercial and mixed use precinct with significant foreshore parkland. The most efficient solutions are provided to the area, keeping in mind public accessibility of the site by ensuring integration and inclusion of Barangaroo within Sydney as a whole. Some of these proposed systems include light train, new bus routes on Hickson Road, as well as the completion of a 1.4 kilometre foreshore promenade connecting the whole city to the Barangaroo site.

The proposed art exhibition center is located within the central public domain of Barangaroo. This new center of activity will potentially attract many users because of its advantageous site location; near Headland Park and proximity to waterfront. In addition to the accessibility offered by the volume it also offers a unique feel of built space for the users creating a sense of drama and excitement every time they visit the exhibition centre. In short it will serve as a great addition to the community of Sydney.

From the technological point of view, a lot of consideration has been invested in using the available sustainable green technologies and making the building perform efficiently. This in turn will ensure that the building stays green and leaves less carbon footprint. The use of a green roof is justified as an advantage point in this project for numerous reasons. The use of three passive measures and the technologies within helps us in attaining the requirements for thermal, visual and psychological comfort.

For the structural design of this project, in order to cover wide spans across the center, the single-span half step-up truss roof has been used. The building has been divided into seven structurally sound parts by providing the required dilatations. Since we needed a light weight structure, instead of reinforced concrete the obvious choice was a steel framed structure. The design choices, calculations and choice methods have been thoroughly verified.

Chapter 7

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