UTS UNIVERSITY OF TECHNOLOGY SYDNEY

The Green Mesh: A Community-activated Green Network Enabled Through New Spatial Technologies

by Jeremy Chivas

Thesis submitted in fulfilment of the requirements for the degree of

C03001 Master of Architecture (Research)

under the supervision of Martin Bryant and James Melsom

University of Technology Sydney
Faculty of Design, Architecture and Building (DAB)

Nov, 2021

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, *Jeremy Chivas* declare that this thesis, is submitted in fulfilment of the requirements for the award of *C03001 Master of Architecture (Research)* in the *Faculty of Design, Architecture and Building (DAB)* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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BY JEREMY CHIVAS

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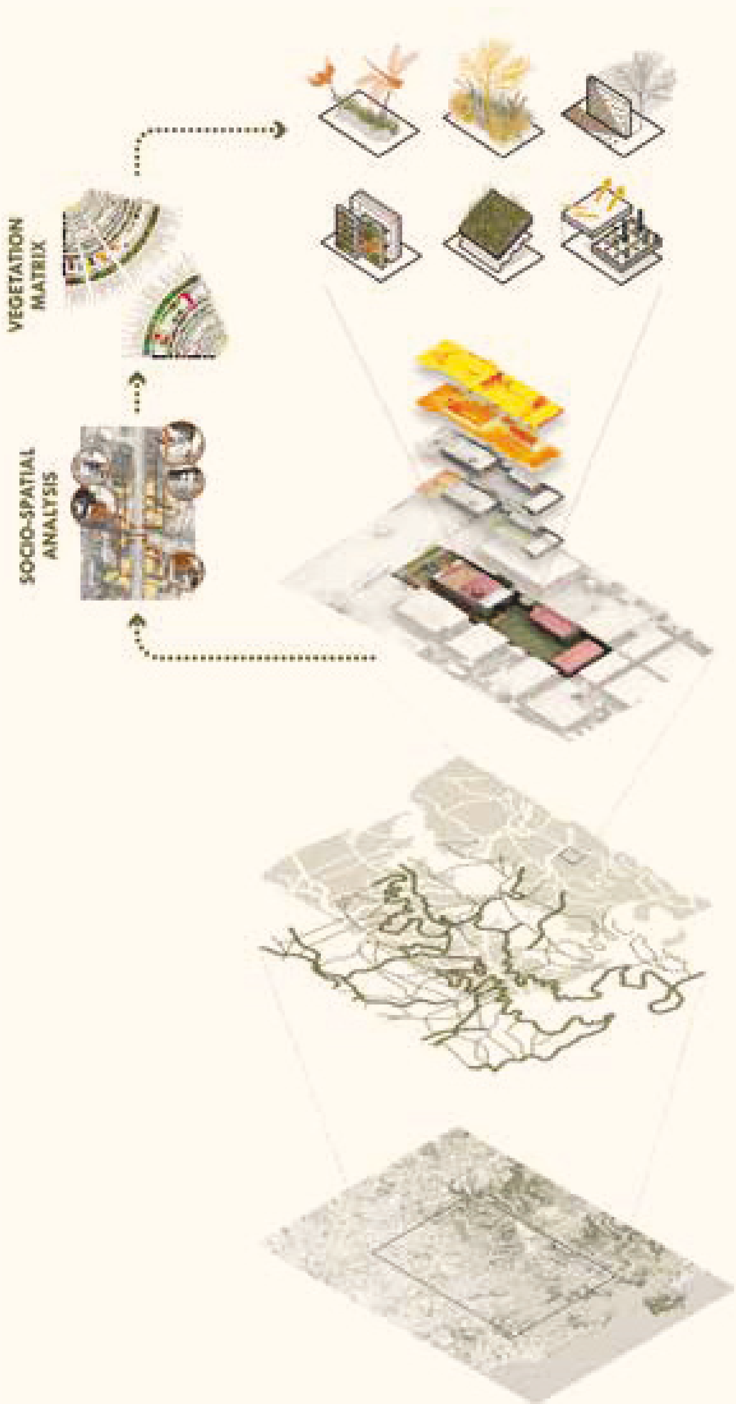


IMPLEMENTATION

A ***theoretical online interface,*** *simplifying the Green Mesh methodology into a graphic platform, accessible to the general public.* ***24 design principles*** *inform the physical implementation of ecologically integrated and sustainable practices by the community, within their private lands to fill the gaps within Sydney's Green Grid network.*

TECHNOLOGY

Highly-detailed and property specific 3D spatial data, enabling comprehensive ***micro-climate simulation*** *through Grasshopper. Associated socio-spatial considerations and a diverse* ***vegetation matrix*** *enable comprehensive environmental responsiveness.*

STRATEGY

A finer-grain green network, ***the Green Mesh****, supplementing the Green Grid to reconnect a matrix of small, remnant vegetation communities within private lands.*

ISSUE

Habitat fragmentation and biodiversity loss due to Urban Development.

Fig. 01.01.01 An illustration of the scope of research presented within this dissertation, to be read from the bottom-up.

01. PROJECT INTRODUCTION

Q: How can new spatial technologies enable a finer-grain green network throughout Greater Sydney, and, how can this network be activated through community participation within private lands?

01.01 Abstract

Habitat fragmentation is a global environmental issue resulting from land-use change and urban development. As cities have grown and developed throughout the world, anthropocentric ideologies have driven humanity's desire to 'conquer' nature, prioritising our own species whilst clearing the habitats and ecologies of others. Contemporary landscape architecture practice has sought to address habitat fragmentation through the implementation of urban greenways, linear parklands, vegetation corridors, and metropolitan green strategies, seeking to re-establish ecological linkages throughout our built environment. However, barriers to the implementation of these strategies limit their overall capacity for holistic ecological integration. The Sydney Green Grid (SGG), for example, whilst establishing a network of green corridors and active transport connections throughout Greater Sydney, is limited in it's confinement to public space and concentration along linear corridors. It misses an opportunity to reconnect the finer matrix of remnant vegetation communities within private lands, which remain vulnerable to natural or human impacts.

The research presented within this dissertation seeks to address these limitations through the concept for a novel green network, the 'Green Mesh' - a finer-grain, community-activated green network, enabled through new spatial technologies. Filling the gaps within the coarser SGG structure, the Green Mesh adopts a community participatory approach for the dispersal of ecological implementations throughout private lands, intertwining the two networks into a cohesive, multi-layered green strategy for Greater Sydney. Resolving this concept into a theoretical platform, a unique methodological approach was developed throughout this dissertation, focusing on three major challenges of this concept; firstly, the disconnect between traditional GIS data and ground-level nuances, and how new 3D spatial technologies may overcome this. Secondly, how this new spatial data may be used remotely to derive an environmental baseline for smart and scalable ecological implementation. And finally, how to translate this methodology into an accessible platform for residents and community members, enabling them to populate the Green Mesh within their own gardens, and gradual city-wide dispersal.

Testing and exploration of these three components led to a number of unique and practical outputs that seek to inform future design practice. Grasshopper was used to simulate micro-climate factors across three distinct urban areas, through the use of detailed 3D photogrammetry models. Micro-climate outputs were then synthesised to produce a replicable methodology for achieving a holistic environmental baseline. An integrated vegetation matrix uses this baseline to define species suitability within specific backyards, whilst socio-spatial analysis reintroduced the 'human' and 'place' narrative back into an otherwise highly quantitative process. Observations throughout these fieldwork components resulted in a taxonomy of 24 ecological and sustainable design principles that became the physical components of the Green Mesh. Finally, this methodology was packaged into a theoretical online interface, demonstrating the potential to translate this process into a simplified and implementable strategy to facilitate community participation.

This interface is positioned for further research and development through contributions of design professionals and local governments, advocating for the further adoption of 3D spatial data within practice, to overcome the barriers of green network implementation.

KEY WORDS

Green network, community participation, ecological integration, new spatial technologies, micro-climate simulation

01.02 Project Development & Evolution

Review of this research over the course of study was defined by four assessment milestones, providing regular feedback every 3-5 months of the 14-month research period. The first three stages were presented via zoom to an external crit panel for feedback and comments, with the fourth stage presented through an exhibition held at UTS, and a longer-term assessment period of 3-6 months for assessors to review the written dissertation. The following logs provide a brief summary of progress, comments, and responses to each of these milestones.

***

STAGE 01 ASSESSMENT: CONFIRMATION

15th June, 2020.

Guest Panel: Lizzie Yarina, Ivan Valin, Scott Hawken

Title: 'The Liberation of Urban Ecological Design'

Q: How might a finer-grain, 'bottom-up implementation' approach to metropolitan scale green planning enable a greater degree of urban ecological integration in Sydney, and, how can new spatial technologies be utilised to facilitate this as a framework?

The first three months of research until Stage 01 focused on refining the original research proposal. Initial exploration within the research areas of green infrastructure and metropolitan green networks was undertaken through background research and readings, with preliminary testing and ground truthing of early methodological approaches. This process resulted in three key research opportunities identified within the broader topics of green strategy planning, informed by global ecological issues, and a critique of the Sydney Green Grid. These opportunities included the need to incorporate private lands within the broader green network, the need for a finer-grain, site-responsive spatial methodology behind green strategy planning, and finally, the adoption of new models of implementation (bottom-up), and 3D spatial data typologies that would enable this. This concept was subsequently coined the 'Green Mesh'.

Feedback from Stage 01 suggested three areas of focus that to guide exploration into the methodologies behind the Green Mesh; the 'social-dimension', using spatial data simulation to identify urban micro-climates, and the accommodation of unplanned ecologies to within the green network.

STAGE 02 ASSESSMENT: INTERNAL

11th September, 2020.

Guest Panel: Lizzie Yarina, Ivan Valin

Title: 'A Platform for the Proliferation of Urban Ecological Design'

Q: How might new spatial technologies enable a finer-grain, evidence based platform for the proliferation of small-scale urban ecological implementations across a metropolitan scale, within a bottom-up implementation strategy?

Work throughout Stage 02 focused on further progressing the 'Green Mesh' concept, whilst working to resolve it through a practical, feasible methodological framework - guided by Stage 01 feedback.

Investigation into the 'social-dimension' involved socio-spatial studies undertaken at six different locations throughout Willoughby LGA - revealing unique site-specific narratives of place, understanding the actors and programs working together, and the key opportunities for ecological integration through observation. Three of these sites were 3D scanned using a drone to produce dense point cloud and photogrammetry data for micro-climate simulation. Four environmental simulation plugins for Grasshopper were used to holistically understand the micro-climates that existed on-site, and to inform subsequent strategies of ecological implementation - commencing a process of translating research outcomes into the implementable strategies, aided by analysis of unplanned urban ecologies, and the physical attributes that enable them. Through the amalgamation of observation and findings within these three areas, a taxonomy of eighteen ecological and sustainable 'design principles' were produced.

Key points of feedback from Stage 02 suggested the need to specify a target audience going forward, and the opportunity to introduce an app interface for connecting the general public to the Green Mesh, which could therefore be delivered as a service or a platform.

Fig. 01.02.01 Project timeline

STAGE 03 ASSESSMENT: PRE-FINAL

7th December, 2020.

Guest Panel: Scott Hawken, Linda Matthews

Title: 'The Green Mesh: A spatially responsive methodological framework for widespread urban ecological integration'

Q: How can new spatial technologies facilitate highly-responsive, fine-grain and community-activated ecological integration, throughout our existing urban and suburban built environments of Sydney?

Continued development of the methodological framework was undertaken throughout Stage 03, along with the specification of a target audience and end-user, and initial investigation into a theoretical app interface. The project was repositioned, targeting it towards LGAs and local councils in order for further investment and development into a resolved platform in the future. The end-users, being the general public who would implement the Green Mesh within their own properties and gardens, informed the evolution of the 'online interface' into a simplified and graphic website or app that would still retain all information needed for implementation.

Aiding in this, the vegetation matrix was incorporated into the methodology as a way of recommending species suitable to the spatial micro-climates of their property – demonstrating the finer-grain and site-responsive capabilities of the Green Mesh. Three 'Exemplar Design Cases' were produced, applying the methodology to real-world scenarios, and locating suitable design principles within each - demonstrating the replicability and flexibility of the Green Mesh system.

Feedback from Stage 03 suggested adding a critique of 'smart cities' in the initial chapters, with the potential for the Green Mesh to integrate within the smart city concept to provide a more robust ecological consideration.

STAGE 04 ASSESSMENT: FINAL SUBMISSION

7th May, 2021.

Guest Panel: Mark Tyrrell, Sue Anne Ware

Assessors: Bruno Marques, Ilmar Hurkxkens

Title: 'The Green Mesh: A Community-activated Green Network Enabled Through New Spatial Technologies'

Q: How can new spatial technologies enable a finer-grain green network throughout Greater Sydney, and, how can this network be activated through community participation within private lands?

Prior to the final submission and presentation of Stage 4, comments from Stage 03 were addressed, and final edits were made to refine text and drawings where needed. Primarily, a number of precedent projects and a smart cities critique was added, and the 'online interface' was developed further, illustrated with a conceptual graphic user interface (UI). This UI joined a number of other final outputs from this research dissertation, including the high-level Green Mesh concept itself, the enabling Methodological Framework, the unique taxonomy of Design Principles, and Exemplar Design Cases.

The final project was presented at UTS in May 2021, to a guest crit panel both in-person and streamed overseas via Zoom. The project was commended for the depth of analysis and feasibility of implementing such a strategy, and it's exploration into the 'private-land' potentials of a green network - an area with little prior research.

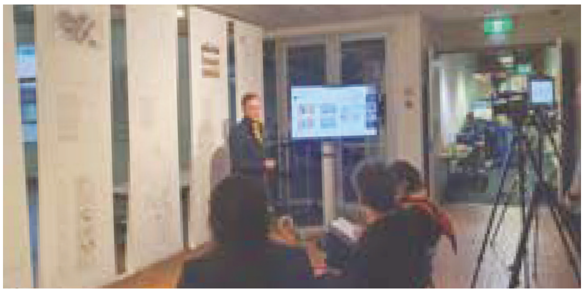
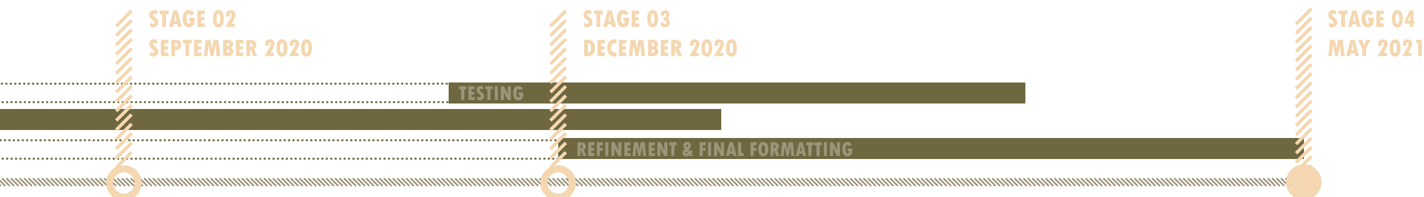


Fig. 01.02.02 Final presentation at UTS



ECOLOGICAL ISSUE: THE IMPACTS OF ANTHROPOCENTRIC URBAN DEVELOPMENT

02

02. ECOLOGICAL ISSUE: THE IMPACTS OF ANTHROPOCENTRIC URBAN DEVELOPMENT

"In anthropogenically-modified landscapes, humans have been destroying habitat at rates that are without precedent in the Earth's evolutionary history" (Skole & Tucker, 1993)

02.01 Chapter Overview

The growth and development of cities all throughout the world has led to significant habitat loss and fragmentation, as land is cleared and ecological connections are broken to make way for larger, more expansive urban environments. This is a global ecological issue, the result of our anthropocentric mentality and outdated urge to 'conquer' nature rather than living in balance.

Setting the scene for the research within this dissertation, seeking to reconnect ecologies throughout existing built environments, this opening chapter explores the ideologies, urban growth patterns, and current planning responses that seek to address this phenomenon. The broader study area of metropolitan Sydney provides the grounds for more focused analysis and critique of urban development, and current green strategy planning.

Fig. 02.02.01 Land-use change due to urban development in Kellyville, Sydney, 2010-2018. Source: Nearmap

02.02 The Anthropocentric Ideologies Driving Ecological Degradation

The 18th century onwards saw dramatic changes in human attitude and treatment towards nature, a departure from traditional hunter gatherer practices, living off the land, and respect over nature's resources. Instead, spurred by greed and growing civilisations, our shift into the age of industrialisation revealed new ways of mass-production, and an unprecedented need for raw materials - with large, coal-burning factories constructed for manufacturing. 'Nature' became a barrier for which to overcome, and "conquering nature... was a common purpose of human civilisation" (García-Acosta, 2010).

Our environmental impact from this period onwards has become so significant that it has defined a new epoch; the age of the 'anthropocene' ('anthro' - human, '-cene' - epoch). The anthropocene, our current period of earth's history, is defined by the fact that humans have become the "single most influential species on the planet, causing significant global warming and other changes to land, environment, water, organisms and the atmosphere" (Pavid, n/d). In the mere 200,000 years of modern human existence, "we have fundamentally altered the physical, chemical and biological systems of the planet on which we and all other organisms depend" (Pavid, n/d), triggered by radiation, non-renewable energy production, and the extensive use of hard, man-made geologies such as concrete.

Many of these environmentally destructive practices can be associated with urban development, in order to feed our expanding cities to accommodate booming global populations - approaching the limit at which our resources on earth can cope. As cities have grown, habitats have been cleared 'en masse', at rates "...that far exceed the capacity for most species to adapt and respond" (Pimm et al., 1995; Myers & Knoll, 2001), a significant cause of global biodiversity loss and species extinction.

ECOLOGICAL FRAGMENTATION DUE TO URBANISATION

Global populations are projected to continue growing into the future, and by 2050, 68% of the world's population will live in urban areas (UN, 2018) [Fig. 02.02.03]. This is an increase from around 45% in 2010. This will not only place increasing pressure on already stressed natural resources, agricultural production, and supply of urban areas to house this additional population, but will see the densification of existing urban areas.

Such significant changes in the population spread and density places increasing pressure on cities and public infrastructure, with greater demand for housing, transportation, along with liveability standards and mental health - through the supply of green open space. Traditional development to meet this housing demand has led to extensive land clearing and land-use change. In the United States alone, "metropolitan areas are experiencing a net loss of about 36 million trees nationwide every year... that amounts to about 175,000 acres of tree cover, most of it in central city and suburban areas but also on the exurban fringes" (Nowak & Greenfield, 2018).

The phenomenon of 'land-use change', referring to "all components of change in the quality and quantity of land cover types as habitat for organisms and productive land for humans" (Didham, 2010) has in turn led to severe ecological consequence of urbanisation, including the most extensive of which - habitat fragmentation [Fig. 02.02.02].

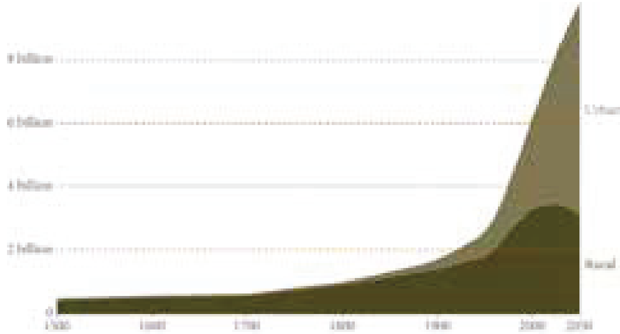


Fig. 02.02.03 Global Urban and Rural Population Projected to 2050. Source: UN World Urbanisation Prospects 2018

'Habitat fragmentation' is the "division of large, continuous habitats into smaller, more isolated habitat fragments" (Didham, 2010), and is the "leading cause of the loss of biodiversity and ecosystem services [globally]"

- Jacobson, et al, 2019

Habitat fragmentation refers to the isolation of vegetation communities into remnant 'patches', the result of land being cleared around them. Due to their reduced scale, smaller biodiversity of flora and fauna species' and populations, and their disconnection from other ecological communities, these fragments are highly vulnerable to change from both human and natural factors such as storm events and disease.

Fig. 02.02.02 Magnitude of global habitat fragmentation. Source: Author

Fig. 02.02.04 The world's longest running study of rainforest fragmentation, The Biological Dynamics of Forest Fragments Project (BDFFP) , Amazon rainforest.

Research into the ecological effects of habitat fragmentation has been undertaken by The Biological Dynamics of Forest Fragments Project (BDFFP), a research collaboration between the Instituto Nacional de Pesquisas da Amazônia and the Smithsonian Institution. Beginning in 1979, it is the "only experimental study of the process of habitat fragmentation under way in the Amazon basin... [and] one of the longest-term projects evaluating the impacts of human activities" (ForestGeo, n/a).

The ongoing research seeks to determine the impact of habitat isolation and fragmentation, and it's various factors, on species diversity and survival rates. Methodology included a census of flora and fauna within 12 patches of forest comprising of either 1, 10 or 100ha, before the surrounding forests were clear-cut to create a situation of habitat isolation. The experiment has, so far, demonstrated that within these patches of isolated habitat, some species will become extinct, whilst other, often closely related species, survive. Scientists are now using control patches of undisturbed forest to determine the factors that decide this disparity.

Overall, habitat fragmentation leads to a gradual decline in biodiversity, resulting in species' becoming threatened or extinct. Both flora and fauna extinction rates are accelerated, as connectivity and ecological ties are broken, food sources are disrupted, and predator-prey populations become unbalanced.

THE ROLE OF NATURE AND BIODIVERSITY IN CITIES

Whilst research shows that cities generally "contain substantially more threatened species per unit area than non-urban areas" (Ives et al., 2016), due to the displacement of species from their natural habitats, by contrast, "urban environment[s] can prove an attractive habitat for a wide range of taxa because of abundant food and shelter" (State of Environment Australia, 2016). Plant selection and a more stable provision of resources within cities can also lead to some species being better off. Most commonly, these areas of urban animal habitation coincide with vacancy from human activity, however whilst *animals* themselves are deterred from human activity, "the presence of wildlife in urban areas can enhance *human* quality of life" (State of Environment Australia, 2016).

Nicholas de Monchaux's publication 'Local Code', explores the potential of such vacant urban spaces, positing their potential in "play[ing] an essential and unique role in providing ecological, social, and cultural resilience". Furthermore, formalised policy and legislation in cities around the world have led to the utilisation of vacant roof and wall spaces for re-vegetation and habitat creation.

Through ecological design implementations within our urban environments, there is significant potential to accommodate fauna and flora habitat within our cities and suburbs. Encouraging and facilitating these implementations, however, is a barrier as the general public are unaware of the possibilities and benefits enabled.

Fig. 02.02.05 Intensive green roof, Wiegmann-Klinik Berlin Germany. Source: Bundesverband GebäudeGrün e. V. (BuGG)

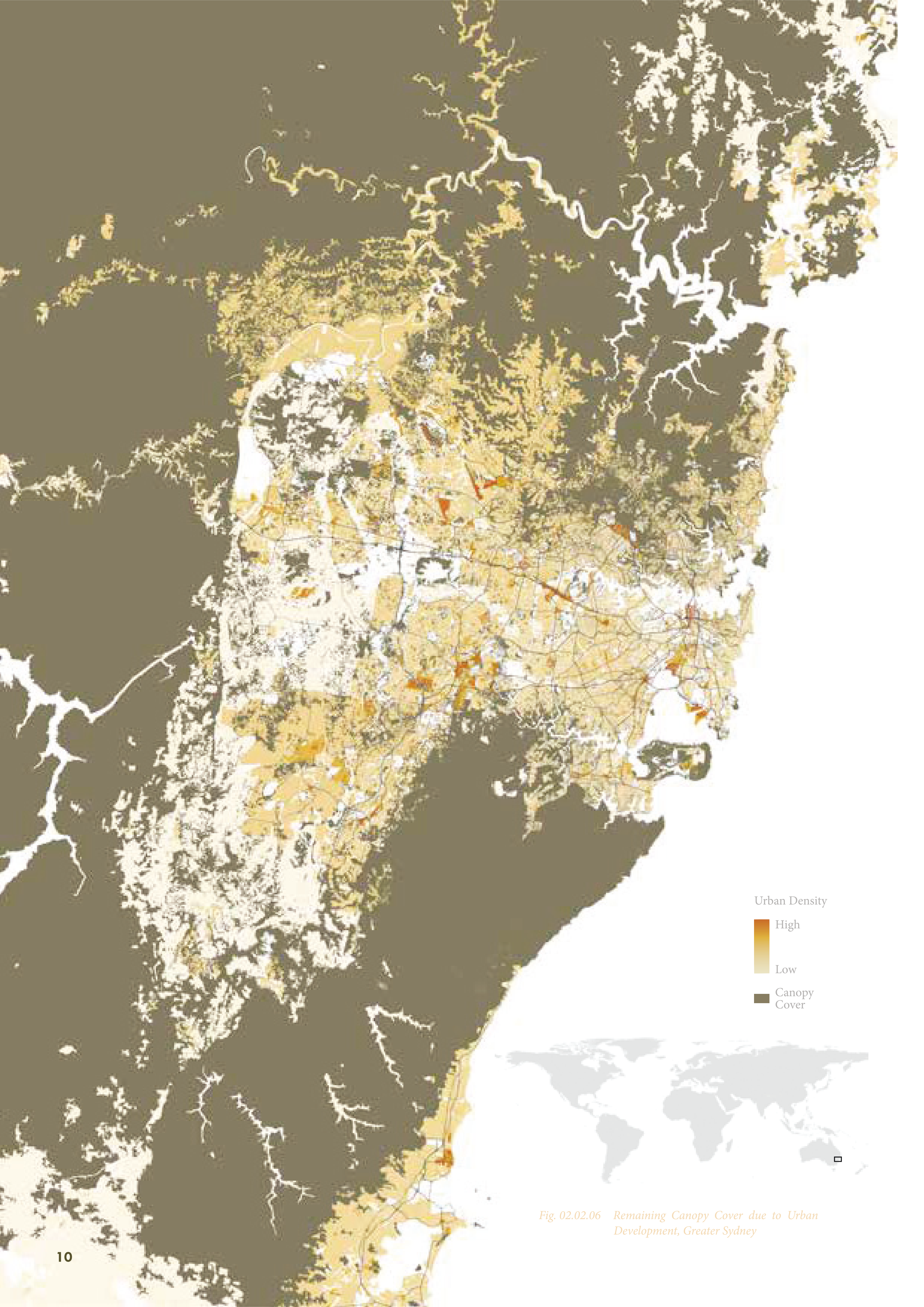


Fig. 02.02.06 Remaining Canopy Cover due to Urban Development, Greater Sydney

02.03 The Background of Urban Development in Sydney

By 2060, Sydney's population will grow by 80% to surpass 8.4 million people (Australian Bureau of Statistics), meanwhile City of Sydney (CoS) aims to increase average canopy cover from 15.5% (2013) to 27.13% by 2050 (CoS Urban Forest Strategy, 2013)

SYDNEY'S URBAN GROWTH

Like many cities around the world, Sydney's growth since the late 1800s has been carved out of native ecologies and landscapes, resulting in a stark and recognisable division between the built environment and surrounding National Parks to the north, south, and west. This, along with the fragmentation of canopy cover within the urban extents is visible in Fig.02.02.06.

Landform and topography played a significant role in influencing these traditional urban development practices during early European settlement of Sydney. Botany Bay, "the site of the first encounter on the east coast of Australia between the traditional Aboriginal owners of the land [the Dharawal nation of Gweagal and Kameygal people] and a European exploration party" (Royal Botanic Gardens[2], n/d), was deemed too swampy and with poor access to fresh water, with landing instead taking place at Port Jackson and Sydney Cove (Parker 2009). Thereafter, slope and aspect determined the suitability of land and ease of construction, and in the early days, access to natural resources. Native forests and vegetation communities were felled to create cleared land, and expansion of Sydney's suburbs occurred along ridge-lines due to their flatter topographies and less-dense vegetation. Subsequently today, much of Sydney's remaining density of native ecological communities exist along these lesser-preferred (for development) creek-lines and steeper embankments.

Similarly to Sydney, the early establishment of Bathurst saw influence through topography for settlement. An expedition over the tough and rugged Blue Mountains in 1813, resulted in the discovery of the rich grasslands that are now the Emu Plains - the lands of the traditional Wiradjuri people. These grasslands were created through the land management practices of the Wiradjuri, through periodic burning, however was seen by European settlers as ideal land for agriculture and food production. Bathurst was subsequently established in this location for its flat, yet elevated position above flood waters, access and proximity to the river, and its rich and fertile soils (Macquarie, The Colonial Journal - Volume 1, pg74).

In more modern times, urban expansion of Sydney largely remained confined to the proximity of what is now the CBD, until 1900s (NYU Stern Urbanization Project, 2014). Thereafter, corridors of expansion to the north, west, and south, saw the development of areas such as Strathfield and Hurstville, following the rail network, with further expansion from the 1940s-70s enabled through the popularisation of the private car - leading to urban sprawl (Transport Sydney, 2014). The 1980s-90s saw the urban fringe, of which formerly reached only as far as Blacktown and Liverpool, pushed further out particularly within Central-Western and South-Western Sydney, until the present scenario where Parramatta is now established at the geographic centre of Sydney. Much of this later development, as seen within Fig 02.03.01, continued the trend of urban sprawl, extending up to surrounding national park reserves.

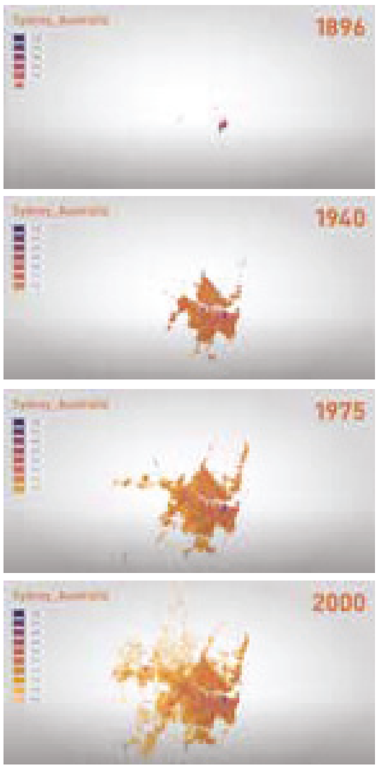


Fig. 02.03.01 The expansion of built up urban land in Sydney (1808-2000). Source: NYU Stern Urbanization Project, 2014

SYDNEY'S POLYCENTRIC VISION

Fig. 02.03.02 'Metropolis of Three Cities' polycentric Sydney vision. Source: Greater Sydney Commission, 2017

With available development land within the bounds of surrounding national parks quickly diminishing, new strategies for densification rather than sprawl are beginning to see implementation - in order to build 'up' rather than 'out'. In 2017, the Greater Sydney Commission released their draft document 'Metropolis of Three Cities', outlining a vision for Sydney as a polycentric city to centralise job opportunities within three distinct centres, whilst distributing facilities and services to residents in no more than a 30 minute commute.

Along with the traditional Sydney CBD, this model introduces new CBDs within Parramatta and Badgerys Creek (Western Sydney Airport), completing the three cities' aim. Effectively, this would see the densification of urban areas surrounding these new centres, establishing vertical growth to help combat urban sprawl. This densification, if not managed properly, would place further pressure on already fragmented and isolated remnant vegetation.

ECOLOGICAL CONSEQUENCES OF URBAN DEVELOPMENT, SYDNEY

The '2019 report for the Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES)' has outlined the fact that "biodiversity - the diversity within species, between species and of ecosystems - is declining faster than at any time in human history" due to land (and sea) use change recognised as the primary driver for "an unparalleled degree" (IPBES, 2019) of alteration to nature. As outlined, Sydney has not been immune to habitat fragmentation resulting from urban growth. Whilst climate change is a major concern - placing increasing pressure on natural and built environment resilience due to more frequent and severe weather events, fragmentation is also a significant threat within Sydney, caused by the "encroachment of urban development on the Cumberland Plain Woodland in the Sydney Basin... [reducing] the community to small fragments scattered across the western suburbs of Sydney... now listed as critically endangered" (State of Environment Australia, 2016).

Both climate change and fragmentation are significant contributers in particular to the "exceptionally severe" rate of extinction within mammals in Australia, within a global context (Woinarski et al, 2015). Furthermore, this rate of extinction is ongoing, with "two Australian endemic mammal species... rendered extinct [in the last decade], one reptile species has been made extinct and two other Australian reptile species have been rendered extinct in the wild" (Woinarski et al, 2015), with a University of Sydney study showing a potential "40 percent of [insect] species threatened with extinction" (Dr F. Sanchez-Bayo, 2019). These extinctions can be directly connected to ecological fragmentation as "small habitat remnants cannot support populations for long periods and are more susceptible to threats and loss of biodiversity following local disturbances..." (Australian Government Department of Agriculture, Water and the Environment, 2004).

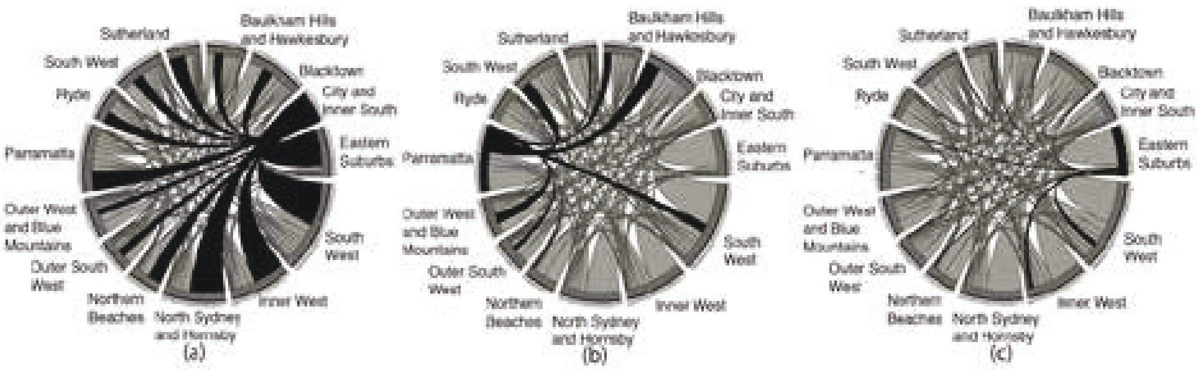


Fig. 02.03.03 Testing polycentricity via net inflows: (a) Sydney City and Inner South (Sydney CBD), (b) Parramatta, (c) Eastern Suburbs. Source: S. Sarkar, D. Levinson, H. Wu. The Conversation, 2019.

Much like anywhere else around the world, urban growth requires either additional land, or existing land used at a greater intensity. Throughout Australia, our major cities "continue to expand into natural areas on the city fringes, despite well-recognised problems associated with higher infrastructure costs, lack of amenity, car dependency, poor job access, and diminished agriculture and open space" (Newton, 2012). Within Sydney, the previously outlined 'Metropolis of Three Cities' vision is one way of addressing this issue of expansion over the broader context, however with additional intensity of land use comes a densification of built form, higher concentrations of population, and greater requirements for public open space as a measure of liveability.

Fig. 02.03.05 Urbanisation of Chatswood CBD, Willoughby LGA. Source: Mark Merton

As seen within areas of Sydney such as Willoughby LGA, where densification within Chatswood, for example, creates a stark, concrete and glass obtrusion within the suburban landscape, there are significant steps that need to be taken to improve the way that urban development responds to, and accommodates native ecologies and communities. Albeit at a smaller scale, the example of Chatswood illustrates how densification through a polycentric model will not necessarily provide environmental benefits from a habitat perspective, instead requiring further planning controls and strategies to embed ecological design within our built environment.

Fig. 02.03.04 Willoughby LGA built form and ecological fragmentation

02.04 Sydney's Lineage of Green and Ecological Strategies

THE GREEN BELT, 1948

The 'Green Belt' strategy aimed to contain urban sprawl within Sydney, creating a ring of protected bushland and farmland around the outskirts of development. Toted as "visionary and radical" (van Onselen, 2018) at the time, the Green Belt came just after WWII, commensurate with a wave of population growth - the post-war 'baby-boom', along with a rise in immigration. This unpredicted population growth "was dramatically underestimated [by the County of Cumberland], because the 2.25 million they predicted for 1981, was reached in 1961" (Meyer, 2018), which placed increasing pressure on the value of remaining land for housing and development, subsequently raising the cost of many privately owned parcels that the government would need to acquire to implement the strategy.

The addition of the 'Green Web' within the belt included 'green lungs' as breathing spaces "as a network of greenways to link existing tracts of landscape and waterways, establishing landscape buffers between differential land zones" (Kilbane, 2016). Whilst the web had much greater success, comprising a smaller amount of land at 8900ha, implementation was similarly ill-fated after 12 years of opposition, and federal funding eventually removed (Dictionary of Sydney Staff Writer, 2008).

Fig. 02.03.06 1948 Sydney Green Belt and Web. Source: Winston, Denis (1957)

SYDNEY REGION OUTLINE PLAN, 1968

The 'Sydney Region Outline Plan' represented a complete departure from previous ideas and notions of the 'Green Belt', instead focusing on a need for Sydney to decentralise, "developing the Sydney-Newcastle-Wollongong area as one inter-related, linear urban complex with special emphasis on a north-south communications corridor linking the three areas" (SROP 1968, pg.16), therefore facilitating rather than inhibiting growth. Acquisition of land once again became a major priority, with the formalisation of the 1951 Cumberland Development Fund (CDF) policy enabling extensive land designation for open space and roads within the scheme (Evans, 2019).

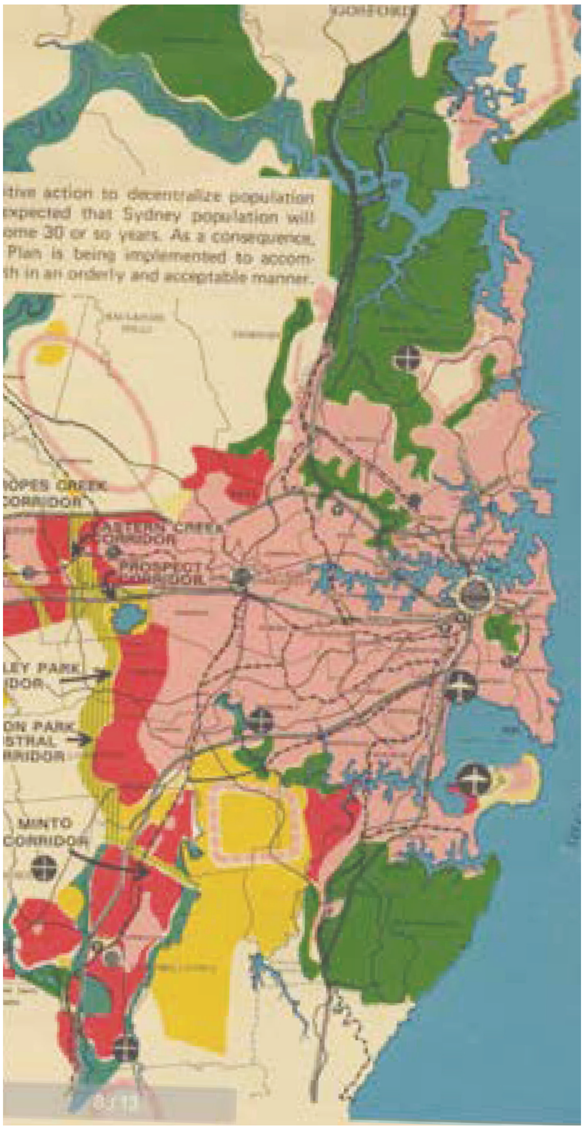


Fig. 02.03.07 1968 Sydney Region Outline Plan. Source: NSW State Planning Authority (1968)

THE SYDNEY GREEN GRID, 2017

The Sydney Green Grid was initially conceived by The office of the Government Architect NSW, for the NSW Department of Planning, Industry and Environment (DPIE), and was subsequently mapped and spatialised by Tyrrell Studios in 2017. The strategy was intended as a step in the ongoing process for developing a new interconnected and high performance green infrastructure network for Sydney, throughout six districts that together comprise the greater metropolitan area.

The result of this process is a high-level network of strategic corridors for ecological and transport connectivity, aligned with existing roads, creeks and walking trails throughout Greater Sydney. The strategy, along with policy document 'Greener Places', aims to provide a spatially based plan to deliver a language of sustainability permeated throughout Sydney's polycentric metropolitan area (Evans, 2019).

Whilst the Green Grid shows a marked progression in the level of detail and complexity when compared between the two prior strategies, a level of specificity and responsiveness to ground and place are still required, with the resulting mapping of the Green Grid remaining "coarse and imprecise" (Kilbane, 2016). The strategy instead relies on individual LGAs to resolve this level of specificity through design interpretation, for implementation at a ground-level. This has resulted in an uneven uptake of the Green Grid, due to differences in funding priorities between LGAs, and a lack of integration of the 'Greener Places' document into state-wide policy that will instead take time to inform in a more gradual manner.

"Well designed and planned green infrastructure will help absorb flood water, cool the urban environment, clean the air, provide space for local food production and ensure the survival of Sydney's flora and fauna as well as providing space for recreation, sport and leisure"

- Schaffer (2015)

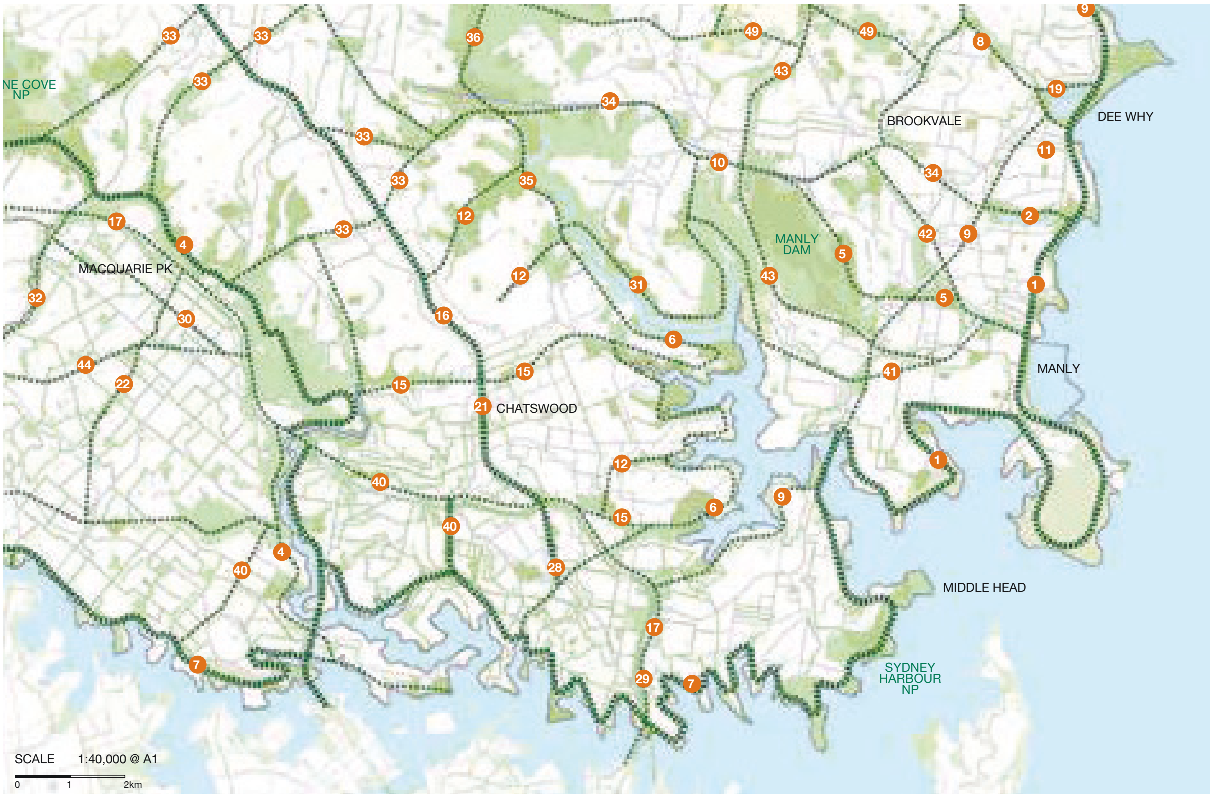


Fig. 02.04.01 2017 Sydney Green Grid mapping of the North District Green Grid Opportunity Corridors. Source: 'Sydney Green Grid North District', Tyrrell Studios (2017)[1].

SYDNEY GREEN GRID - METHODOLOGICAL APPROACH

The Sydney Green Grid (SGG) utilised traditional 2D GIS methodologies to analyse the existing built and environmental features of Sydney, and produce outcomes in response.

GIS layers were classified into one of eight 'grids'; the Hydrological, Ecological, Recreational, Agricultural, Transport, Utilities, Development, and Historical grids. The first four grids, the landscape layers, fed directly into the consolidated Green Grid - consisting of a network of 'green' corridors, while the latter four were used in identifying potential catalyst projects, and areas of 'high value'. Throughout the process, workshops held by the Greater Sydney Commission (GSC) incorporated feedback and communication with local and state agencies, and stakeholders, confirming or advising on current, potential and speculative projects relating to the environment.

"Each district is analysed for its spatial qualities, open space, waterways, its context and key natural features. This data informs a series of strategic opportunities for building the Sydney Green Grid within each district." (Tyrrell Studios, 2017)

From this list of projects, categories were created to split them into one of two strategies; the "protectionist strategy", and the "projectionist strategy". The 'protectionist strategy', as the name implies, aimed to protect existing high value lands through long-term planning, with the 'projectionist' approach aligning or overlapping projects with current urban development or priority precincts, strategic lands or open space needs including areas of deficiency or disadvantage.

"The Green Grid methodology... seeks to identify and create an open space planning approach that is site specific and responds to local character and needs." - Tyrrell Studios, 2017).

Small scale catalyst projects were identified through McHargian 'sieve' mapping and the McHargian 'Overlay Method', drawing out spatial 'deficiencies', missing links, and potential 'stitch' projects to bridge gaps in connectivity. The 'Overlay Method', which was pioneered by Ian McHarg through his 1968 publication 'Design with Nature', enabled strategic planning across broad areas and regions by drawing out patterns and interconnections between environmental, urban and demographic spatial characteristics. More modern spatial datasets have the capabilities of taking this methodology much

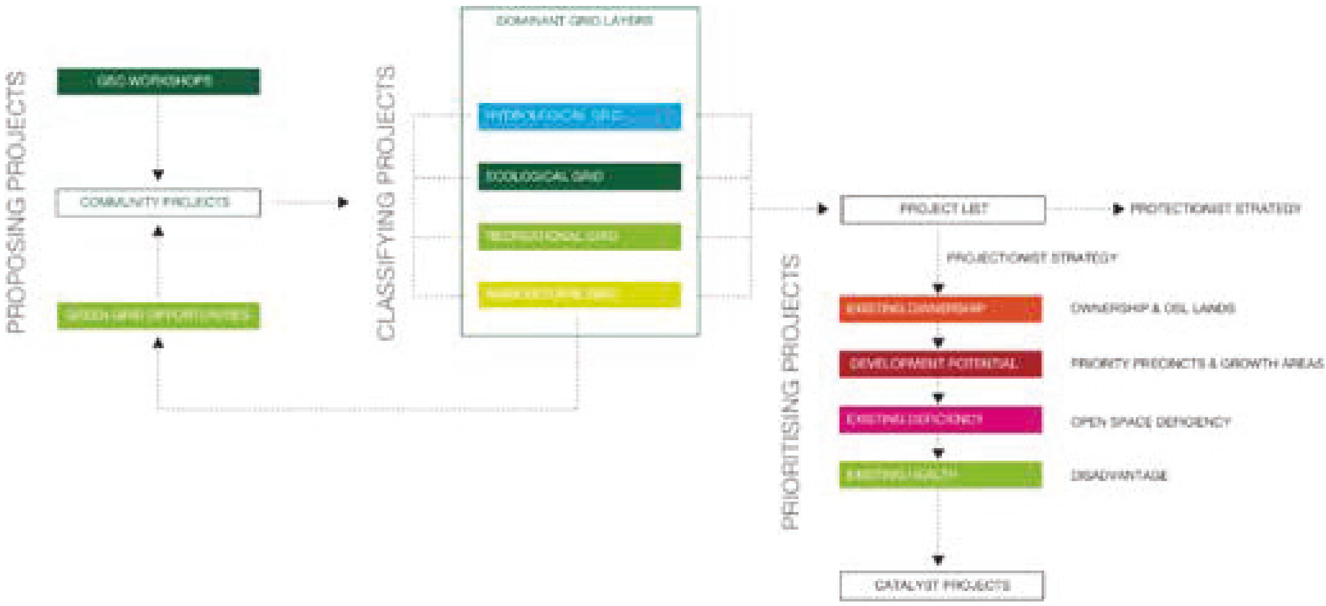


Fig. 02.04.02 The 2017 Green Grid methodology for proposing, classifying and prioritising project opportunities. Source: Tyrrell Studios 2017, Sydney Green Grid Introduction

further, introducing precise, 3D representations of urban built form and environmental features that can be hybridised with the more traditional 2D mapping layers of GIS.

Whilst the Sydney Green Grid aims to be "site specific and respond to local character and needs" (Tyrrell Studios, 2017), the high-level 2D mapping methodologies and traditional data inputs limit this specificity to "future development plans, strategic lands, complimentary infrastructural projects or local government priorities… [along with the] landscape character features in each district", with each of these aspects representing broader moves or features generalised throughout the each district as a whole. This shortcoming in the responsiveness to the local scale is true for many policy and schemes similar to the Green Grid "frequently exist[ing] only as a planning overlay and could benefit from significant design refinement and resolution at the local scale" (Kilbane, Weller, & Hobbs, 2016). The source of this "coarse and imprecise design" (Kilbane & Kosinski, 2016), as revealed through the methodologies used within the conference paper 'Evolution and Evaluation of Contemporary Greenways and Green Infrastructure in Sydney, Australia' (Kilbane & Kosinski, 2016), at the fundamental level is the mapping process itself, and the inherent resolution of the GIS data used. As a result of this high-level mapping, implementation is therefore more difficult, and the refinement of design becomes the responsibility of individual Local Government Areas (LGAs), where simplified and less ecologically rich solutions may be devised. This, along with the fact that the accompanying policy-influencing document 'Greener Places' has not been fully embedded into hard policy, has led to an "uneven uptake of [the] SGG across agencies" (Evans, 2019).

"polic[ies] and schemes (such as the SGG) that are common globally… frequently exist only as a planning overlay and could benefit from significant design refinement and resolution at the local scale" - Kilbane, Weller, & Hobbs, 2016)

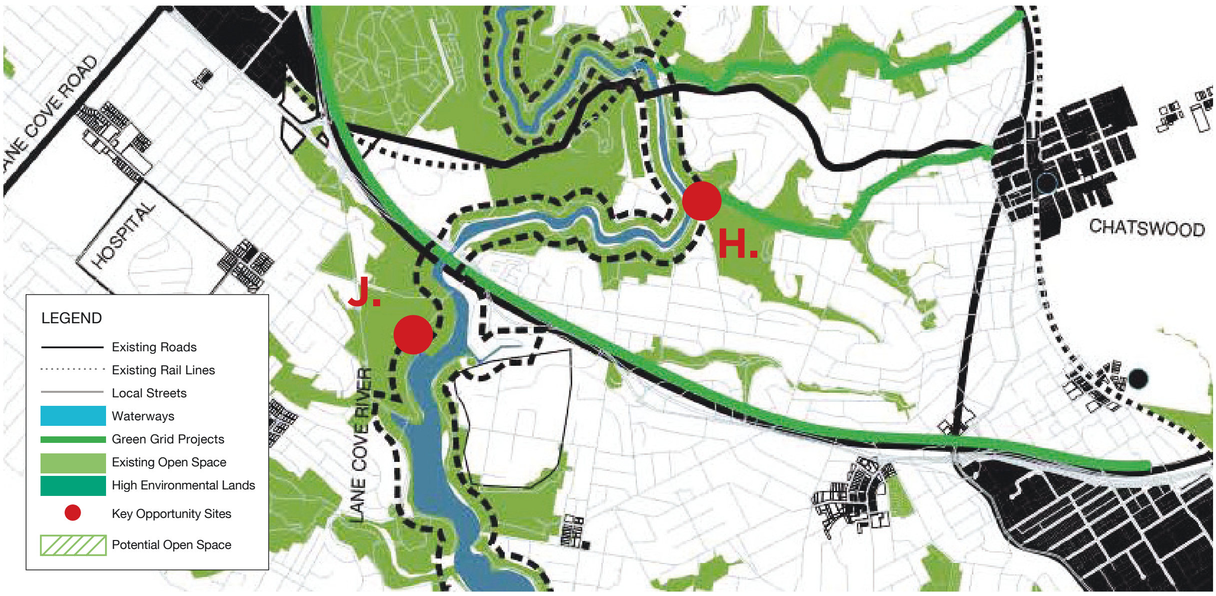


Fig. 02.04.03 An example of Sydney Green Grid mapping, detailing a potential focus area, the Lane Cove River. Source: Tyrrell Studios 2017, Sydney North District Green Grid

02.05 Findings: Key Opportunities and Barriers to Implementation to Overcome

ACTIVATING PRIVATE LANDS

Current green strategies represent a 'hard', top-down approach to governance (Evans, 2019), relying solely on public space (or the acquisition of private lands) for their scope of implementation. Throughout Sydney, this significantly limits the scope of strategies such as the SGG, with a significant proportion of land within LGAs comprised of private lands as revealed within Fig 02.05.01. This mapping of 'private lands' include all residential zoning according to LEP data, along with private recreation areas.

Within current practice, green link implementation may rely on the acquisition of private lands for their path to be completed. This not only requires a transfer of ownership and zoning for this to link to be possible, but presents further costs associated with the green network, and the displacement of people from their homes.

Adopting a new approach to implementation, activated through community participation and involvement, has potential to lift this barrier to private lands - broadening the scope of ecological integration and connectivity. This will enable a less dense, but more evenly dispersed network, opening up all of this potential land for integration within a metropolitan green network.

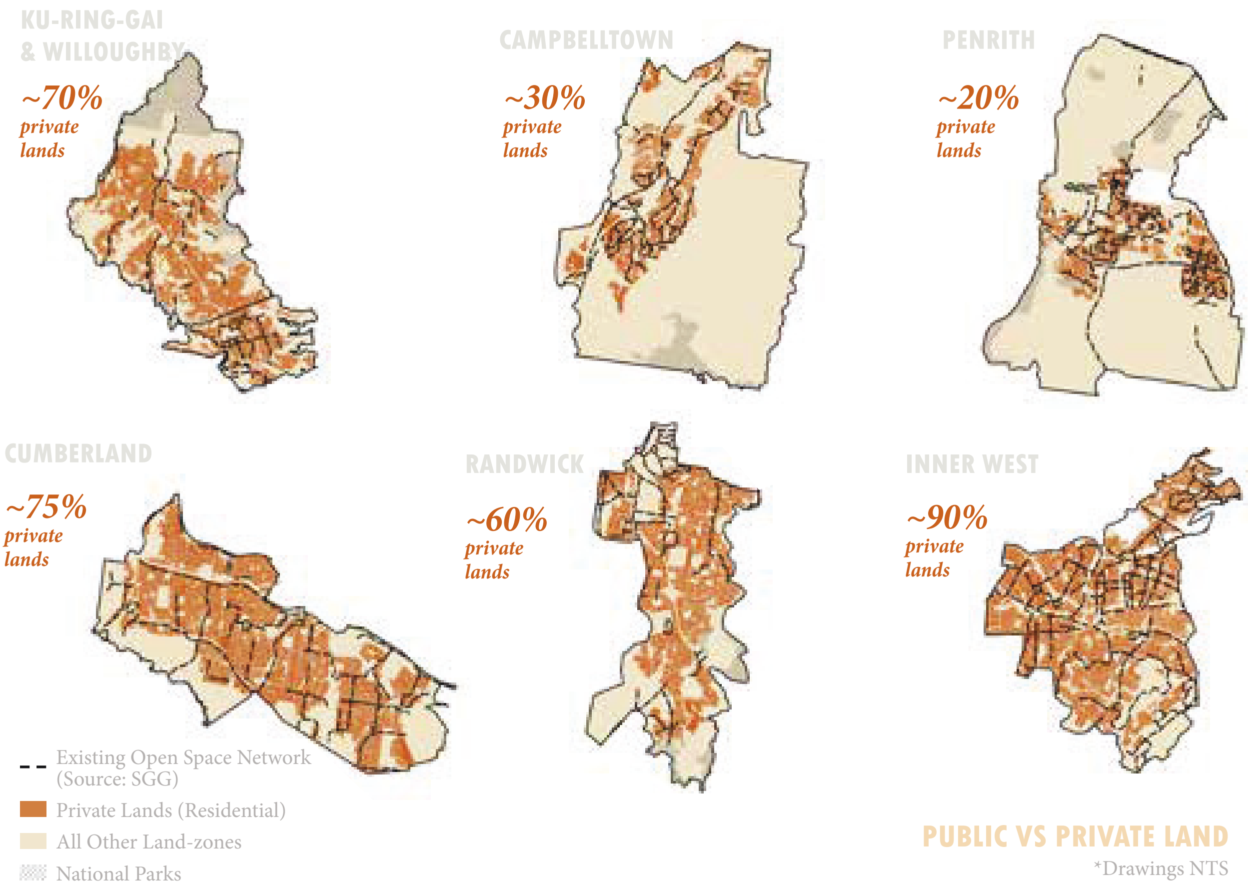


Fig. 02.05.01 Analysis of the percentage of private lands across several LGAs within Sydney. Source: Author.

BROADER ECOLOGICAL DISPERSAL

Many LGAs throughout Sydney have highly diminished canopy cover, with targets to increase this figure through planting and revegetation. Currently, the SGG and existing open space network where much of this replanting is likely to occur, miss the potential of reconnecting the majority of fragmented vegetation remnants, as shown in Fig 02.05.03. This is due to the coarseness of corridor their structure, and aforementioned implementation barrier to private lands.

This shows that in order to address habitat fragmentation, a more evenly dispersed green network needs to be implemented that departs from the corridor structure of the SGG, and instead creates an evenly dispersed ecological strategy across the city. This will create ecological connections to small, remnant vegetation communities within backyards, more cohesively facilitating environmental restoration within urban and suburban areas.

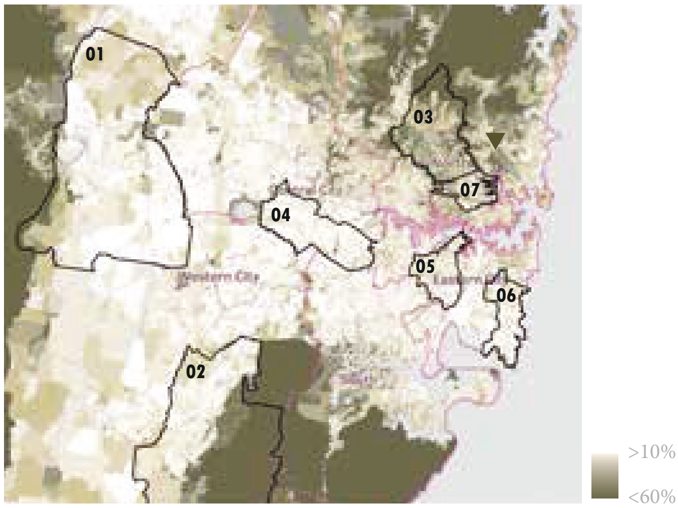


Fig. 02.05.02 *'The Pulse of Greater Sydney' - Remaining canopy cover percentages across Sydney. Source: Greater Sydney Commission (2019).*

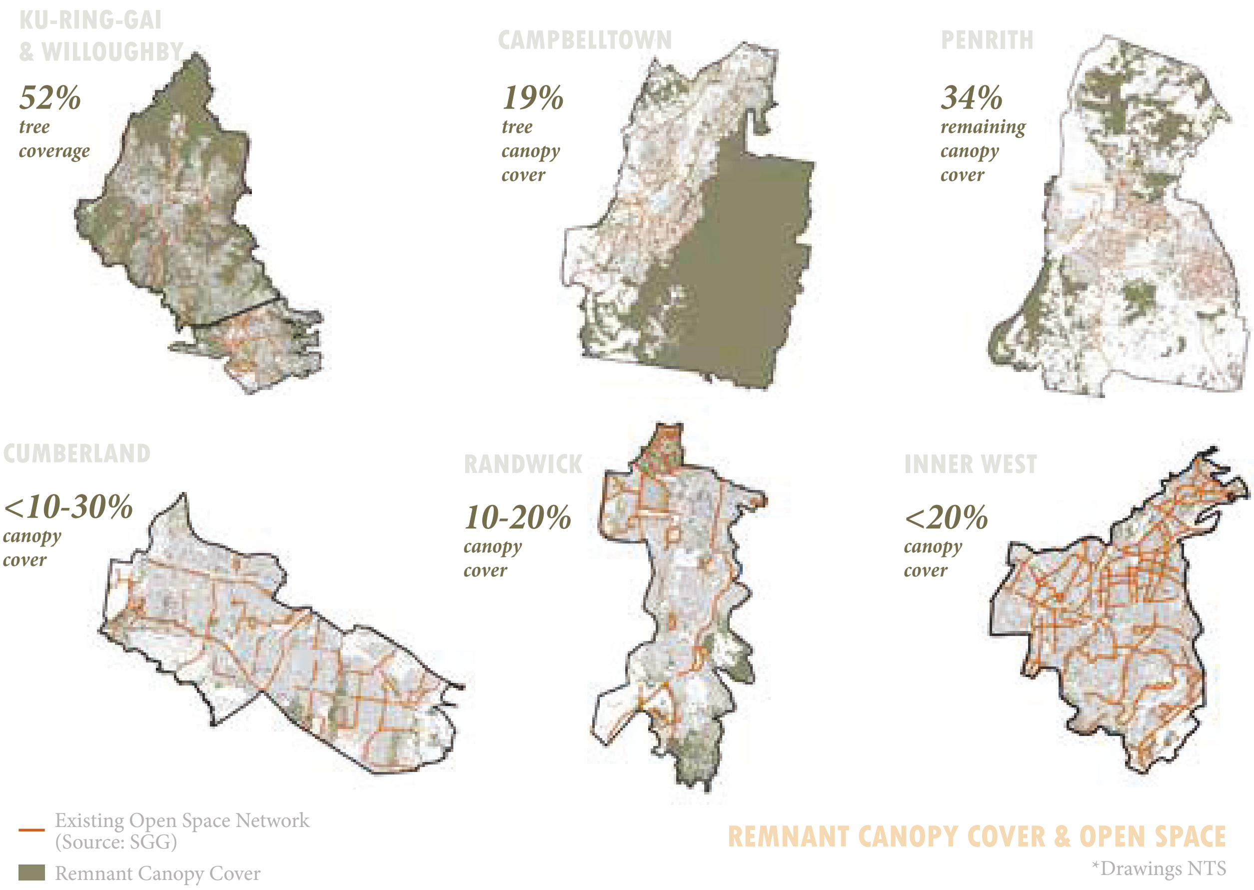


Fig. 02.05.03 *Analysis of habitat fragmentation and the alignment of existing open space corridors throughout several LGAs. Source: Author*

THE SPATIAL GAP IN TRADITIONAL GIS MAPPING

Traditional GIS methodologies such as 'sieve' mapping mentioned previously, portray of a top-down, deterministic view of planning, where it is blindly accepted that the superimposing of various mapping layers will produce 'correct' design outcomes [Fig 02.05.04]. This methodology, whilst widely accepted and practiced through large-scale strategic planning, as with the Sydney Green grid, is firstly, highly reliant on the quality and resolution of data - locked to the intended scale of each mapping layer input, and secondly, a process which lacks consideration for the qualitative human aspects of site - the finer nuances of unintended program, and spontaneity that such a rigid, top-down planning process inhibits. These dynamic and inherently 'human' considerations of place are ultimately what give a place its unique character, promoting a sense of ownership and belonging within its residents, of whom, shape their surroundings to suit their own character and personality.

GIS data is ultimately derived through traditional mapping where detail, accuracy and extent are dictated by scale and paper size, preventing the scalability of data and subsequently creating a spatial-gap between broader-scale mapping and ground-level complexities. GIS data can be delivered in one of two forms; vector and raster, with the former being a cell-based representation appropriate for national and regional scales, and the latter having the ability to be represented through dynamic shapes and forms, yet "is [still] dependent on the scale of the original mapping product, resolution of the DEM (Digital Elevation Model), or quality of digitisation" (Yeh, 2005). Whilst the majority of GIS data exists at a level of detail acceptable for high-level mapping and analysis, there is a limited ability to transition seamlessly between regional mapping and local or detail scales, for example, which introduces incongruities further exaggerated by the possibility of outdated or contradicting data. The source of these discrepancies, is the existence of many independent agencies, governments and private institutions that offer and deliver these datasets, each dealing at a variety of scales, surveyed within different periods of time, taking varying amounts of time to process and exchange information, and lacking in coordination. Our constantly evolving cities and natural environments mean that these datasets require frequent and periodical updates to remain accurate and relevant.

Traditional GIS practices therefore create a disconnect to the individuals and communities who dynamically shape Their environment through localised programs, activities and textures that contribute to creating a sense of character and place.

"[The] approximate nature of most GIS data and numerical model predictions... [means that] the value of any site specific prediction (pixel scale) provides only a rough approximation of reality" (Netmaptools.org, n/d)

An evolution from these traditional GIS methodologies and datasets is imminent, with a range of competing or supplementary spatial technologies currently finding their place within urban planning. 3D Digital Twin modelling, currently under development by CSIRO for Sydney, and LiDAR point clouds and large-scale photogrammetry models are able to portray the metropolitan-scale at much greater detail than traditional 2D GIS maps, introducing the possibilities of scalability, and a textural connection to the ground. Furthermore, these 3D spatial datasets allow for a whole host of smart environmental and urban simulation and analytical tools, that can be used to inform current and future urban development. With a greater ability for understanding the more detailed and finer-grain scales, it then becomes possible to fold in a complex analysis of the social realm, including the small human programs and interactions that exist at the ground level.

This next evolution of spatial data, and the possibilities they enable, will therefore be the key to bridging the gap between traditional GIS datasets, and the finer-grain nuances evident at the ground-level. This missing link will facilitate a highly responsive ecological grid that can be easy to implement as they have integrated responses to ground-level complexities, and the to taking metropolitan-scale ecological strategies to the next level, will be provision of a far-greater level of detail and guidance to the local governments, communities and individuals who will be key in their implementation.

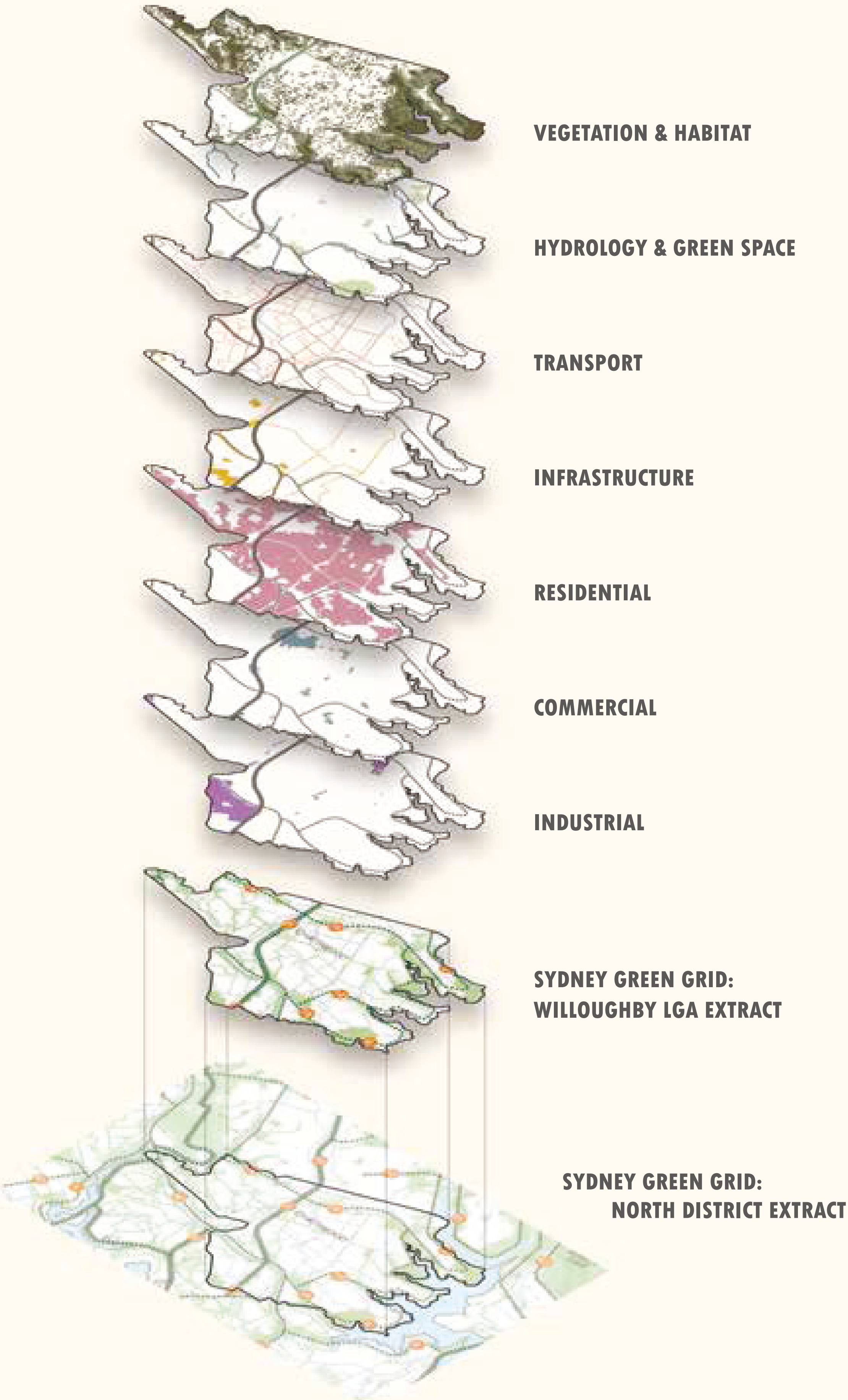


Fig. 02.05.04 A re-creation of GIS 'sieve mapping' layers contributing to the Sydney Green Grid (SGG) strategy, for the LGA of Willoughby within the North District. Source: Author

03

03. FUTURE VISIONS: PRECEDENT PROJECTS, IDEOLOGIES & CONCEPTUAL CITY MODELS

03.01 Chapter Overview

A breadth of existing knowledge and prior research into green strategy planning, innovative policies, ecological principles, and implementation methods have subsequently guided and informed the direction of research within this dissertation. Many of these precedents, established as theoretical goals or future framework concepts, will not have any environmental benefit unless adopted through practical implementation.

From the global scale to the local, Sydney scale, the practical implementation of these strategies face challenges through barriers of human systems - preventing the adoption of a post-anthropocentric mentality within planning practice. With an ever-pressing immediacy for environmental action within the realms of landscape architecture, urban and environmental planning, it is crucial that any theoretical environmental goals be considered and adopted through practical implementations, so that their environmental benefits are able to be realised.

These findings reveal a need for a holistic and replicable ecological strategy that not only adopts this prior theory, but enables a process for their widespread integration into cities. Beginning at the metropolitan scale of Sydney, this strategy or tool needs to incorporate these environmental principles in a practical sense throughout all land typologies, not only public but also private - making the most of community participation and remnant vegetation communities within backyards. The financial barriers need to be lifted, as while a significant investment in initial funding would be required, distributed through grants and incentives, the long-term environmental and economical benefits would far outweigh this. For example, the decentralisation of water and electricity through the simple implementation of water tanks and solar panels, feasibility immediately at the residential scale, would reduce the need for investment into centralised dam infrastructure and environmentally-destructive coal power plants. Furthermore, integrating food production into urban rooftops and suburban backyards would support a decentralisation of farming and agriculture, freeing up huge amounts of productive lands for re-wilding or ecologically-sustainable development.

The following chapter therefore presents a number of background precedents and literature, that are each valuable considerations towards the research of this dissertation - that should be addressed and accommodated into this work to support, enable and promote the physical implementation of these ideas.

03.02 Global Environmental and Human Development Goals

POST-ANTHROPOCENTRISM

With the realisation of humankind's environmentally destructive practices since the late 1700s, defining a new epoch; the Anthropocene, more contemporary design and development practices are starting to adopt a new notion of the 'Post-Anthropocentric'. Post-Anthropocentrism seeks to promote the consideration of all forms of life equally, representing a crucial shift not only in the design practices of Architecture, Landscape Architecture, and Urban Design, but something that needs to be reflected through planning policy, everyday decisions, and consumer behaviour.

Emerging as a critical social issue in the past several decades, the underlying concepts of post-anthropocentrism were raised around the 1960s with R. Buckminster Fuller, a professor at Southern Illinois University, who recognised the ability and potential for design to identify and address major world problems, driven by the realisation of environmental degradation, pollution, widespread extinction, and an accelerated rate of global warming that have been caused by human 'development'.

Ecological design aims to address these environmental issues within our built environment, to "improve ecological functioning, preserve and generate resources for human use, and foster more resilient approaches to design and management of our built environments" (Rottle & Yocom, 2010). However, whilst ecological design has gone so-far in addressing the issue of our anthropocentric practices through isolated implementations, it's full potential of integrating valuable habitat and ecologies into our built environments is hindered by economic and legislative barriers such as cost benefit analysis, maintenance burdens, planning zone constraints, and safety considerations.

Dramatic changes are needed in governmental policy and legislation, lifting these barriers and driving a process of ecological integration within our cities and towns. Outdated legislation still founded on the old 'anthropocentric' mode of thinking, which prioritises human benefit over natural environments, form barriers to the implementation of ecological design implementations. These attempts to accommodate ecologies within cities and towns are rendered uneconomical and therefore not worthwhile as they bring 'little benefit' to human habitation - meanwhile extinction rates rise to "hundreds, or even thousands, of times higher than the natural baseline rate" (National Museum of Natural History, n/d).

"Across Australia, there is a core-level support for the principles of urban greening in our large towns and cities. However, legislative barriers exist at all levels of government that need to be overcome before widespread adoption can occur..." - Nursery Papers (2016)

Fig. 03.02.01 Ecological design as a major component of the proposed Soprema Headquarters in Strasburg - Vincent Callebut. Source: ArchDaily

UN SUSTAINABILITY GOALS

In 2015, the United Nations introduced the '2030 Agenda for Sustainable Development', providing "a shared blueprint for peace and prosperity for people and the planet, now and into the future" (United Nations, n/d). The agenda included 17 Sustainable Development Goals (SDGs) which are "an urgent call for action by all countries - developed and developing - in a global partnership" (United Nations, n/d). The goals seek to prompt action in ending poverty, improving health and education, reducing inequality and promoting economic growth within all 193 UN Member States.

As a broader goal and aspiration, many of the SDGs are aimed squarely at combating climate change, and preserving earth's oceans and forests. Directly translatable into targets for landscape architecture and urban design, it is now on the behalf of all member states to begin implementing these goals, taking steps to incorporate them fundamentally within design practice going forward.

Fig. 03.02.02 The United Nation's 17 Sustainable Development Goals, adopted as a blueprint for addressing global social and environmental challenges by all united nations in 2015. Source: United Nations (n/d).

WORLD BANK GREEN INFRASTRUCTURE FINANCE

The 'Green Infrastructure Finance: Framework Report', by the World Bank and World Resources Institute, lays out a framework and analytical methodology that uses environmental economics and project finance practices as a way to assess the financial viability gap of low-emission projects, in order to strengthening green investment through opportunities specific to a given country.

The report introduced a 'new generation' of infrastructure project possibilities, combining traditional grey infrastructure with low-emission green infrastructures "that harness the power of nature… [and] help achieve development goals" (World Bank[2], 2019)

"Measures like replanting wetlands can shield cities from storms and flooding, and protecting forests improves watersheds. Infrastructure should make use of plants and nature to boost resilience and create a more livable environment." - World Bank[3], 2019

03.03 Future City Concepts

SMART CITIES

The Smart City movement establishes a sensor-based urban framework where "Information and Communication Technology (ICT) is merged with traditional infrastructure, coordinated and integrated using new digital technologies" (Batty et al, 2012). Within this framework, individual city services such as traffic management, the public transport network, and energy distribution, are able to communicate and respond accordingly to immediate urban issues. Connected traffic lights can reduce congestion by adjusting their timing, smart garbage disposal can communicate with waste management to prompt collection, and Electric Vehicles (EVs) can communicate with parking meters and charging docks for availability in real-time. A matrix of embedded sensors and monitoring devices within public infrastructure enable this real-time data collection, promoting a highly democratic planning process whereby the growth and needs of the city are determined through the demand of the city's population.

This sensor-based approach, often portrayed as the 'utopic' city model that has an answer for 'any urban issue' we may face today, presents a fundamental problem in its 'reactive' rather than 'proactive' method of dealing with and managing these issues. This 'reactive' quality, which adapts city services to address urban issues as they arise, potentially ingrains poor habits within urban life by accommodating them and working around them. Instead, a 'proactive' system would foresee and avoid the problem before it happens, preventing these issues from arising in the first place. Artificial Intelligence (AI) and machine learning present significant potential in achieving this foresight through the automation of future cities. These technologies are able to process huge amounts of data, to compare and learn from previous urban issues, predicting and preventing them before they eventuate.

Furthermore, whilst some of the smartest cities in the world such as New York, Amsterdam, Singapore and Tokyo, feature an extensive array of 'smart' implementations that focus on the human aspects of a city (the economic, social and infrastructural systems), many of these concepts are lacking in their consideration of the ecological. In recent years, there has been a "shift in cities striving for smart city targets instead of sustainability goals" (Marsal-Llacuna et al, 2015), though at the same time, many smart city goals are shared with the sustainable cities movement that preceded it. Whilst smart cities and sustainable cities alike, aim to address greenhouse gas emissions and the efficient, sustainable production of energy, the underlying technological foundation of the smart cities approach and bias towards human systems leads to investment in these areas rather than considerations for non-human forms of life.

Environmental indicators as a component of Smart City implementations is beginning to emerge, through 'Digital Twin' models such as the 'Virtual Singapore' tool. Such tools enable environmental system visualisations, including temperature and sunlight, to validate the effects of green infrastructures such as green roofs on the local environment.

"The effects of climate change, an ageing population and infrastructure, water and energy provision are all presented as problems for which smart cities have an answer... Why do smart cities offer only improvement? Where is the possibility of transgression?"

- Koolhaas 2014

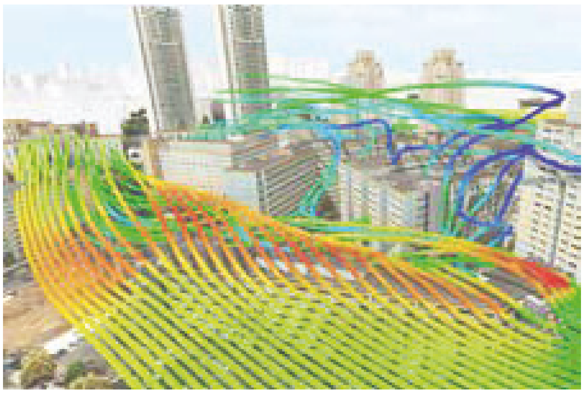
Fig. 03.03.01 BOSCH Smart City Vision, Vietnam, 2019.

NEW YORK

With a focus on equability and the use of digital tools for the welfare of the people, New York's 'Open Data Law' mandates the free availability of all public data on a web portal, including everything from crime stats to tree locations. By establishing this transparency of data, the aim is to empower citizens to solve the issues of fellow residents. In addition to this, NYC features a matrix of physical smart infrastructures from city-wide ultra high-speed WiFi, the creation of the 'Lowline' – an underground park, and the 'Midtown in Motion' traffic management initiative.

AMSTERDAM

An early adopter of the smart cities approach, Amsterdam is now a leading smart city in Europe. Through its smart and holistic strategy of 2009, modelled on a quadruple helix concept of government, business, universities and research institutions, this strategy incorporates a bottom-up methodology for smart growth, startups, social inclusion and quality of life, furthermore, encouraging a 'circular city' concept where all resources are re-used or recycled. An online platform and smartphone app, 'Urby', promotes data accessibility and transparency, as well as citizen participation and inclusiveness.



SINGAPORE

Singapore's extensive adoption of smart city technologies, from shared and automated mobility for elderly residents and students on university campus, to the digitisation of the healthcare system, has led the city to become the smartest city in the world (IESE Cities in Motion Index, 2020). Furthermore, Singapore's smart city approach has focused on cybersecurity to support businesses and collaboration through data-sharing, and education through artificial intelligence. The 'Virtual Singapore' 3D city model is used to analyse light and temperature for solar potential, whilst containing in-depth city infrastructure information.

TOKYO

The smart city approach demonstrated throughout Japan has a primary focus on 'smart grids' as a method to achieve Smart Energy goals whilst creating a cost-effective, sustainable and renewable energy production network. Within Tokyo in particular, the Tokyo Electric Power Company (TEPCO) are implementing 27 million smart meters as a city-wide energy management platform, whilst enabling households to monitor their energy consumption. With Japan's history of nuclear and natural disasters, 'Smart Towns' seek to equip each home with solar power generation and storage batteries to decentralise the power network for more reliable energy.

Fig. 03.03.02 [Top Image] NYC Data Visualisation. Source: CESIUM & NYC OpenData Portal (n/d). [Second from the top] Amsterdam Smart City. Source: Amsterdam Economic Board (n/d). [Second from the bottom] Virtual Singapore Simulation. Source: Dassault Systèmes (2017). [Bottom] Japanese 'Smart Town'. Source: Panasonic (n/d).

THE BIOMORPHIC CITY

Biomorphic Urbanism presents a theoretical foundation for architects and urban designers to accommodate continued and rapid urbanisation into the future, whilst protecting, strengthening, and restoring natural ecosystems at the same time. Stemming from a similar concept to 'biophilia' of the late 20th century, the theory of connecting individuals to nature through the merging of natural and man-made elements within architecture, 'biomorphic urbanism' acts at a broader, city scale, to create 'cities formed by life'. Both concepts are founded on our innate human desire, and deep physical attraction to nature, proven to improve liveability, quality of life, and reduce stress, whilst "hold[ing] the key to our aesthetic, intellectual, cognitive and even spiritual satisfaction" (Wilson, 1968). At the same time, the integration of green elements within our built environment should be equally beneficial to natural ecosystems as to humans, avoiding arbitrary 'greening' for the sake of appearing 'sustainable'.

Seeking to conceptualise a methodological framework for achieving these Biomorphic principles within existing and future cities, SOM Architecture and National Geographic presented the collaborative Biomorphic City concept, within the 'Future Cities' 2019 issue of the National Geographic Magazine. The concept city "begin[s] to frame a method to apply the concept of biomorphic urbanism to new and existing cities… developed in stages, with the natural environment as the first consideration" (SOM Architecture, 2019). The method outlines eight stages, from research through to implementation, mapping existing environmental systems and defining areas suitable to development, to specifying built-form densities, land-use and connectivity. With scalability, the methodology can be applied to "communities of any size, from small towns and villages to major metropolitan regions and emerging megacities" (SOM Architecture, 2019), informed by a series of four high-level, basic principles;

1. Restore Natural Systems;
2. Densify Urban Districts;
3. Diversify Land Uses, and;
4. Connect Communities

"It is not enough for the built environment to look sustainable, through the addition of individual elements such as green roofs and walls. We need a more meaningful and comprehensive approach to the design of our cities — an approach that will protect ecological systems and regenerate the environment." - SOM, 2019

Fig. 03.03.03 'Cities of the Future', SOM Architecture and National Geographic. Source: National Geographic Magazine, April 2019 Issue: Cities

The proposed methodology outlined by SOM Architecture is as follows:

1. Map all natural features, including animal habitats, vegetation, hydrology, topography and climate
2. Define conservation areas to protect existing natural features
3. Locate appropriate areas for urbanisation, outside of conservation areas
4. Define density and land-use within urban areas
5. Introduce connectivity between urban areas, via sustainable modes of transportation
6. Preserve cultural heritage and character
7. Implement 'smart city' concepts and technological connections
8. Implement new types of sustainable infrastructure

The methodology itself, whilst founded on the 'revolutionary' Biomorphic City concept, is relatively ordinary in it's underlying data technologies, and implied division between areas of natural conservation and urban density. Beyond the traditional forms of mapping used for the initial stages of the method, closely related to McHarg's 'Overlay Method', there are opportunities for the utilisation of new spatial technologies, enabling a whole new wealth of site-specific environmental understanding in 3-dimensions, and subsequent increase in site-responsiveness within urban planning. Such data could be used to more explicitly integrate human and natural systems, removing the perceived separation between the two, with responsiveness down to the micro-climate scale of built form - for an ecologically-rich urban environment, evenly-dispersed with green infrastructures and ecological corridors.

Fig. 03.03.04 Seagull Island Master Plan, China. Source: SOM Architecture

THE WOVEN CITY

Proposed for a 700,000sqm former factory area at the base of Mount Fuji, Japan, a joint collaboration between Toyota Motor Corporation and Bjarke Ingels (BIG Architects) have created the 'Woven City' concept - a prototype city to be built from the ground up, pushing the notion of 'smart cities' to the extreme. The city will establish a foundation and living laboratory for the redesign of digital and sustainable infrastructure of the future, powered by hydrogen fuel cells, whilst accommodating both full-time residents and researchers alike. With the intention to extend this research opportunity to other commercial and academic partners, the aim of the project is to "test and develop technologies such as autonomy, robotics, personal mobility, smart homes and artificial intelligence in a real-world environment" (Toyota, 2020), seeking to radically change urban lifestyles through emission-free and shared mobility.

Within an interwoven and organic 3x3 grid pattern, the concept utilises three novel street typologies to support a network of fully-automated, zero-emission vehicles along main thoroughfares, micro-mobility types (along slower-paced recreational promenades), and pedestrian-only linear parks for people and nature. Built from the ground-up, these street typologies demonstrate the possibilities enabled by new mobility technologies, free from the limitation of existing street typologies with curb-side parking and the obtrusive barriers, whilst an underground goods delivery network alleviates large trucks from these roads. Main thoroughfares constitute the outer perimeter of each 3x3 grid, which are then permeated by recreational promenades and linear parks to establish pedestrian connectivity to centralised green courtyards. Each of these 3x3 grid structures are then free to twist and distort, creating a shift from the rigid outer extents, to the organic and circular shapes of the inner grid, accommodating the perfect circle of the Central Park.

Built form within the city is constructed through a synthesis of automation and robotics, and traditional Japanese cultural practices. Natural, carbon-sequestering wood materials employ Japanese joinery methods for construction, contrasting the implementation of high-tech AI sensors and photovoltaic panels for health monitoring and energy generation, respectively. In alignment with the broader aspirations of the city, residents will test these new in-home technologies such, to assist in daily living and basic tasks such as grocery deliveries, laundry and trash disposal.

"The city is planned to be fully sustainable, with buildings made mostly of wood to minimize the carbon footprint, using traditional Japanese wood joinery, combined with robotic production methods" - Toyota, 2020

The Woven City concept seeks to present automation and robotics within a 'utopic' vision of future cities, where mobility, green space and built form are re-imagined through the lens of new technologies, and a testing grounds for the future of urban development. Focusing primarily within the human-based realms of automated mobility, integrated smart technologies, and sensor-based AI, the Woven City concept leaves further opportunity for similarly data-driven responses to ecological systems. Extending the same sensor-based methodologies to ensure the maintenance and restoration of our natural environment, this consideration has significant potential in embedding human and ecological systems, together with responsive technologies, to establish a more holistic vision of future cities that ties together smart city concepts and biomorphic city principles.

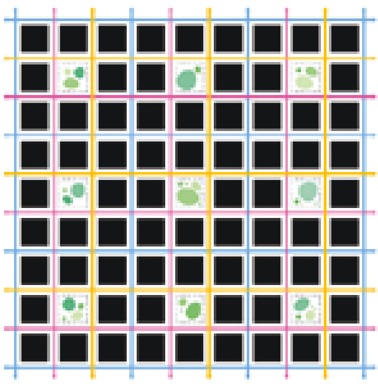


Fig. 03.03.05 Replicable woven module, composed of numerous 3x3 city grid structures connected with a series of vehicular and pedestrian streets. Source: BIG Architects

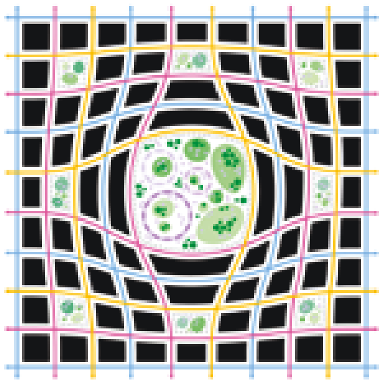


Fig. 03.03.06 A centralised main square to provide city-wide public space, shown within a distorted city grid. Source: BIG Architects

Fig. 03.03.07 Visualisations of the 'Woven City' concept by BIG Architects and Toyota Motor Corporation, 2020. Source: Big Architects

03.04 Green Infrastructure Implementations

GREEN / VEGETATED ROOFS

SIGNIFICANCE

Increased building heights within urban environments has led to the overshadowing of ground-plane surfaces, creating an environment that only shade-tolerant species can thrive. Meanwhile, hard, man-made materials across rooftops face full-sun exposure, significantly contributing to the 'urban heat island' (UHI) effect through the absorption of solar irradiance. With a high percentage of horizontal surface area within our urban environments comprised of bare rooftops, green roofs provide a potential to address both of these aforementioned urban issues - creating gardens that can thrive in full-sun, whilst providing thermal insulation to the buildings below - reducing energy usage by lowering indoor temperatures in the summer.

The following precedents of existing green roof installations range from extensive applications with large shrubs and small trees, through to lightweight examples that can be supported by a wide variety of existing roof structures. They demonstrate a range of human programmatic functions from passive amenity and shade, to the sustainable practice of productive urban gardening. The numerous benefits of green roof installations will therefore be a high priority for consideration throughout this dissertation, with the ability to promote habitat and biodiversity across existing built form typologies, and further address a number of pressing urban issues.

TONI AREAL - PIXEL PARK, STUDIO VULKAN
ZURICH, 2014

Constructed upon a former 'Toni Milk' processing building within District 5, Zurich, Pixel Park establishes a 'rugged' rooftop landscape of stacked and pre-cultivated wooden boxes, supporting a mix of lush perennials, herbs and small shrubs. The 2,600m^2 rooftop garden is conceptualised around the idea of 'decay', with the factor of time leading to the degradation of the timber boxes, and leaving a series soft soil mounds as a remnant. These mounds will form the base soil layer to support the further growth of plants and vegetation within the garden.

"A 2,600 m^2 urban world with the appearance and radical individuality of a small private garden. The stacked boxes were pre-cultivated over two years with a colourful mix of plants suitable for the environment, including perennials, herbs and small shrubs such as willow" - Studio Vulkan Landscape Architects (2016)

Fig. 03.04.01 Toni Areal - Pixel Park, Studio Vulkan, Zurich 2014.

NATHAN SQUARE PODIUM GREEN ROOF, SHORE TILBE & HOERR SCHAUDT, TORONTO, 2010

A podium green roof installation, the largest in Toronto, seeks to revitalise Nathan Phillips Square through its modular design of publicity accessible landscaped gardens, courtyards, terraces, and walkways. Surrounding the Toronto City Hall, this green roof delivers much needed greenery above the large expanse of hard pavement in the original Nathan Phillips Square, envisioned as a public meeting space like an ice rink or main square. The lightweight, modular, and low-lying vegetation of the green roof provides an urban habitat for Bees, along with aesthetic improvements and mental health benefits to the human inhabitants.

COMMUNITY-LED GREEN ROOF PROJECT 38 WESTBURY ST MELBOURNE

Once a bare, reflective 1950s apartment rooftop, a group of residents at 38 Westbury St, Melbourne, have transformed the space into a retrofit rooftop garden. Combating the inner city shift towards apartment living, with a subsequent loss of green space, biodiversity and water permeability, the committee of residents sought to promote the untapped potential of similar older style apartments. The retrofit process involved extensive research, workshops and discussions to gain the required knowledge for the project to be undertaken, indicating the need for a publicly accessible repository of knowledge for these projects to become widely adopted.

'UNCOMMON GROUND' ORGANIC ROOFTOP FARM CHICAGO

Realising the untapped potential of their Chicago restaurant rooftop, with its "vast open expanse of sun", Uncommon Ground features a certified organic rooftop farm that grows much of the produce that then makes its way to the plates of diners beneath. The garden consists of 10 large and 17 small growing beds that contain a composition of herbs, edible flowers, and crops that have a quick harvest window. Furthermore, a rooftop Bee hive provides the pollination required for many of these plants to bear fruit, whilst providing honey as an additional ingredient in the menu items.

VICE MEDIA ROOF GARDEN, UHURU DESIGN & VICE MEDIA BROOKLYN

The 1900sqm Brooklyn rooftop of broadcast company Vice Media features a lush meadow garden, providing habitat to pollinators such as Bees and Butterflies, whilst establishing a habitable space for employees and visitors to relax and engage with nature, whilst taking in the Manhattan skyline. The installation is planted within a 0.2m irrigated medium, supporting a wealth of low to mid-level vegetation, including daisies and coneflower that attract pollinators and migratory birds. 'Solar Outposts' designed by Uhuru Design integrates off-grid workstations amongst the vegetation, with shaded wooden picnic tables with facilities to charge devices through solar.

Fig. 03.04.02 [Top Image] New Toronto City Hall green podium. Source: Shutterstock. [Second from the top] Apartment block green roof, St Kilda East, Melbourne. Source: Sonia Bednar. [Second from the bottom] 'Uncommon Ground' restaurant, Chicago. Source: Uncredited. [Bottom] Solar Outpost, Uhuru Design. Source: Core77.

GREEN WALLS / VERTICAL GARDENS

SIGNIFICANCE

Green Walls bring a number of benefits to both human and non-human systems within our urban environments, with the ability to increase biodiversity along with mental health and environmental benefits. Green Walls on buildings can increase energy efficiency through increased insulative properties, reducing the need for internal air conditioning, whilst also providing cooler outdoor ambient temperatures through active evapotranspiration process and lower rates of solar heat absorbed through hard, man-made materials.

This selection of precedents demonstrate existing green wall applications though a number of scales and typologies. An understanding of existing capabilities enable the research and methodologies within this dissertation to accommodate, and respond to, the potentials that these green infrastructures may bring - particularly through the integration of built form within private lands into the broader green network.

ONE CENTRAL PARK, JEAN NOUVEL & PATRICK BLANC SYDNEY, 2014

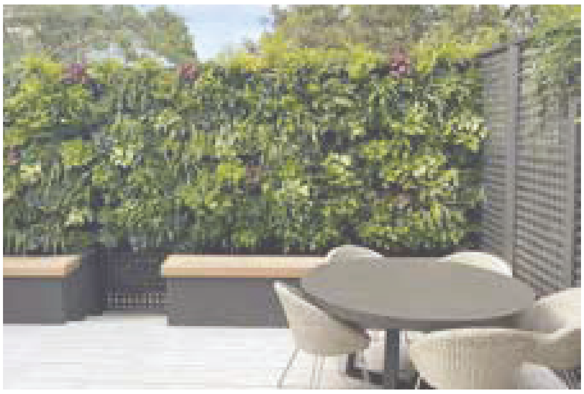
Ateliers Jean Nouvel, in collaboration with PTW Architects, Aspect Studios and OCULUS, designed the One Central Park building which features over 1000m^2 of vertical gardens across two towers, with the tallest single green wall being 150m high. These gardens, planted with over 250 species of native Australian plants, respond to urban issues such as water scarcity and the UHI effect, by improving the thermal performance of the building, utilising recycled water for irrigation, and regulating stormwater impacts - all whilst increasing urban biodiversity.

Plants are arrayed across the facade through a combination of hydroponic planter boxes, tensile steel cables, and a modularised green wall system, with water and nutrients mechanically dispersed to support plants. Particular species have been positioned in response to identified 'zones' of exposure to wind and sunlight, ensuring plants are suited to their environment and micro-climate.

Fig. 03.04.03 One Central Park, Jean Nouvel & Patrick Blanc, Sydney 2014

BLACKWALL TUNNEL APPROACH (A12)
LEASIDE PLANNING, LONDON

Aiming to increase the quality of life of nearby residents to the A12 motorway in London, Leaside Planning worked with Transport for London (TfL) and the University of East London to devise a number of small-scale enhancement projects to benefit physical connectivity, the health of residents, biodiversity, noise and pollution. Along with further projects under trial by TfL, including an 'intelligent street' featuring energy generation through solar roofs and canopies, and a 'flexible boardwalk' encouraging pedestrian walkability, these projects seek to incubate new ideas for the enhancement of streets throughout London.

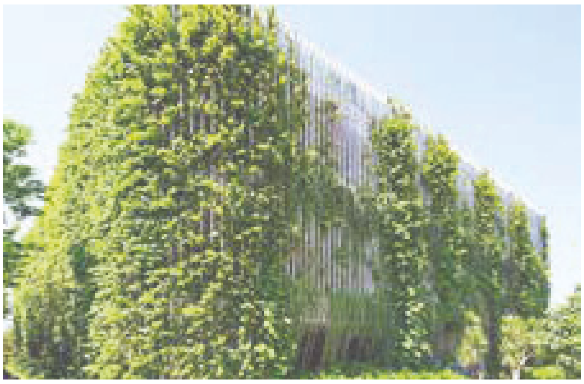


RESIDENTIAL GREEN WALL, VERTICAL GARDENS AUSTRALIA, MELBOURNE

Vertical Gardens Australia (VGA) offer a variety of six different modular green wall systems, suited to both indoor or outdoor locations, and within commercial or residential settings. A team of horticulturalists, engineers and architects have ensured the systems is easy to install, typically within a day, and highly flexible, with applications suited to offices and office partitions, to backwards, courtyards, houses and apartments. The systems support a selection of 60 plants that can be specced to suit a range of sun conditions and local climates, with in-built and automated irrigation options.

L'OASIS OF D'ABOUKIR, PATRICK BLANC
PARIS

With a long-running history of parks, formal gardens and urban greenery within Parisian culture, contemporary 'guerrilla gardens' have begun to populate the streets, demonstrating the ongoing reinterpretation of ways in which green spaces can be implemented. This mindset has instigated a series of official greening projects, including green and living walls such as that of L'Oasis of d'Aboukir by Patrick Blanc, on the side of a residential building. Represented through projects like this, is the departure from a 16th century 'control over nature' mentality, to living with and embracing nature, for its rejuvenation.



BABYLON HOTEL, VO TRONG NGHIA ARCHITECTS
VIETNAM, 2015

Concrete louvres of the Babylon Hotel enable hanging gardens that encompass the architecture and interior. Known for their innovative use of vegetation within projects, Vo Trong Nghia Architects aimed to provide guests with a relaxing environment, connected with nature and centred around landscape. This experience of connectedness to landscape is enhanced through the use of natural stone and bamboo materials, amongst the greenery of climbing vegetation that creates a separation and visual barrier to the interior.

Fig. 03.04.04 [Top Image] The Green Mile. Source: Leaside Planning. [Second from the top] Residential vertical garden. Source: Vertical Gardens Australia. [Second from the bottom] L'Oasis of D'Aboukir. Source: Dezeen. [Bottom] Babylon Hotel. Source: Hiroyuki Oki

03.05 Landscape Architecture Projects & Current Applications of 3D Spatial Data

SPATIAL DATA PRECEDENTS

SIGNIFICANCE

'Landscape Architecture and Digital Technology' (J. Walliss and H.Rahmann, 2016), highlights a wide range of potentials that new spatial technologies can bring to contemporary landscape architecture practice. These technologies, explored and understood within research and theoretical knowledge, still remain underutilised within professional practice, due to the inability to translate this understanding into practical processes and methodologies. Since the Christophe Girot's 'Gotthard Landscape' research project in 2014, Girot has been instrumental in pioneering the use of point cloud data for landscape representation, analysis, and performance orientated outcomes. This project has informed subsequent practical applications of this data in the 'Ciliwung River' and 'Singapore Rail Corridor' projects, enabling new levels of detail in digital analysis through environmental simulation, and integration into existing contexts. Finally, 'Local Code' by Nicholas de Monchaux demonstrates the abilities of data-driven methodologies in enabling intricate, spatial responsiveness to site through a range of digital tools and design prototypes.

Whilst these key projects and literatures are crucial in informing the use of 3D spatial data throughout this dissertation, there are also potentials of expanding this knowledge by addressing common limitations. Namely, all projects here concern public space. How might the same fine-grain spatial data be utilised across private lands to facilitate ecological integration? How can landscape architecture practice connect communities to this data to inform spatially responsive ecological solutions?

'LOCAL CODE: 3659 PROPOSALS ABOUT DATA, DESIGN, AND THE NATURE OF CITIES' , NICHOLAS DE MONCHAUX

Integrating technology, ecology, and city to achieve urban resilience, 'Local Code' by Nicholas de Monchaux presents 3,659 site-responsive design interventions for vacant spaces in San Francisco, Los Angeles, New York City, and Venice. Each site is spatially diagrammed, outlining its energy performance and remediative potential, in terms of stormwater and runoff reduction, urban heat island energy savings, atmospheric carbon, and food produce. These potentials are framed as social and political benefits - reallocating funds rather than spending more, in order to support the communities and ecologies of our cities that are in most need.

The methodology used by de Monchaux has its strength in the sheer quantity of data processed through automation, and the ability to synthesise environmental and social layers of our urban landscapes. The resulting spatial diagrams present an abstract understanding particular to each individual vacant space, though with little integration to each other, or their surroundings. Each site remains as isolated fragments, with no broader structure connecting them or forming a cohesive greening strategy that would ultimately reap the most benefit to our urban environment.

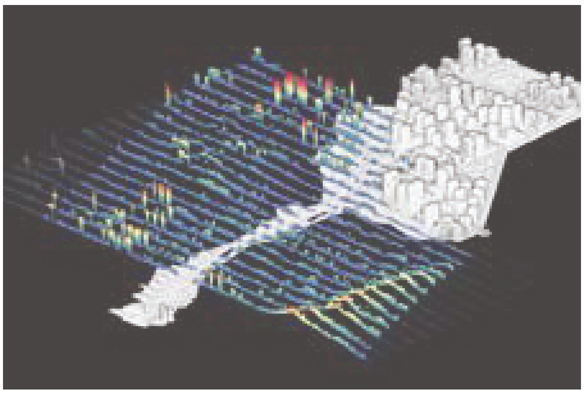
Fig. 03.04.05 Local Code, Nicholas de Monchaux

GOTTHARD LANDSCAPE: THE UNEXPECTED VIEW
LVML & CHRISTOPHE GIROT, 2014

Christophe Girot, in collaboration with two schools of Architecture from ETH Zurich and Mendrisio AAM, developed a large-scale point cloud model of the Swiss Alps, consolidating multiple data sources including topographic data, and point cloud tunnel data for rail lines and the autobahn highway. The resulting visualisations and sections portray everything from distinct rock formations and town infrastructure, both above and below ground, creating a novel perceptual dimension of the alpine landscape. The result of this research has informed further projects including the Ciliwung River Project and Singapore Rail Corridor.

CILIWUNG RIVER PROJECT, ETH FUTURE CITIES LAB
KAMPUNG MELAYU, JAKARTA

Each year, the city of Jakarta, Indonesia, is subject to significant flooding of major roads, streets, and homes along the Ciliwung River, quickly overwhelming the city drainage system, dams, and sluice gates. The Ciliwung River Project therefore sought to introduce a softer, less engineered solution to flooding, utilising drones to capture high-resolution point cloud data for use in performance testing flood solutions. A decision-based approach was applied to this process, responding to Grasshopper (Rhino3D) simulation data, to test a variety of scenarios including normalisation of the river, partial normalisation, and green infrastructure implementations such as retention basins and aquatic vegetation.



SINGAPORE RAIL CORRIDOR
PHILIPP RW URECH, FCL, ETH ZURICH

The Singapore Rail Corridor project utilises point cloud modelling to combine spatial, aesthetic and quantitative features of both the natural and built environments, in order to test a variety of spatial design configurations of the urban environment. Applicable to almost any location, this process of combining analogue and digital modelling – integrating design solutions into studies of the existing context, can be used to inform solutions for rising water levels, flooding, forest fires, noise pollution, air pollution, and the urban heat island effect.

'LANDSCAPE ARCHITECTURE AND DIGITAL TECHNOLOGY'
J. WALLISS AND H.RAHMANN (2016), RMIT UNIVERSITY

Published in 2016, ‘Landscape Architecture & Digital Technology’ from RMIT University draws upon knowledge from interviews and project case studies to advocate for the practical application of digital technologies within landscape architecture practice. These technologies, including parametric modelling, scripting, real-time data, simulation and CFD, prototyping, fabrication, and BIM modelling, seek to inform a contemporary landscape architecture practice based on complexity and performance. Utilising these technologies will result in more environmentally responsive and tested design solutions – benefiting both human and non-human systems.

Fig. 03.05.01 [Top Image] Gotthard Landscape, The Unexpected View. Source: Prof. Christophe Girot. [Second from the top] Ciliwung River project / Department of Architecture, ETH Zurich. Source: Future Cities Laboratory. [Second from the bottom] Singapore Rail Corridor 3D scan. Source: Philipp RW Urech, FCL, ETH Zurich. [Bottom] 'Landscape Architecture and Digital Technology' book exerpt. Source: RMIT.

PRIOR WORK - AUTHOR

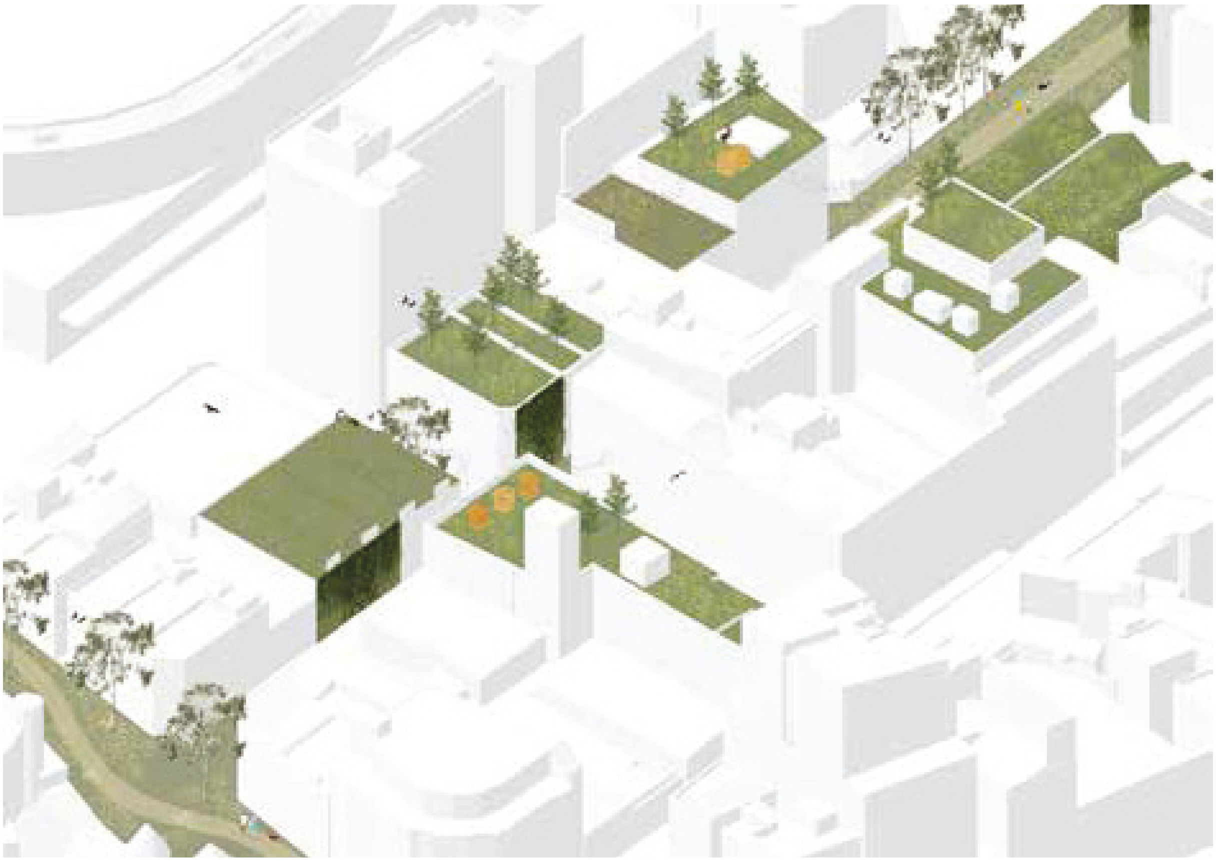
THE GREEN RIBBON
STUDIO 8 UNDERGRADUATE LANDSCAPE ARCHITECTURE

The Green Ribbon, developed as my final Landscape Architecture studio project, was an intensive green corridor strategy to provide habitat linkages between City of Sydney Ecological Priority Sites. In particular, it targeted a missing potential connection between Glebe foreshore ecologies and Pyrmont bush regeneration sites, to Hyde Park and eventually the Royal Botanic Gardens. It formed a continuous vegetation 'ribbon' that not only aimed to transform particular streets into 'wild' urban meadows and forests, but integrate ecologies into the built environment through living walls and rooftops to give the appearance of a green 'wilderness' that has been draped over the city - the 'Green Ribbon'.

From an ecological perspective, the project had a primary focus on creating and promoting bee habitat, with each and every plant species chosen for its flowering characteristics and potential for attracting and providing for native bees. Bees are a crucial part of ecosystems all around the world, facilitating the growth and production of around one-third of all the plants, vegetables and fruits we consume, and at the same time, promoting the biodiversity that forms the basis for a resilient system.

The 'Green Ribbon' forms a continuous vegetation corridor through the Sydney CBD, transforming particular streets into 'wild' urban meadows and forests, integrated into the built environment through living walls and rooftops to 'drape' wilderness over the city.

Fig. 03.05.02 Seasonal gardens were located on rooftops, based on simulated sun exposure potential during their flowering period. Source: The Green Ribbon, Author.



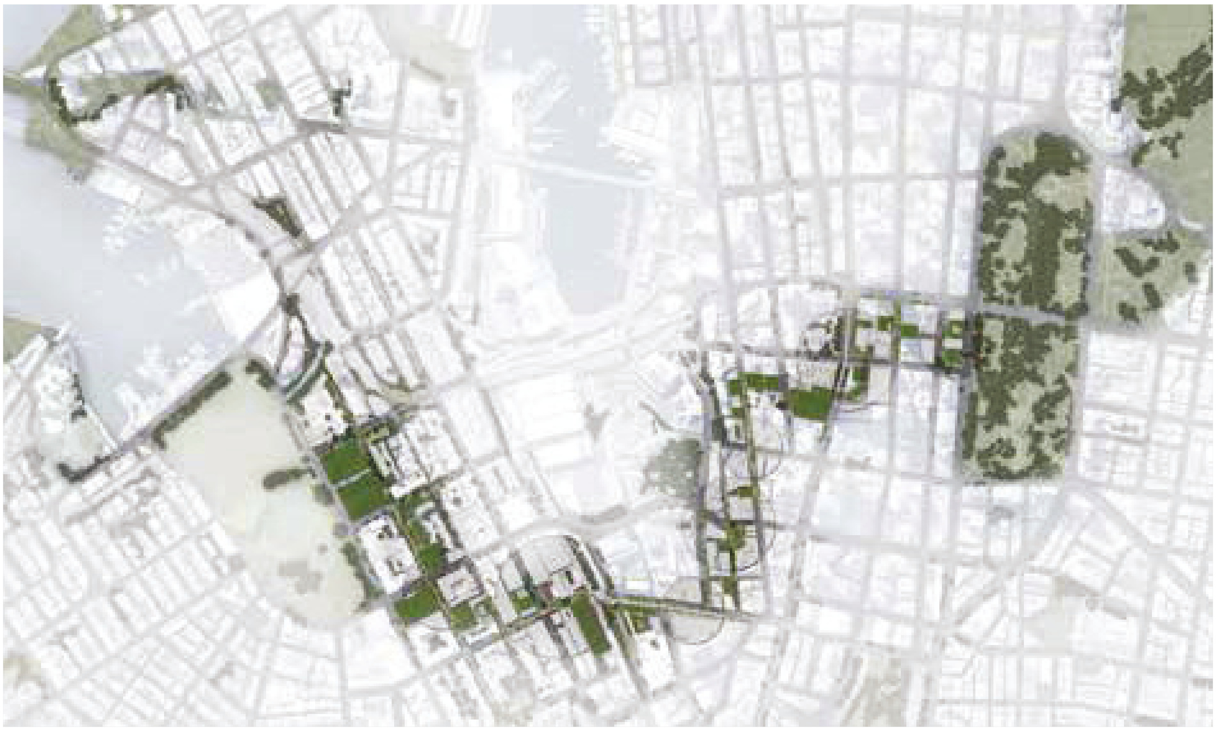


Fig. 03.05.03 The Green Ribbon sought to connect the Glebe foreshore to Hyde Park and Royal Botanic Gardens, utilising green roof and wall typologies and vegetation species promoting bee habitat. [Top] Isometric illustration, [Bottom] Plan. Source: The Green Ribbon, Author.

GREEN MESH CONCEPT: A FINE-GRAIN, COMMUNITY-ACTIVATED GREEN NETWORK

04

04. GREEN MESH CONCEPT: A FINER-GRAIN, COMMUNITY-ACTIVATED GREEN NETWORK

The Green Mesh aims to provide a finer-grain green strategy for Sydney, activated through community participation, to establish an interwoven ecological fabric throughout our urban and suburban built environments.

04.01 High-Level Concept: Introducing the Green Mesh

THE GREEN MESH

The Green Mesh presents a novel green network concept that responds to limitations and opportunities identified within the current implementation of the SGG, for the context of Greater Sydney.

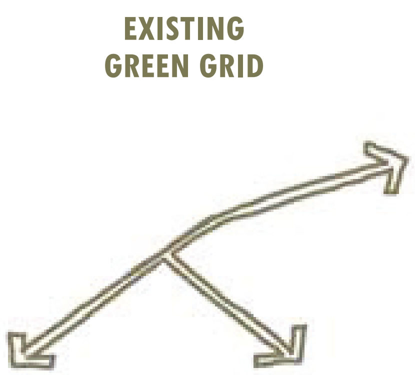
At a metropolitan scale, the Green Mesh aims to stitch the gaps between coarse SGG corridors, reconnecting a matrix of fragmented and vulnerable vegetation communities within private lands into the broader green network. This is achieved through the 'mesh' pattern created by many small-scale ecological implementations within backyards, across the rooftops, and draped upon vertical walls. These implementations are enabled through community participation, promoting a 'many hands make light work' philosophy in achieving widespread ecological integration.

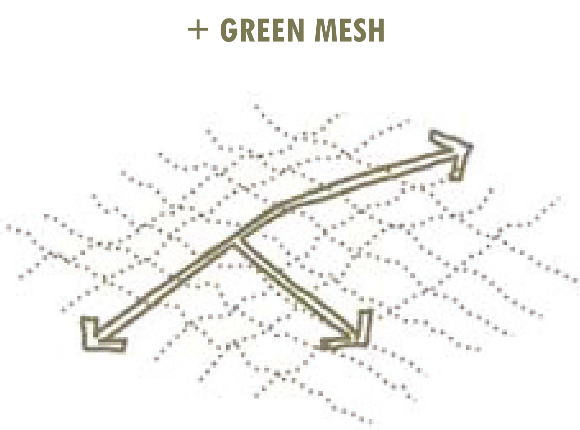
The subsequent chapters of this dissertation seek to develop this concept into an implementable strategy, through the use of novel methodologies and the use of new spatial technologies.

COMMUNITY PARTICIPATION

With the ever-increasing awareness of humankind's negative environmental impacts on habitat and biodiversity, a community-activated green network will enable an environmentally-conscious population, and passionate individuals, to drive a process of ecological integration within our built environments. Targeting all private lands which fall outside of the SGG scope, each and every backyard, apartment rooftop, industrial warehouse, or vacant brick wall presents an opportunity to add a point in the mesh, and over time, create a rich and diverse, interconnected ecological fabric throughout Greater Sydney.

Achieving this level of coordination and environmental responsiveness through the general public however, presents a significant challenge. The Green Mesh will therefore need to be communicated in a simple and accessible means for the target audience, to deliver an informative and accurate 'platform' that directly and explicitly informs implementation. Furthermore, it needs to be site-specific and replicable across all LGAs of Sydney, with consideration for their unique environmental needs and characteristics.





GREEN MESH
HIGH-LEVEL CONCEPT

EXISTING GREEN GRID

Coarse, corridor-based public Green Grid network

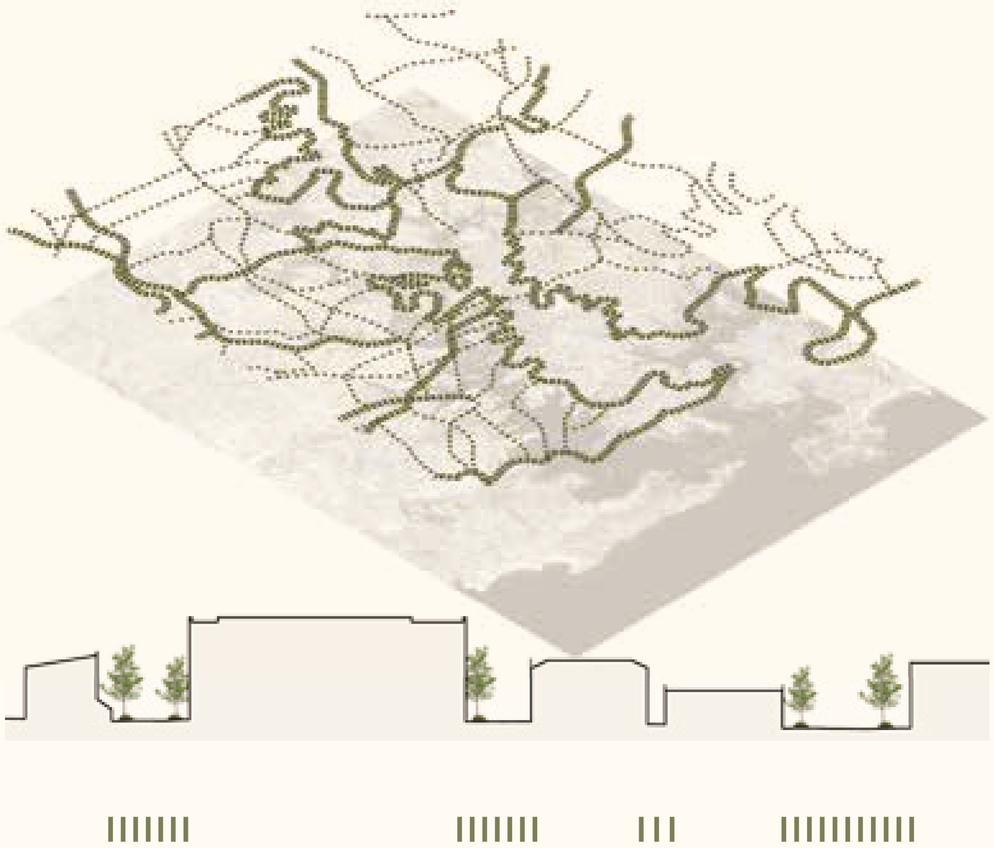
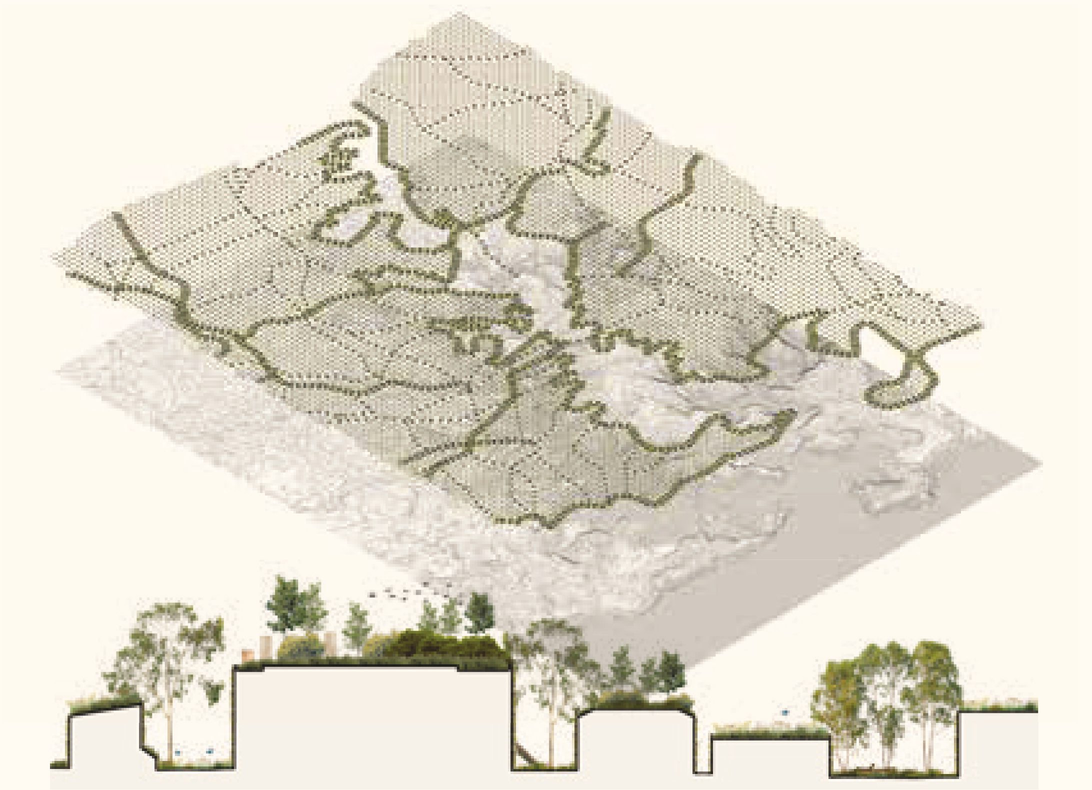


Fig. 04.01.01 *A high-level comparison between the coarse green network of the Green Grid [Left page], to the potential integration of private lands within the Green Mesh strategy [Right page].*

+ GREEN MESH

Finer-grain linkages established through Green Mesh implementations, evenly dispersed across built form and throughout private lands



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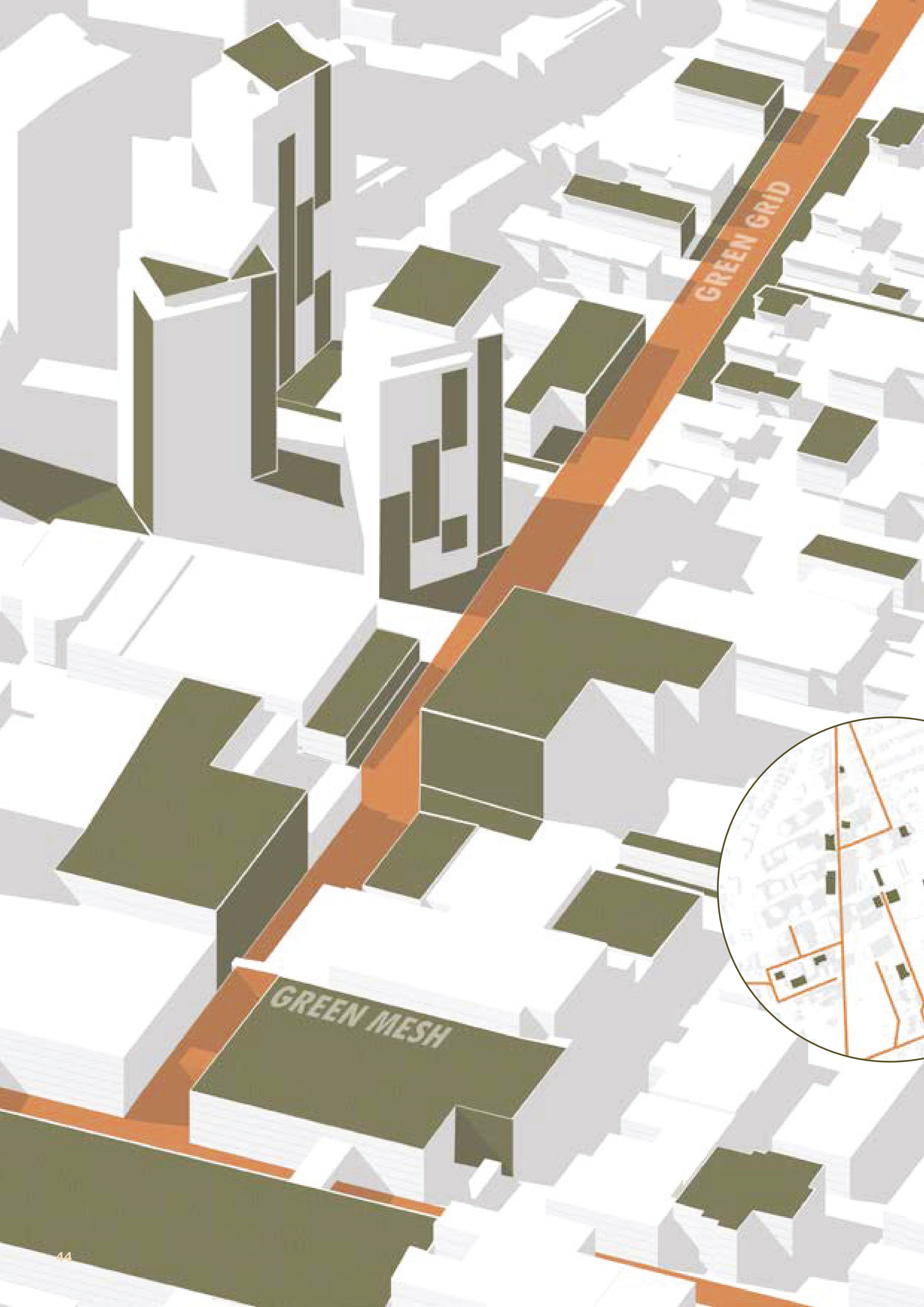

GREEN GRID
GREEN MESH

04.02 Intended Audience and Growth Pattern of the Green Mesh

INTENDED AUDIENCE

Ultimately, the end-user of the Green Mesh will be the general public - accessing the platform in order to inform and drive their individual implementations. Environmentally-conscious and enthusiastic community members will lead the adoption of this strategy, becoming the catalyst for further adoption and widespread dispersal.

Prior to this, however, further development and collaboration across numerous professions will enable the Green Mesh to respond to the unique environmental character and needs between different LGAs, whilst refining and further contributing to a range of innovative and implementable green infrastructures. Therefore, the Green Mesh is targeted towards a collaboration of Local Government Area councils, Landscape Architecture and Urban Planning professionals, Environmental Engineers, and Ecologists, to translate the conceptual ideas, findings, and methodologies from this dissertation into, firstly, a working prototype for the platform, and ultimately, a working system adopted within the green network of Sydney.

GROWTH PATTERN & BENEFITS

Once this working system is achieved, initial adoption within the general public will take place, assisted and promoted through LGAs themselves. This will instigate a process of gradual and dynamic growth of the Green Mesh, proliferating throughout our city and suburbs, and stitching the gaps within the SGG and Existing Open Space Network [Fig. 04.02.02].

It will potentially take a number of years for these linkages to start forming through the connectivity of adjacent lots, though once at a stage of decent maturity and density, the environmental benefits will begin to take place. Liveability will be improved through connectedness with nature and lower outdoor ambient temperatures, whilst endangered flora and fauna will be supported through fine-grain species selection - targeted specifically to the LGA, and environmental exposure of the individual lot. Furthermore, integrated strategies for water management and solar energy will reduce the reliance on centralised energy and water supply systems, two important sustainability practices that will also act to benefit human resilience as well.

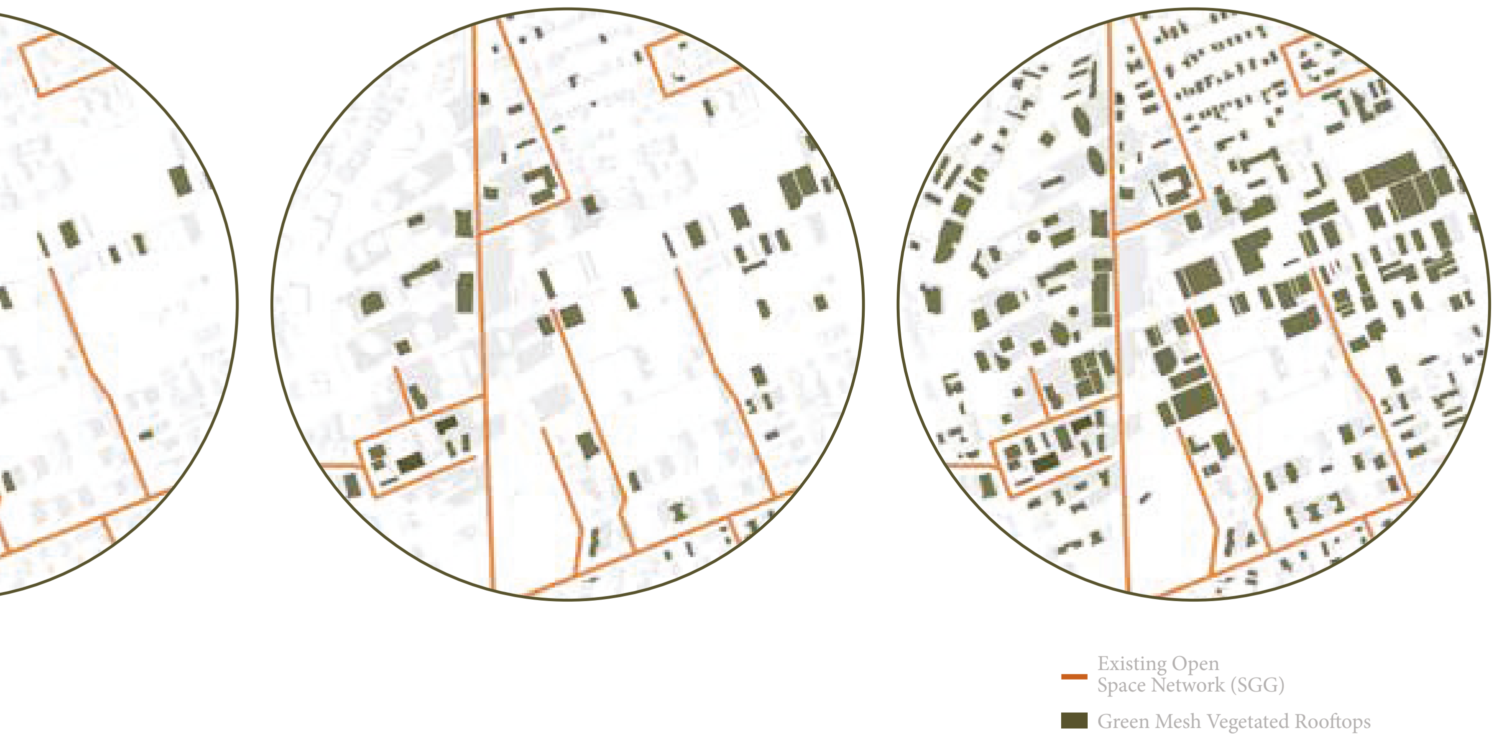


Fig. 04.02.01 [Above] Green Mesh growth over time, shown in relation to existing Chatswood CBD built form and the existing open space network mapped by the SGG.

Fig. 04.02.02 [Left page] 3D visualisation of Chatswood CBD, showing the intended spatiality of the Green Mesh, and it's integration within Green Grid corridors.

CONCEPT TESTING: GREEN INFRASTRUCTURE POTENTIALS OF EXISTING BUILT FORM

05

05. CONCEPT TESTING: GREEN INFRASTRUCTURE POTENTIALS OF EXISTING BUILT FORM

05.01 Chapter Overview

Prior to more extensive research and development of the Green Mesh methodologies, the broader concept was tested against a range of existing built form scenarios to assess it's real-world potential. This required the identification of a more specific 'study area', along with subsequent on-ground exploration.

Willoughby LGA was established as this study area due to its diversity of built-form typologies, proximity to ecologically significant vegetation communities, and evidence of extensive land clearing since the mid 1900s. Time was spent on-site exploring a number of streets and urban environments, with the aim of identifying key opportunities for integrated ecological design within the existing built form of the area. This process resulted in eight 'immediately implementable' green infrastructure opportunities, confirming a baseline feasibility to inform further development of the Green Mesh concept.

A range of illustrations were used to superimpose these 'greening opportunities' within their real-world scenarios, before being synthesised into an holistic ecological concept to conclude the chapter. This ecological concept demonstrates the ability to achieve ecological connectivity perpendicular to the street, utilising private lands to stitch the gaps between SGG corridors, and showing how the Green Mesh and Green Grid can co-exist in a single, cohesive green network.

Fig. 05.01.01 A diversity of urban and suburban streetscapes and built form typologies throughout the Willoughby LGA. Chatswood CBD [Top], light industrial in East Chatswood [Middle], residential in Castlecrag [Bottom]. Source: Author.

05.02 Defining a Study Area for Concept Testing: Willoughby LGA

Choosing a 'refined study area', at a smaller and more targeted scale than that of Greater Sydney, allows for more focused and site-specific research to inform on-going testing and development of the Green Mesh.

As one of several LGAs mapped and analysed in the initial chapters of this dissertation, Willoughby LGA was chosen for its diverse range of urban typologies - from the dense Chatswood CBD to the surrounding low density residential areas, along with adjacent reserves and National Parks providing connectivity opportunities to local biodiversity. Furthermore, like the majority of Sydney's LGAs, native vegetation has been subject to significant land-clearing, with "...nearly 90% of the land… cleared for development" (Willoughby City Council[3], n/d), resulting in habitat fragmentation, and small, isolated pockets of remnant vegetation throughout both public and private lands.

Urban development in Willoughby LGA is situated along a major ridge-line between the Lane Cove River and Middle Harbour, proving significant to the land-use and development of the area over time. Comparing aerial imagery between the years of 1942 and present [Fig. 05.02.01] reveals a number of examples within the LGA where extensive land clearing has taken place for residential development.

The dense, high-rise urban environment of Chatswood CBD [4] features several major shopping destinations, a major transport hub for heavy rail and Metro, and entertainment landmarks such as The Concourse. Some of it's surrounding residential suburbs of Castlecove [1], Lane Cove North [2], and Chatswood West [3], carved out of former ridgeline and gully ecologies, now feature low-density detached dwellings, with a mixture of contemporary and traditional housing styles - using different materials and roof styles, and a variety of lot sizes.

Willoughby LGA therefore provides a diverse range of opportunities to test and develop the Green Mesh throughout this, and subsequent, chapters of research. Evidence of land-use change through clearing and development are combined with a diversity of built form typologies to challenge the Green Mesh as much as possible.

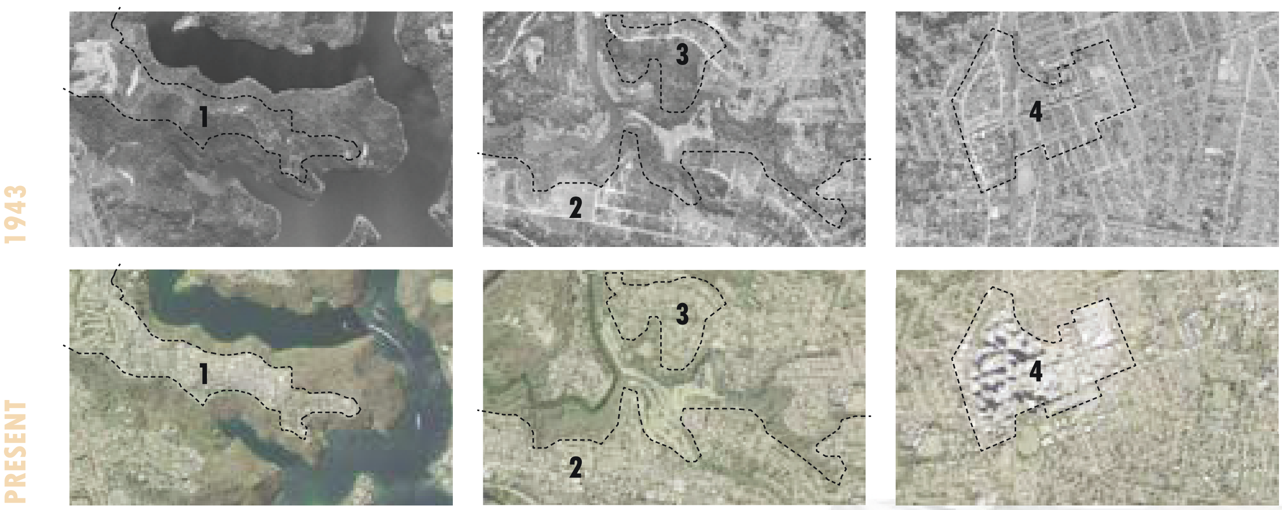


Fig. 05.02.01 [Above] Evidence of extensive urban and suburban development in Willoughby LGA, 1943-present. Source: SIX Maps

- - Significant land clearing or urban development since 1943

05.03 The Immediate Green Infrastructure Opportunities within Willoughby LGA

Throughout the course of research, many hours and days were spent 'in the field', exploring and observing the streets and built form of Willoughby LGA. As an initial test of the Green Mesh concept, these observations were focused on identifying 'immediate' opportunities for the integration or retrofit of green infrastructure within current built form. This ground-proofing against current urban conditions revealed a number of current and novel green infrastructure typologies that, with their implementation, have the potential to begin populating the individual 'points' of the mesh pattern.

Eight of these green infrastructure typologies were identified as a result of this process, including green roofs and green walls - well established green infrastructure typologies that are traditionally implemented in isolation from one another, and therefore with no connectivity function. A number of less common greening opportunities were also identified, including laneway wilding, parking space reclamation, and ecological road crossings to allow for the safer movement of native ground-dwelling fauna. These typologies were spatially arrayed within a 3D representation of the suburb of Willoughby's local centre [Fig. 05.03.01], revealing the ecological 'mesh' pattern - demonstrating how these individual typologies can, together, form a cohesive, fine-grain ecological network within existing urban areas.

The eight typologies below are detailed further on the following pages, and superimposed within the real-world scenario where their potential was envisaged.

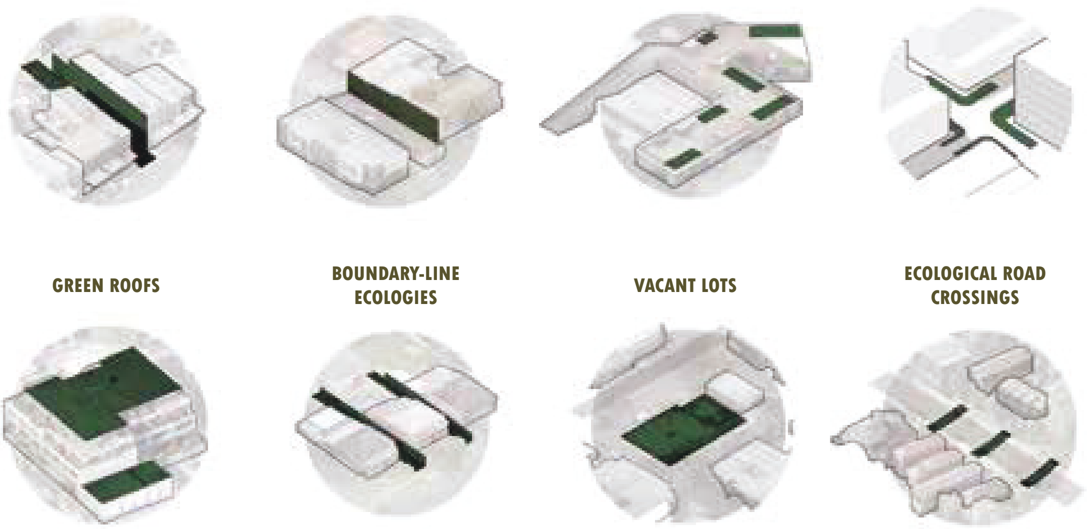
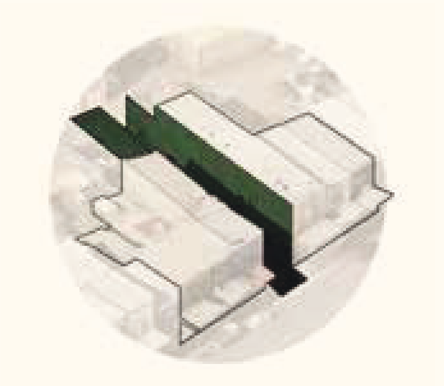
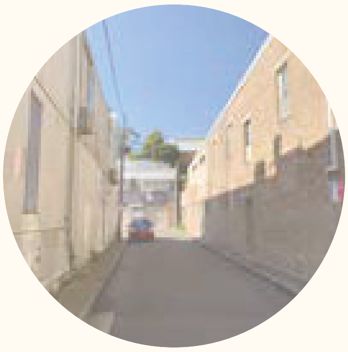


Fig. 05.03.01 A series of greening typologies that have immediate potential for implementation within the existing built fabric of Willoughby LGA.

01
LANEWAY WILDING





Existing ▲

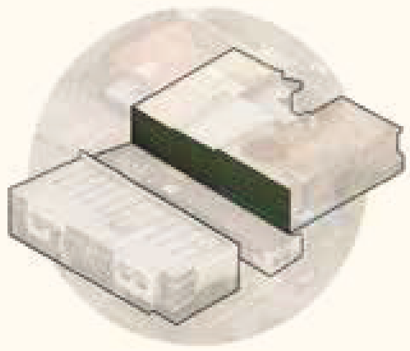
Throughout the commercial and industrial extents of Willoughby, service alleyways form breaks between otherwise impermeable lines of building facade. These alleyways, upon initial inspection, remain largely vacant, except only for short, fleeting use as access driveways for employee parking, and delivery vehicles.

Opportunity

With bare concrete or brick walls either side and no ecological value, there is potential for these spaces to be 'wilded' through the use of vertical gardens and green walls, whilst maintaining their current access function. This will make the alleyways more inviting for every-day inhabitation, both human and non-human, whilst providing ecologically valuable habitat for numerous insect and birds. ▶

Fig. 05.03.02 A service alleyway off Willoughby Rd, a local commercial centre within the suburb of Willoughby, visualised with green walls on either side, maintaining vehicle access but introducing ecological value.

02
GREEN WALLS



Existing ▲

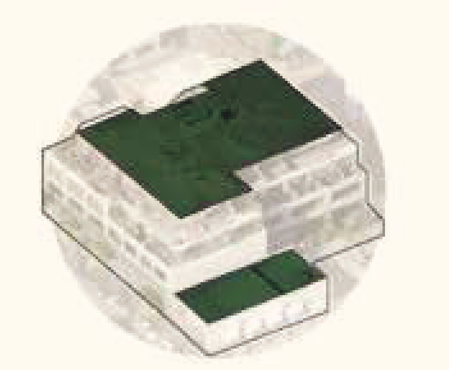
Many larger buildings throughout Willoughby feature expansive, hard, vertical surfaces - some of which may be completely bare, whereas others feature an array of glass windows or other openings.

Opportunity

These surfaces, which contribute significantly to internal and external heat retention during hot summer days, have great potential as extensive green walls, reducing this urban heat and promoting biodiversity and ecological habitation. These green walls or vertical gardens are implementable through a range of methods from minimal, lightweight additions, to more extensively engineered and irrigated walls. As such, this variety of green wall typologies also allow for implementation within suburban and residential dwellings. ▶

Fig. 05.03.03 The bare, brick-wall of a commercial building within Chatswood CBD, visualised as a 'wild' green wall that responds to window openings and creates an intense ecological feature within this concrete urban environment.

03
GREEN ROOFS



Existing ▲

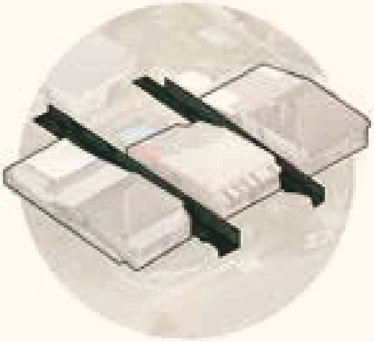
Rooftop surface area within industrial, commercial and residential zones throughout Willoughby account for around 45%, 37% and 24% of total horizontal surface area, respectively. The majority of these rooftops are composed of bare roof-tiles, corrugated iron, or concrete. A minority feature solar panels, whilst others feature miscellaneous services, exhausts and maintenance facilities - particularly on apartment blocks, industrial factories, and commercial buildings.

Opportunity

A range of green roof typologies allow for implementation across almost any type of building. Soil weight is a major consideration, dictated by depth, in turn, specifying the type of vegetation that it can support. Apartment buildings are a great opportunity for communal roof-top gardens such as this. ▶

Fig. 05.03.04 The bare concrete rooftop of a residential apartment block within the suburb of Willloughby, visualised with a diversity of community gardens - a source local fruit and vegetables for residents, and a valuable resource for insects and pollinators.

04
BOUNDARY-LINE ECOLOGIES



Existing ▲

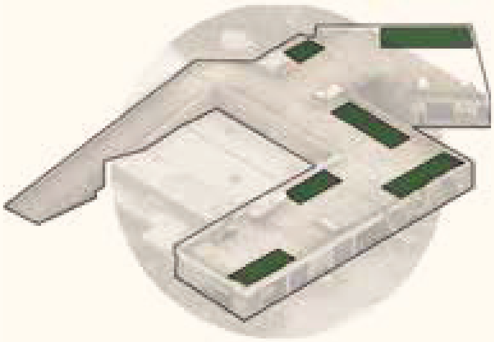
Boundary-lines between both traditional and contemporary residential dwellings, from the sides and the rear, are often signified by walls, fences, or hard driveways. Walls and fences create barriers for the movement of ground-dwelling wildlife, inhibiting their ability to move freely between backyards, habitat, or vegetation for cover, nesting, or foraging. Driveways, on the other hand, are create a harsh, hot and exposed environment that can be dangerous for these same creatures.

Opportunity

For residencies with unused driveways, there is great potential for these spaces to be used to promote biodiversity and productive vegetation, whilst fences can be vegetated, made permeable along their bottom edge, or bridged with trellises and other structures to promote ecological connectivity. ▶

Fig. 05.03.05 The driveway boundary between two traditional dwellings in Auburn, with currently, absolutely no canopy cover, visualised with large trees in introduce canopy cover, ground-cover flower meadow and beekeeping for pollination, and productive vegetable gardens.

05
PARKING RECLAMATION



Existing ▲

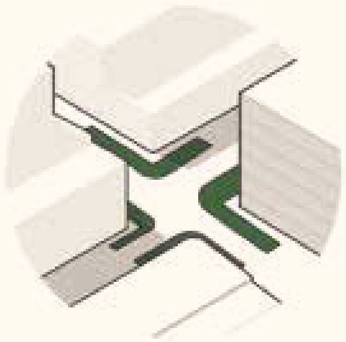
Large, expansive, and bare rooftop carparks within commercial and industrial areas can be very hot during summer, due to their dark surfaces, lack of permeability, and no shade. Furthermore, they are often a last resort for parking, generally avoided due to these characteristics.

Opportunity

▶ Urban greening to reclaim individual, or groups of car spaces, or the entire rooftop carparks, could significantly reduce these temperatures whilst providing valuable social and ecological value through a diversity of vegetation and garden typologies. Furthermore, these carparks already have the structural support for deep soil, due to their original need to support heavy vehicles.

Fig. 05.03.06 One of several rooftop levels of the Westfield Chatswood carpark, which is spread across numerous buildings, visualised as a public garden with extensive vegetation cover and garden beds.

06
FOOTPATH PLANTING



Existing ▲

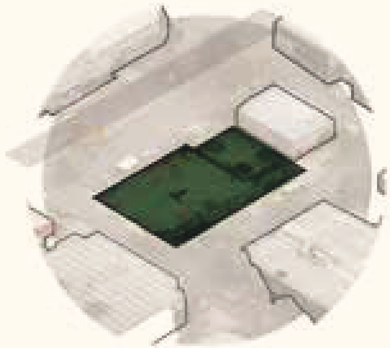
Wide footpaths within the Chatswood CBD are composed of hard, dark, and impermeable surfaces that not only contribute to urban heat, but are engineered to clear rainwater quickly and efficiently into stormwater infrastructure.

Opportunity

Instead, this water can be retained on-site through absorption into the soil and root systems, contributing to the upkeep of urban vegetation and canopy cover. This urban vegetation provides visual amenity, and cooler ambient temperatures (dependent on the maintaining of airflow and circulation of wind through streets), cleaner air, and greater biodiversity potential. ▶

Fig. 05.03.07 A wide, paved footpath within Chatswood CBD, visualised urban vegetation to promote the absorption of rainwater and water filtration.

07
VACANT LOT OPPORTUNITIES



Existing ▲

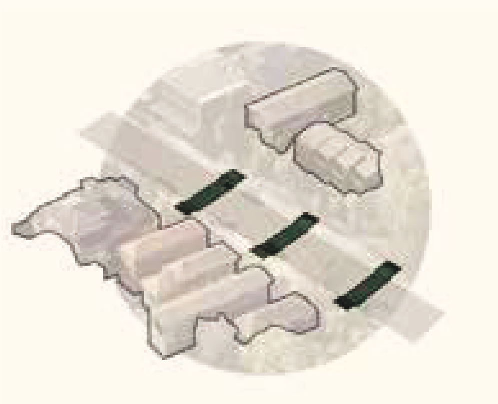
Vacant lots, overgrown residential lots, or concrete-clad former industrial spaces, represent under-utilised urban spaces with a broad range of potential ecological benefits due to their large size, and a lack of existing built form, program or land-use considerations.

Opportunity

Vacant lots therefore have significance in their flexibility to become sustainable and ecologically valuable spaces within our urban environments. Strategies including the re-wilding to create a naturalised habitat, the establishment of a maintained and manicured public garden, or a productive community nursery with urban agriculture are all possibilities for these spaces. ▶

Fig. 05.03.08 A vacant lot located within an industrial area of East Chatswood, visualised as a stormwater retention and filtration, collecting water from local streets to establish an artificial 'wetlands' habitat to promote and support biodiversity and refuge for waterbirds and other aquatic species.

08
ECOLOGICAL ROAD CROSSINGS



Existing ▲

Roadways are one of the most significant barriers to ecological connectivity along the ground-plain within urban environments. They are a hazardous environment to wildlife due to the speed of vehicles, the concentration of pollutants such as petrol/diesel fumes, noise intensity, and lack of ecologically significant vegetation and refuge.

Opportunity

Below-grade ecological 'tunnels' could be implemented, running beneath the road surface, and allowing for this wildlife connectivity within urban and suburban environments. Feasibility will depend on the existing underground services that may include pipelines and cabling. Planting can furthermore contribute to the remediation of pollutants from water runoff, before it makes its way to nearby environments and creek systems. ▶

Fig. 05.03.09 A residential street within Castle Cove, Willoughby, visualising an ecological tunnel that creates a continuous ground-level connection between a bushland area on the left hand side of the road, to residential dwellings and gardens on the right.

05.04 Ecological Concept: A Synthesis of Green Infrastructure Opportunities

URBAN AGRICULTURE

A 2018 study conducted by the Proceedings of the National Academy of Sciences of the United States of America sought to measure "inputs and produce yields over a 1-y period in 13 small-scale organic farms and gardens in Sydney, Australia... [finding] mean yields to be 5.94 kg/m^2, around twice the yield of typical Australian commercial vegetable farms" (McDougall et al, 2018)

With a population in Sydney of 5.73 million (Population Australia, 2019), and a projected growth to 8.6 million by 2060 (Australia Bureau of Statistics, ABS), this means an increased demand in food production of around 8.27 million kg of food per day - using Australian Bureau of Statistics figures of 3.1kg consumed on average per day by Australians over the age of 2 years (ABS, 2011-12).

Using these figures, urban agriculture would need 1.94 million m^2 of land or rooftop space in order to entirely offset the food demand for increases in population to till the year 2060. For Sydney to become entirely self sustainable through urban agriculture (in theory), 2.99 million m^2 of space is required with current population figures, and 4.38 million m^2 in 2060.

THE SYNTHESIS OF GREENING OPPORTUNITIES

Through the synthesis of these green infrastructure opportunities, along with the use of native and productive species to bring benefits to both human and non-human systems, the following ecological concept was envisioned.

Vertical gardens and green roofs make use of bare, man-made surfaces to integrate ecologically valuable meadow planting and other native vegetation species. Meanwhile, urban agriculture, using both native and exotic species, provides locally-grown fruit, vegetables and herbs. Urban beekeeping provides pollination for all species, in combination with wild bees, butterflies, birds, and moths - providing food and habitat to native fauna whilst decentralising agricultural production.

Ecological connections are established perpendicular to the road, expanding upon SGG road corridors to demonstrate the unification of the two green strategies into a single, cohesive, and evenly dispersed green network.

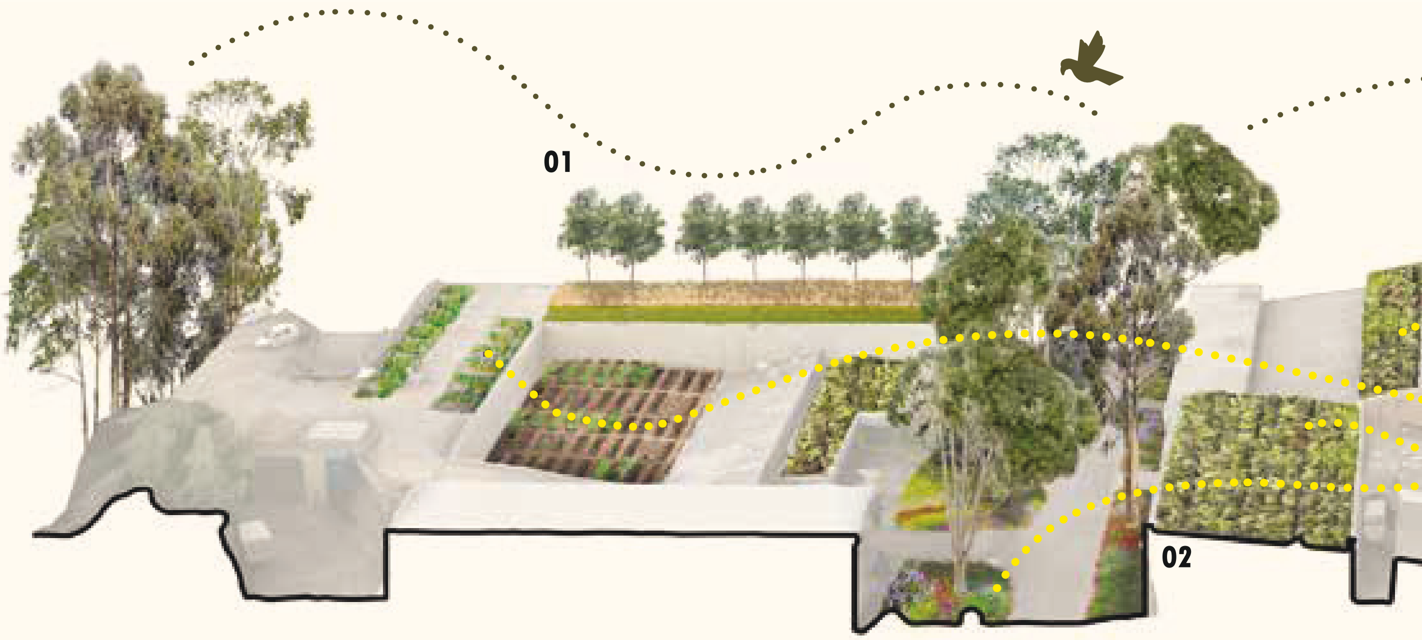
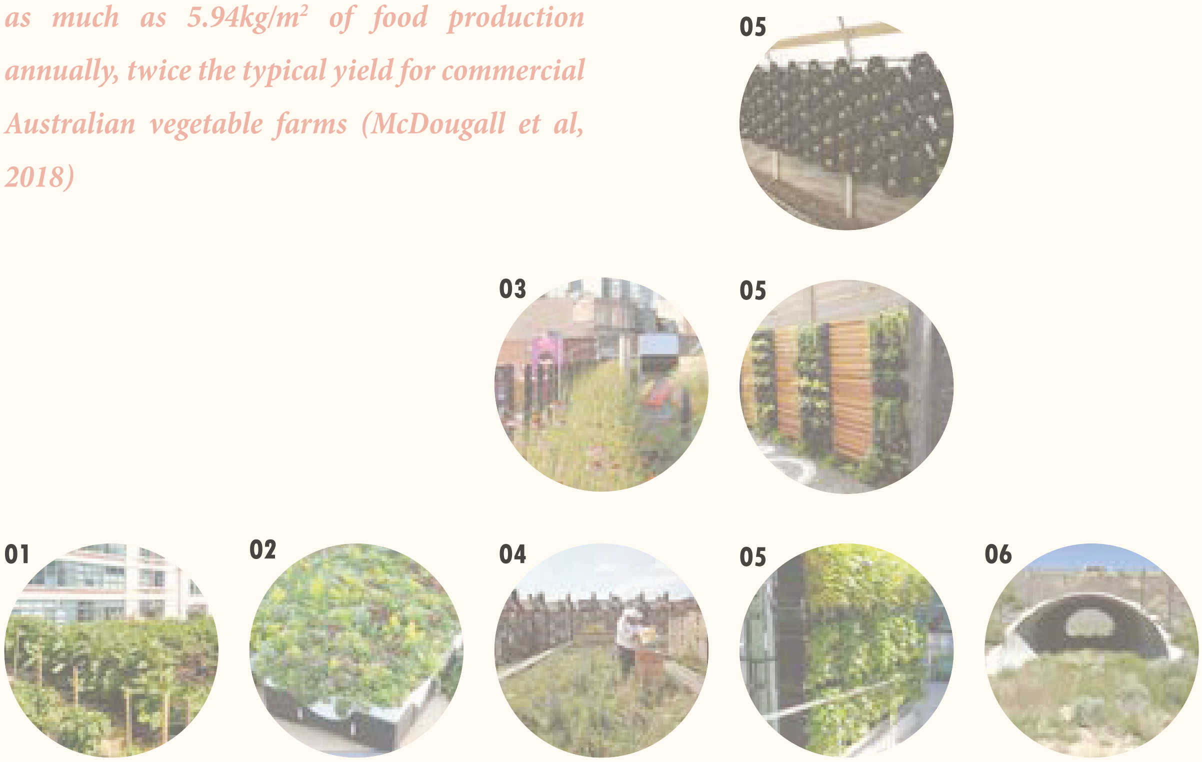
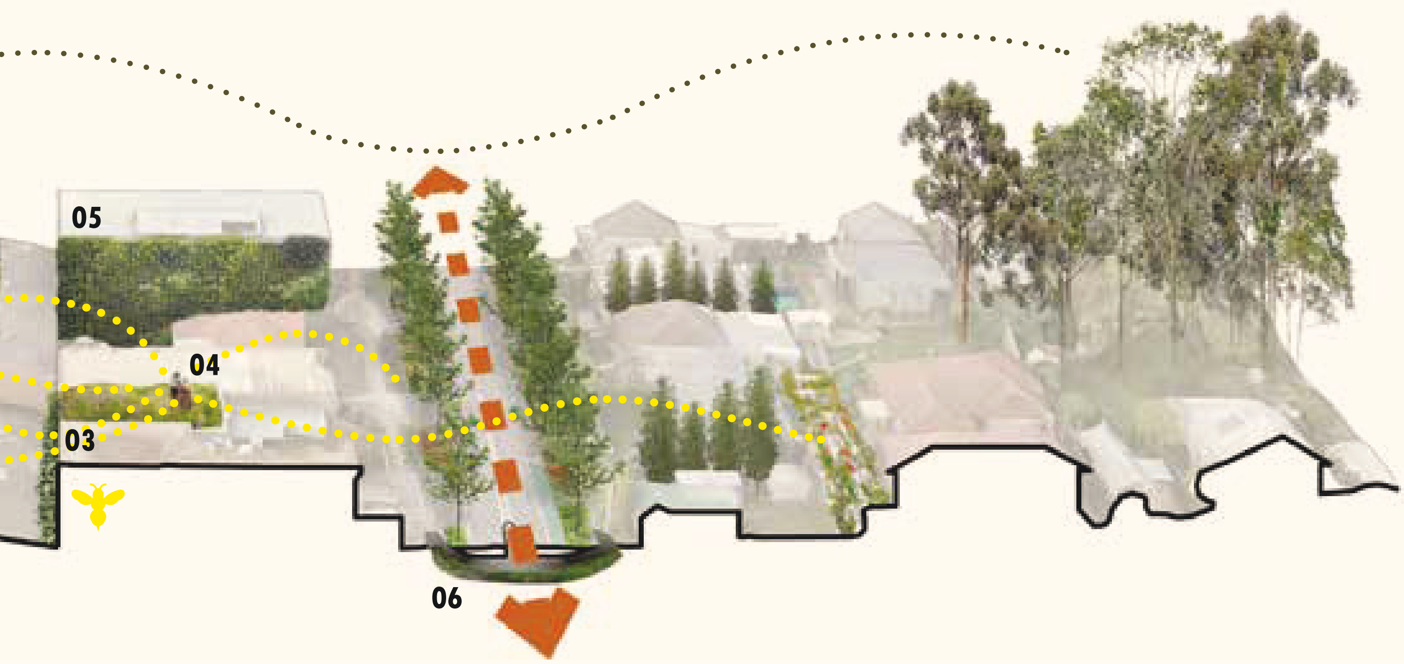


Fig. 05.04.01 The Green Mesh envisions a built environment of environmentally responsive and ecologically interconnected systems of green implementation, promoting resource sustainability and decentralisation, along with an intense meshing of ecological functionality within our every-day lives.

GREEN MESH ECOLOGICAL CONCEPT

Intensive, small-scale urban organic farms and gardens in Sydney have the potential to produce as much as 5.94kg/m^2 of food production annually, twice the typical yield for commercial Australian vegetable farms (McDougall et al, 2018)





06

ENABLING THE GREEN MESH: NEW SPATIAL TECHNOLOGIES AND DATA HYBRIDISATION

06. ENABLING THE GREEN MESH: NEW 3D SPATIAL TECHNOLOGIES & DATA HYBRIDISATION

06.01 Chapter Overview

As previously identified, current green planning within Sydney relies heavily on traditional 2D GIS methodologies for spatial analysis and strategic mapping - as with the SGG. The resulting high-level map are therefore disconnected from the ground-level nuances and site-specific complexities to which the Green Mesh seeks to specifically address and respond to.

Bridging the spatial gap between traditional, broad-scale datasets of 2D GIS, and specific environmental conditions at a human scale, this chapter introduces the potentials of new and emerging 3D spatial technologies as the next step for strategic spatial planning and design practice. In this context, 'new spatial technologies' refer to both 3D point cloud and photogrammetry data, capable of overcoming many of the former challenges of traditional GIS methodologies, whilst enabling a host of smart capabilities for site analysis, simulation, and representation. These technologies will enable the finer-grain and site responsive aspirations of the Green Mesh, allowing for replicable methodologies to intimately understand site, and remotely generate an environmental baseline through data simulation techniques.

This chapter therefore introduces and explores the complex 3D spatial data captured specifically for this dissertation. It covers the methodologies used to generate the data, the quality and accuracy of the data itself, and the benefits of 3D spatial datasets through some initial analytical layers generated from it.

Fig. 06.01.01 Point Cloud representation of Willoughby Rd, Willoughby. Source: Author.

06.02 New 3D Spatial Technologies: Point Cloud and Photogrammetry Data

POINT CLOUD AND PHOTOGRAMMETRY

Point cloud data enables an accurate, 3D spatial representation of built-form and natural environments, created through LiDAR (Light Detection and Ranging) or photogrammetry methodologies. These technologies utilise drones or airplane-mounted sensors, with the ability to quickly and efficiently produce up-to-date spatial outputs within a short timeframe. LiDAR scanners use lasers to determine the shape and morphology of the ground and visible objects, by calculating the time taken for emitted lasers to bounce-back. This technique requires specialised hardware as opposed to photogrammetry, which only requires a standard RGB camera like those already mounted on many consumer drones. Photogrammetry calculates 3D morphology through a comparison of hundreds of overlapping, aerial oblique images. By tracking the parallax effect across objects within these images, the photogrammetry process is able to produce a similar 3-dimensional output to that of LiDAR, albeit much more cost effectively due to the difference in hardware requirements. A primary limitation of photogrammetry, however, is it's lack of ability to see through canopy cover where lasers used in LiDAR are able to penetrate to an extent. This reduces the accuracy of representation below obstructions for the photogrammetry process.

Each of these emerging spatial technologies present an opportunity to achieve an incredibly fine-grain responsiveness that current green strategies such as the Sydney Green Grid lack, through the scalability achieved within these technologies, to achieve a highly-detailed, textural understanding of site. This addresses many of the limitations of traditional GIS mapping, enabling a far greater connection to ground, and the ability for analysis and responsive design moves at the human-scale. Furthermore, through this concept of data scalability, these spatial technologies are able to represent everything from a broader metropolitan scale, down to individual streets, lots, and landscape elements, bridging the spatial gap between traditional GIS data and finer-grain nuances within streets and neighbourhoods.

Beyond simply addressing the shortcomings of these former GIS methodologies, however, the 3-dimensional nature of point cloud data enables a host of additional smart capabilities, from the identification and extraction of particular objects, to complex environmental simulations. This enables the ability to extract precise canopy cover, building footprints, and underlying morphology of site, that are guaranteed to have consistency as this removes the variable from GIS data coming from multiples sources, surveyed

Point cloud and photogrammetry spatial data present an opportunity to achieve an incredibly fine-grain responsiveness that traditional 2D GIS methodologies cannot achieve.

at different points in time, and intended for different scales and levels of accuracy. Simulation capabilities can be achieved through programs such as Grasshopper and ArcGIS, including an array of environmental functions from watershed, sun exposure, solar irradiance, wind, and slope gradient, to human factors such as view-lines, ease of construction, and outdoor comfort. Each of these possibilities combined, allow for a rich, accurate, highly-detailed and consistent array of base data and analysis that can be used as a framework to inform an evidence-based approach to metropolitan scale green planning.

Whilst the implementation of point cloud data within design practice is still relatively new and novel, the extensive capabilities enabled and the fine-grain nature of this data is ultimately what will enable the methodological approach of the Green Mesh, which seeks to use this data down to a property-specific scale, simulating the invisible micro-climate characteristics within a site for a highly-responsive implementation of ecologically significant gardens and green infrastructures.

Fig. 06.02.01 [Top] Canopy cover extraction, and [Bottom] shadow analysis, produced from textured 3D photogrammetry data. Source: Author

DATA HYBRIDISATION

Whilst point cloud and photogrammetry technologies deliver a wide range of data-enabled possibilities on and above-ground, its inherent limitation lies in its inability to represent underground features in the same way, due to the line-of-sight methods of capture through photography and LiDAR scanning. Through Chistophe Girot's 'Gotthhard Landscape' project, it has been demonstrated that underground point cloud representations of man-made tunnels, for example, are possible - however natural soil compositions and smaller infrastructural elements that cannot be explored or scanned, remain in GIS only. 2D GIS datasets have a strength in representing these underground elements where photogrammetry and LiDAR scanning is not possible, including natural geological layers, and infrastructural pipelines. As such, there is potential for data hybridisation between 3D point cloud data and 2D GIS datasets, creating a hybrid and holistic dataset that can represent ground-level conditions with high accuracy, along with an understanding of underground elements as well.

Fig. 06.02.02 Point Cloud Data of Willoughby LGA, hybridised with finer-grain photogrammetry data of Willoughby Rd and High St. Source: Author

06.03 Data Quality and Point Cloud Capture

DATA QUALITY

Point cloud data can vary in density and resolution, with scans taken at a higher altitudes generally resulting in 'less-dense' point cloud outputs. Data at a resolution of 1m can be obtained for free through the website 'ELVIS', from the Intergovernmental Committee on Surveying and Mapping (ICSM). 'ELVIS' provides downloadable point cloud data and 3D digital terrain models (DTM) for all of NSW, and much of the rest of Australia. The resolution of 1m, however, whilst enabling complex analysis of suburbs and streets, has a limited accuracy at the property-specific level.

Photogrammetry, combining RGB imagery with 3D modeling, is the method used by mapping companies such as Google and C3 Technologies (for Apple Maps) to produce textured, 3D models of cities and towns. Generation of this data requires a plane to fly a low-altitude sweeps back and forth over the target location, capturing overlapping RGB imagery, or LiDAR data. Higher resolution site data can similarly be achieved through targeted surveys, once again using aircraft, or even drones, to scan particular areas using these scanning techniques.

Data achieved through these methods would have a higher point density than the 1m resolution from 'ELVIS'.

DATA CAPTURE

To capture the 3D spatial data for this dissertation, the photogrammetry technique was used for three distinct urban areas of Willoughby LGA, generating dense, coloured point cloud data, and textured mesh models. A transect of 350m x 150m was scanned for each site, with a drone flying an automated grid pattern for optimum coverage and accuracy. Each scan resulted in around 400 overlapping images, at an oblique 45° angle to achieve visibility of vertical objects, and beneath tree canopy, as much as possible. DroneDeploy was then used to process the images, reading the geolocation data from each individual image to place it spatially [Fig. 06.03.01 - A], before analysing the overlap between images to calculate height, shape and form of objects and the built environment below - a process more specifically called 'stereo photogrammetry'.

DroneDeploy produced a number of 2D and 3D outputs for each model through this process, as seen below [Fig. 06.03.01]. These included high resolution point cloud models [Fig. 06.03.02], to a point density of 166pts/m^2, a precision of 0.07m, and around 20 million points per model. This data is therefore around 14x denser than that available through ELVIS for the same location.

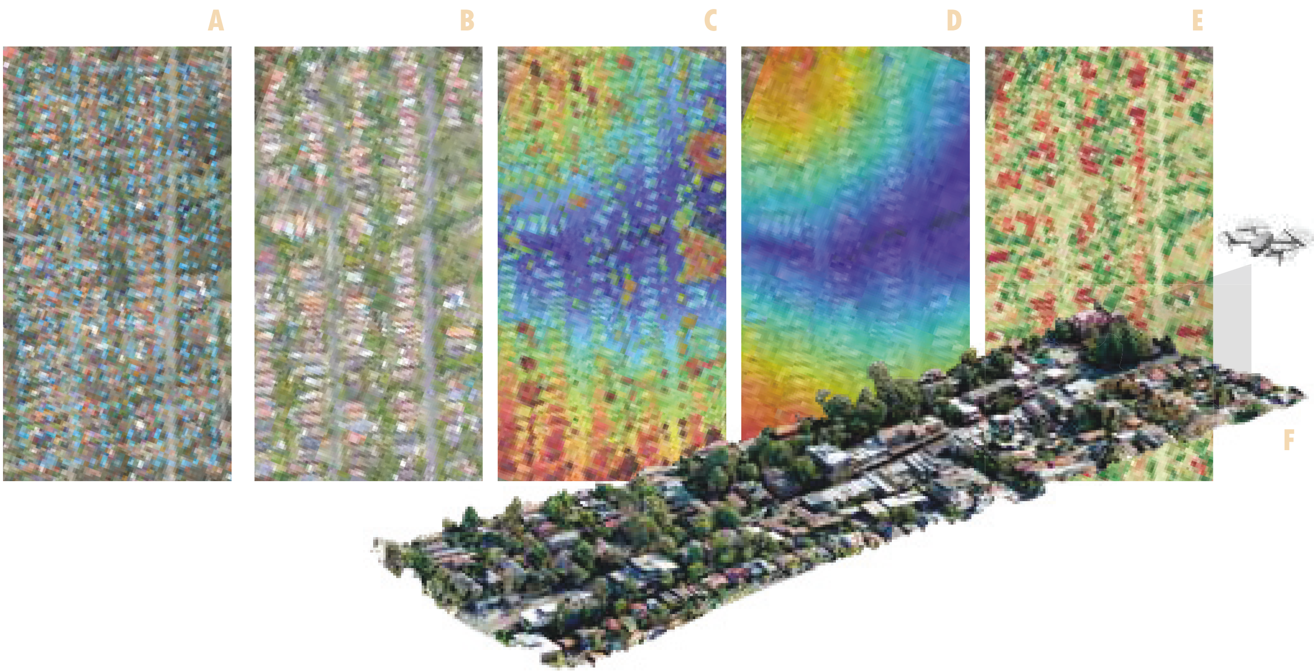


Fig. 06.03.01 DroneDeploy was used to process around 400 drone images per site, captured in the cross-grid pattern shown in [A], with images overlapping to enable photogrammetry processing. A range of 2D and 3D outputs were produced through DroneDeploy, including; [B] ~400mp Orthomosaic aerial photo, [C] elevation, [D] Digital Terrain Model (DTM) heatmap, [E] plant health, and [F] 3D textured mesh.

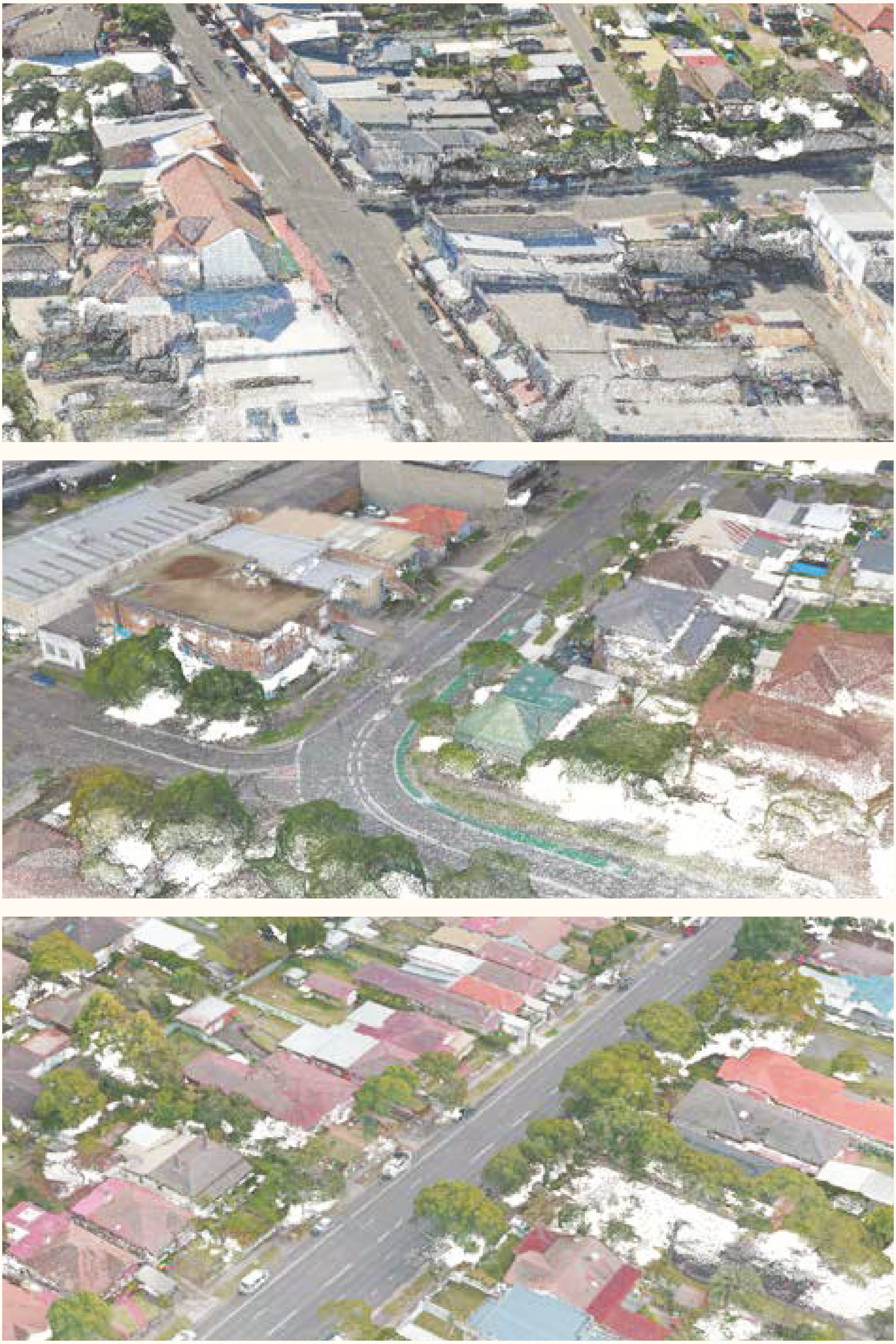


Fig. 06.03.02 *Detailed views of the 3D point cloud spatial data generated from DroneDeploy, enabling numerous potentials for urban analysis, simulation, and representation. [Top] Willoughby Rd, Willoughby. [Middle] High St, East Chatswood. [Bottom] Penshurst/Royal St, Chatswood.*

07 PRACTICAL & FIELDWORK: INFORMING AN EVIDENCE-BASED & HOLISTIC METHODOLOGY

07. PRACTICAL & FIELDWORK: INFORMING AN EVIDENCE-BASED & HOLISTIC METHODOLOGY

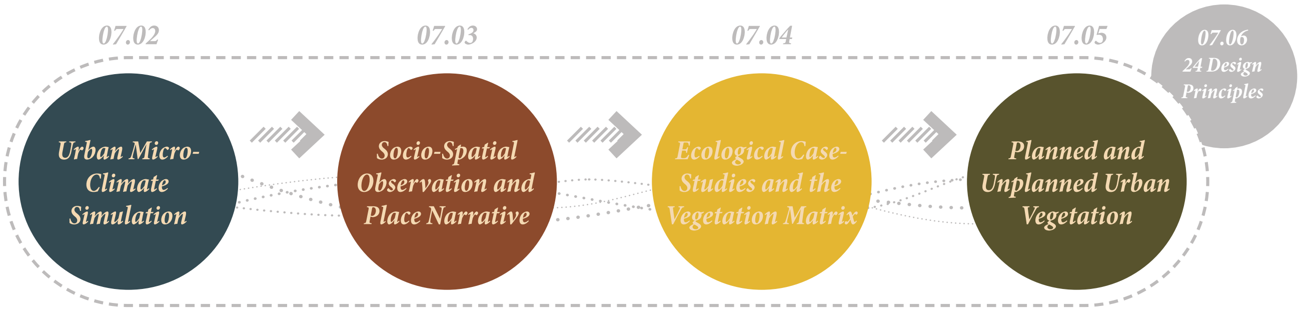
07.01 Chapter Overview

This chapter seeks to resolve the Green Mesh concept through the development of an innovative methodological framework, resolving issues identified in current green strategy planning, and traditional spatial data typologies. The key enabler to the fine-grain and intimate ecological responsiveness of the Green Mesh, new 3D spatial technologies, are embedded at a fundamental level within this methodology. This data not only bridges the spatial gap between high-level 2D GIS mapping and the human-scale on the ground, but creates a highly detailed digital 'clone' of reality that opens up the potential of accurate environmental systems understandings. Four components of this methodology, shown below, demonstrate the integration of these new spatial technologies into a realistic and replicable framework for the Green Mesh - explored through digital and on-site 'fieldwork'.

The first component, 'Urban Micro-Climate', utilises the highly detailed point cloud spatial data introduced in the previous chapter, to run several layers of micro-climate simulation within 'Grasshopper', a component of the 'Rhino3D' CAD program. Through the synthesis of each micro-climate layer, this invisible site characteristic was mapped spatially in 3D, to become the environmental baseline of the Green Mesh. Taking advantage of the human-scale quality of this data, subsequent components were able to directly respond to the micro-climate data created.

The second component, 'Socio-spatial Observation', re-introduced the human qualities of site back into an otherwise intensely quantitative process - through an understanding of existing uses and potential ecological integrations within current urban programs, communicated through narrative of lived-experience. Addressing the non-human biosphere, the third component, 'Species Suitability', produced a holistic vegetation matrix composed of hundreds of native and exotic species' within seven planting typologies. Chosen to support a variety of functions - from direct ecological restoration utilising native local species', to urban food production through properly managed exotic fruit-trees and shrubs, each of these species are researched and documented by their micro-climate preference, allowing the simulation data to explicitly dictate the suitable species of a particular location and function. Finally, the fourth component explores the physical characteristics of urban vegetation - both planned (green infrastructures), and unplanned (spontaneous urban vegetation), informing a final set of six 'Green Mesh Design Principles' to join a further eighteen from prior components.

These 24 principles were identified through observation and best-practice findings, becoming the individual physical implementations of the Green Mesh itself - to be implemented through community participation.



Utilising Grasshopper and complex urban point cloud data to simulate and spatialise the invisible micro-climates that exist within an urban environment. This forms the replicable environmental baseline for the Green Mesh.

Understanding the current socio-spatial interactions, patterns and activities within urban and residential environments of Willoughby, reintroducing 'human' and 'place' considerations back into the Green Mesh.

Case studies for several local, ecologically significant sites, informing a diverse composition of vegetation species, the non-human biosphere, whilst offering a range unique benefits to each of seven planting typologies.

Understanding the specific physical conditions that support the growth of planned and unplanned urban vegetation, from formal green infrastructure typologies, to self-seeded methods.

Six sites within Willoughby LGA were used as 'focus sites' for the development and testing of Green Mesh methodology. These sites feature a diversity of urban conditions, including land zone typologies, building heights and materials, age of built form, and canopy cover.

With many hours and days spent throughout these sites, observing and documenting their conditions, locations 02-04 became the 'primary focus sites' used for point cloud simulation as these were perceived to contain the greatest variety of urban and environmental factors.

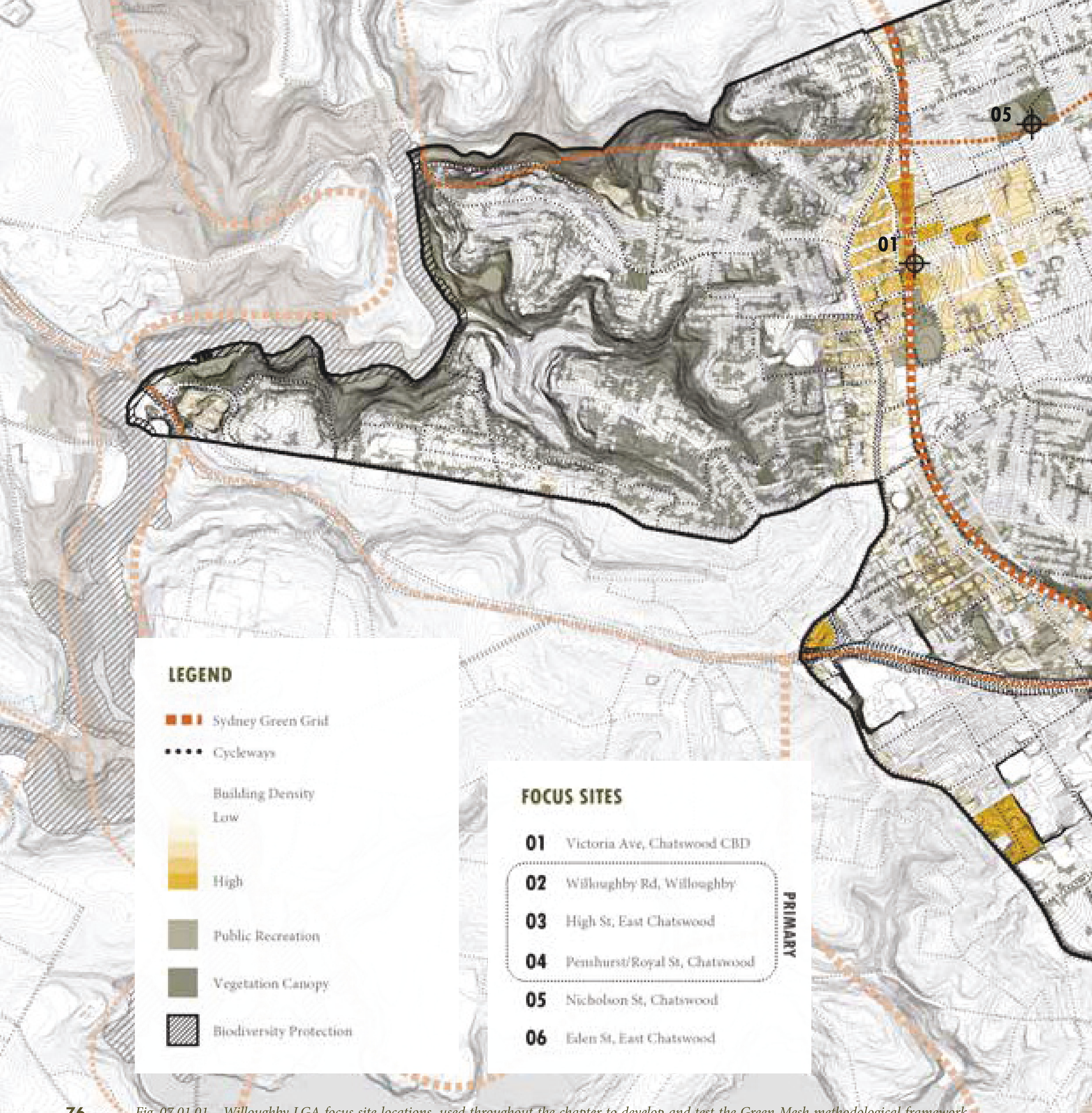
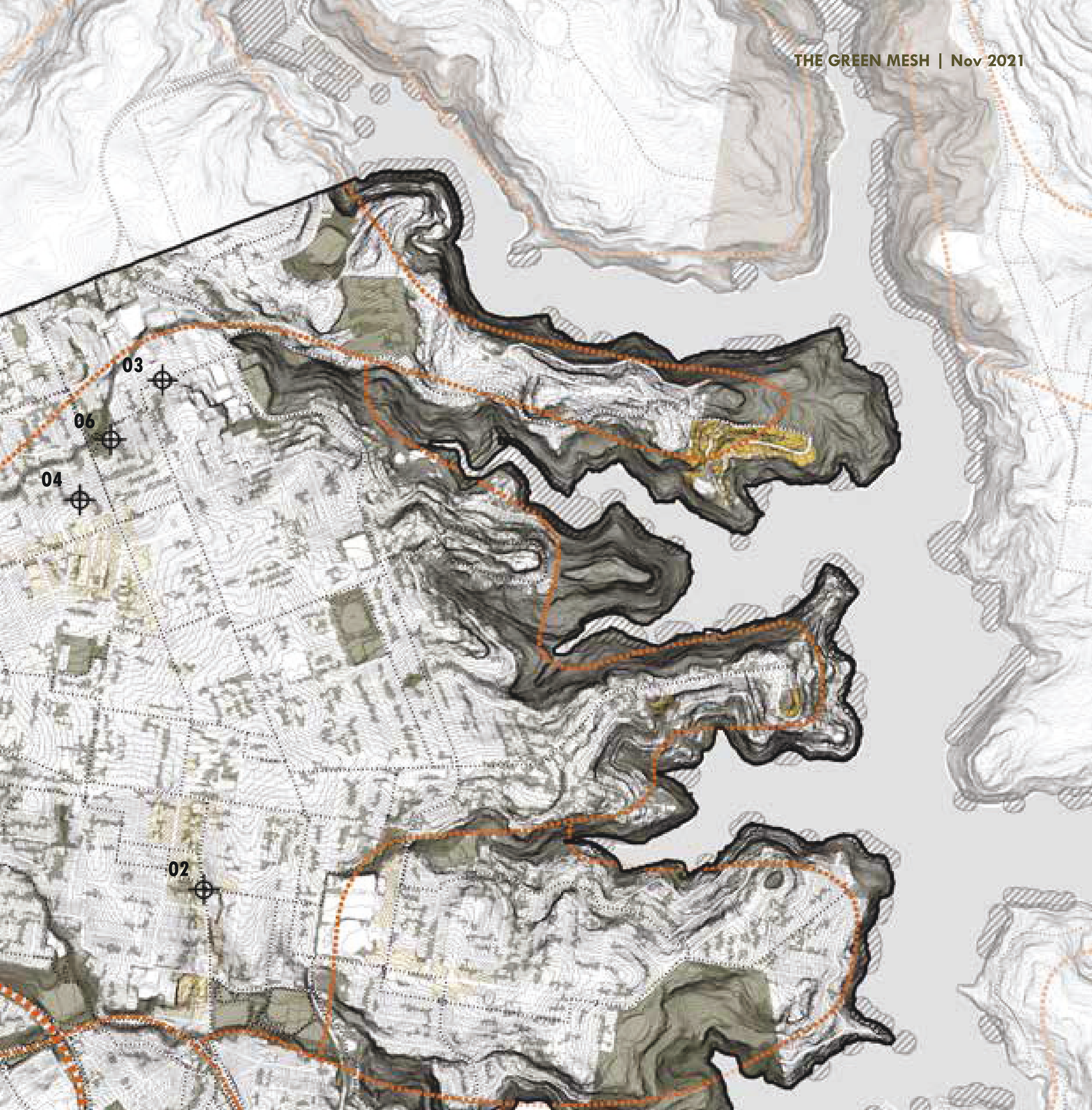


Fig. 07.01.01 Willoughby LGA focus site locations, used throughout the chapter to develop and test the Green Mesh methodological framework through on-site experience and fieldwork.



"The greatest current limitation on our local habitats is their fragmentation… they have become so disconnected with each other that their overall effectiveness as sustainable habitat for many animal species is drastically reduced." - Willoughby City Council[1], 2015

07.02 Urban Micro-Climate Simulation and Species' Suitability Variables

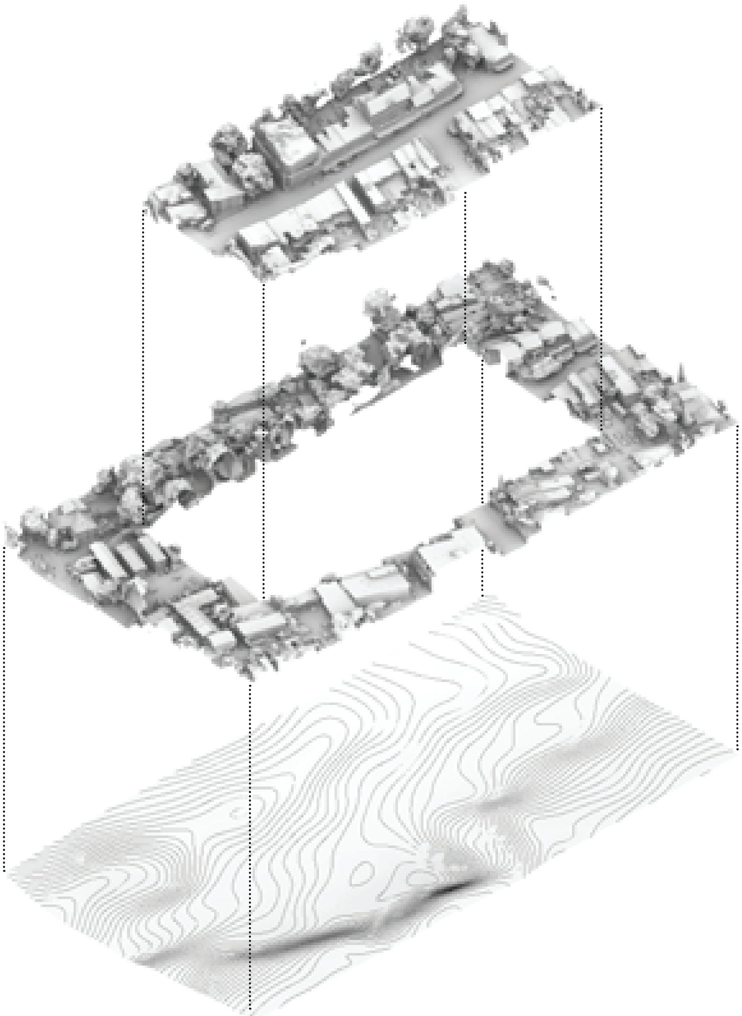
INTRODUCTION

Advanced, high-end simulation softwares such as 'ENVI-met', a computational fluid dynamics (CFD) software used to simulate micro-climate conditions through atmosphere, vegetation, architecture and materiality, exist as stand-alone tools separated from the CAD process of landscape architects and urban designers As such, these tools are "geared more toward scientific applications rather than architectural design" (Jonathan Graham et al, 2020). Similarly, web-based and cloud simulation platforms such as 'SimScale' offer complex simulation tools, however once again, cannot be projected back into CAD programs to directly inform the design process.

METHODOLOGY

Instead, I have chosen to implement a range of 'Grasshopper' plugins to simulate these micro-climate conditions, directly within Rhino3D - a popular 3D CAD program used in many design professionals. 'Grasshopper' is a visual programming interface based on Python code, enabling a wide range of additional functionality beyond the standard capabilities of Rhino3D. Simulation results through this approach are therefore much more translatable to design practice, enabling a finely-tuned level of site responsiveness that illustrates how these micro-climate conditions may both inform, and be informed by, design outcomes - through the ability to re-run simulations on proposed interventions.

Three Grasshopper plugins were used to produce the final set of micro-climate data, with a further range of plugins tested but found to not produce the desired results.



20,000 SQM SIMULATION EXTENT

A ~20,000sqm area was taken from each of the three focus sites, and used as the simulation extent. This area, measuring roughly 200m x 100m, features a high level of detail and complexity, representing a 'digital-clone' of the urban area as it is.

55,000 SQM CONTEXT

An offset boundary of additional context data was used where simulation results within the simulation extent would be influenced by external objects, buildings and landforms. For example, sun exposure analysis results use this context to calculate shade cast by adjacent buildings onto the simulation extent.

UNDERLYING TOPOGRAPHY

Underlying topography was used for wind analysis, as a means of offsetting the simulation plane horizontally above the ground-plane, ensuring wind intersects with built form and other objects.

Fig. 07.01.02 Point cloud derived data inputs used within the Rhino3D and Grasshopper workflow, to produce a range of micro-climate simulations as seen within the following pages.

Firstly, 'Ladybug' is a comprehensive environmental analysis plugin for Grasshopper, with the ability to read and visualise real weather data, using it to simulate sun exposure and solar radiation on 3D mesh surfaces. Ladybug connects to 'EnergyPlus', a global online weather database, accessing 'Typical Meteorological Year' (TMY) or 'Reference Meteorological Year' (RMY) data as an .EPW file to reflect local climatic characteristics within the simulation. This includes annual air temperature on an hourly basis, moisture content, air pressure, wind speed and direction, cloud cover, global solar irradiance, diffuse irradiance and direct radiation (NIWA, 2017), for a full calendar year. Outputs from Ladybug can be seen in Fig. 07.02.07, and Fig 07.03.10.

'Eddy3D' offers a range of wind, air pressure and comfort-rating simulations within Grasshopper. It is the product of a multi-disciplinary collaboration developed between the College of Arts, Architecture and Planning (AAP), and Systems Science and Engineering at Cornell University. It connects Grasshopper to the OpenFOAM platform, allowing complex 'computational fluid dynamics' (CFD) simulations to be run and visualised, making Eddy3D useful for understanding wind speed and movement throughout built form, and resulting air pressure on facades. Eddy3D outputs can be seen in Fig. 07.02.12.

'Kangaroo Physics' is the final Grasshopper plugin used, enabling real-time and interactive physics simulations and form-finding. Of particular relevance to micro-climate simulations is the ability to simulate water particles and flow-dynamics over a surface. This functionality was used to draw flow-lines and derive areas of water saturation (where water collects and puddles) on the models. Kangaroo outputs can be seen in Fig. 07.02.04.

Where relevant, simulations were run twice to reflect both winter and summer solstice extremes, with the raw data on the following pages demonstrating the distinct differences in micro-climate characteristics between these two periods - highlighting seasonality as an important consideration. Simulation of each individual micro-climate factor was then combined to produce a holistic micro-climate drawing in Fig. 07.02.20, showing the ability to determine the unique set of micro-climate conditions on a surface by surface basis.

DATA LIMITATIONS

The 3D point cloud and photogrammetry data represents the powerful potential of modern consumer technology and software. It offers a much higher level of detail than data sourced freely through online services such as 'ELVIS'. However, a primary limitation of the more accessible and consumer-friendly photogrammetry method used to capture 3D data, is it's inability to see-through vegetation canopy and foliage to accurately represent the ground underneath - something that the more expensive LiDAR method is able to do. Positioning the aerial camera at a 45° angle is able to mitigate this to a certain degree, however the resulting point cloud data still shows certain areas beneath trees to have holes, and where software extrapolate has taken place to fill these holes in the mesh data. A solution that could be experimented with through additional time and development, is the capturing of ground-level images that could be added into the processing algorithm along with the original aerial images, offering additional reference data for these areas of the model.

Other small anomalies have also been noticed within the 3D data, caused by smooth textures or reflective surfaces within the scene. With these surfaces, the software lacks consistent visual reference points that the algorithm needs to calculate shape and morphology. This phenomenon can once again result in holes in the model (for features like water that are both reflective and constantly changing), or the algorithm produces false bumps or divots in the data. These anomalies are often very small, and did not fundamentally affect the simulation process.

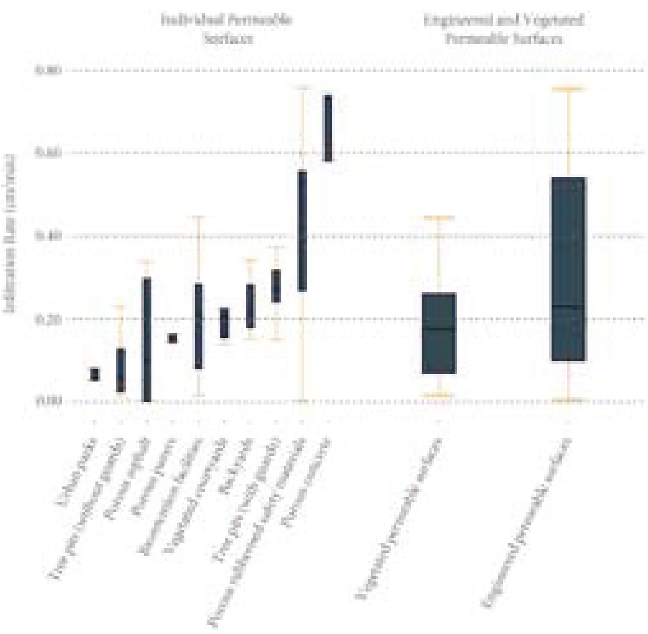
Finally, whilst a primary benefit of the point cloud data is it's accurate up-to-date representation of the site, this point-in-time capture also includes the existence of temporary objects within the scene, such as stationary parked cars. Without significant time spent extracting these objects from the data, they are otherwise included in sunlight, radiation, water runoff, and wind simulations - though once again these are relatively small occurrences within the broader data. Micro-climate conditions can instead be interpolated from the surrounding areas of these objects to factor them out.

MATERIALITY AND PERMEABILITY

MICRO-CLIMATE EFFECT

Within urban environments, materiality has an effect on local micro-climate conditions through two contrasting mechanisms - thermal absorption and surface permeability. Thermal absorption influences the amount of heat absorbed through solar exposure, and subsequently, the amount of heat radiated back into the local area. The difference in the thermal properties between metal, concrete, aggregate, or grassed surfaces, for example, will lead to changes in ambient air temperature and therefore influence the habitability of a space, and the outdoor comfort rating. Of these materials, hard man-made surfaces such as pavements, concretes and metals in urban environments "tend to reflect less solar energy, and absorb and emit more of the sun's heat compared to trees, vegetation, and other natural surfaces" (US EPA, n.d.). Furthermore, darker surfaces will generally absorb less heat than lighter coloured equivalents.

By contrast, permeability influences the amount of water on the surface that either penetrates through into the underlying soils (and retained locally), or flows along a surface such as bitumen, into gutters and drains to be funneled into local creeks or rivers.



Max/Min recorded

Upper quartile

Median

Lower quartile

Fig. 07.02.01 Box plots of urban ground surface infiltration rates measured in New York City and Philadelphia. Data source: Alizadehtazi et al. (2016).

"In cities, much of the precipitated water is directly lost through surface runoff into storm drains, potentially causing severe water shortage of trees growing in areas where only a small fraction of the ground is permeable".
- Gillner et al. (2014)

From an ecological perspective, urban trees greatly benefit from water retention on site, with "impervious surfaces such as pavement in the near vicinity of tree stems... negatively influenc[ing]... water availability, vitality and growth of urban trees" (Schröder, 2008). The implementation of permeable urban surfaces, the benefits of which can be seen in [Fig. 07.02.01], would not only allow water to infiltrate the soils, but reduce extreme soil temperatures caused by the aforementioned solar absorption.

As touched upon, these micro-climate effects have a direct impact on living creatures both human and non-human. Further to ambient temperature and water retention, however, our choice of material within urban environments can further be used to promote co-habitation with insects and animals. For example, many native Australian bee species live solitary lives, creating homes within small holes in tree trunks and other natural crevasses. Whilst hard, man-made surfaces prevent such burrows or holes from being created, there is an opportunity to accommodate this interaction through the sustainable use of natural materials like timber.

OBSERVATIONS

The high-detail and textured quality of photogrammetry modelling made it possible to observe and classify these materialities within Willoughby LGA. Through this analytical tool, it became evident that a significant proportion of horizontal surfaces within the three focus sites are hard, man-made, and impermeable, including traditional ground pavers (d), concrete and asphalt surfaces (e), and tile or metal used for rooftops (a, b). These surfaces prevent water infiltration, indicating a poor condition for urban vegetation. Furthermore, they contribute to the urban heat island (UHI) effect, raising the ambient air temperature unproportionally on warm days to create a less inviting climate for people and animals.

Fig. 07.02.02 Site materiality, and observed permeable and impermeable surfaces.

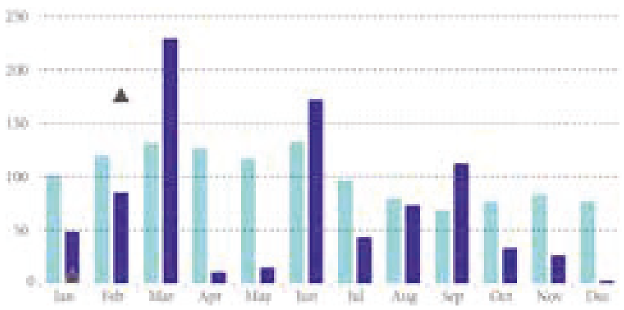
WATER FLOW AND SATURATION

MICRO-CLIMATE EFFECT

Water is a constant and ongoing issue in Australia, with cyclical droughts in both rural and urban areas following the El Niño-Southern Oscillation (ENSO) climatic effect - the shifting pattern of warm and cool ocean currents along the Australian east coast, mirrored on the west coast of USA. As seen in Fig 07.03.02 below, rainfall in Sydney can vary significantly. During El Niño, the eastern coast of Australia is subject to warmer temperatures and reduced rainfall. This results in a greater risk of bushfires, and decreased alpine snow depths, with furthermore, "most major Australian droughts... associated with El Niño" (Australian Bureau of Meteorology, n.d). These effects are all instigated by a change in ocean surface temperature, affecting the moisture content of air carried over land.

These periods of little rainfall result in water usage surpassing the rate of replenishment into centralised reservoirs and dams, placing increasing pressure on stored water. As such, water management practices need to be implemented that target the efficient and sustainable use of available water - decreasing per capita usage, whilst creating further potential for the capture and storage of water through decentralised means. Reducing stormwater runoff through rainwater harvesting, the widespread adoption of residential water tanks, implementation of retention pits and WSUD, and the promotion of permeable surfaces can all contribute towards addressing these water shortages.

Humidity is yet another consideration influenced by local water levels, and more specifically, the rate of evaporation - a product



▲ Max/Min rainfall records (mm) 2020*

Rainfall (mm) 2019

Mean rainfall (mm) for years 1858-2020

*Fig. 07.02.03 Mean rainfall (mm) for closest weather data location, Sydney (Observatory Hill). Data source: Australian Government, Bureau of Meteorology. *As of August 2020*

"here [in Australia], water plays a massive role [in landscape architecture]... different micro-climates deal with water differently... how do we retain water, how do we plant things that can handle water... essentially what you have to do is not fight the climate." - Brett Robinson (2019)

of sun exposure, air temperature and wind. Evaporation, either directly from the ground or through evapotranspiration in plants, has a substantial cooling effect within urban environments, therefore offering a potential solution to areas affected by the Urban Heat Island effect (UHI). Ultimately, this cooling effect reduces reliance on artificial cooling within buildings, whilst promoting greater outdoor comfort levels and liveability in our urban environments.

SIMULATION RESULTS

The Grasshopper plugin 'Kangaroo' was used to simulate water movement and stagnation over the 3D models, using a density of 1 particle/m^2 over each 20,000m^2 site. The collision modeling of Kangaroo simulates each particle individually, accurately portraying interactions from one particle to another, to achieve realistic flow characteristics. The paths that these particles took during the simulation, and their final resting locations, were recorded to give water flow and saturation, respectively.

Of most interest, were the locations where water collected and pooled. Such areas can be identified as locations for Water Sensitive Urban Design (WSUD) implementation, in order to capture and treat water runoff, retaining it on-site. Naturalistic planting through WSUD provides a high-level filtration function through the root systems and ground substrate.

Simulation results as shown in Fig. 07.02.04 demonstrate a high degree of accuracy of flow modelling, depicting even the subtle engineering effects of road convexity, as water is drained either side to the curb and guttering. Darker blue spots show saturation and stagnation - where the particles came to rest.

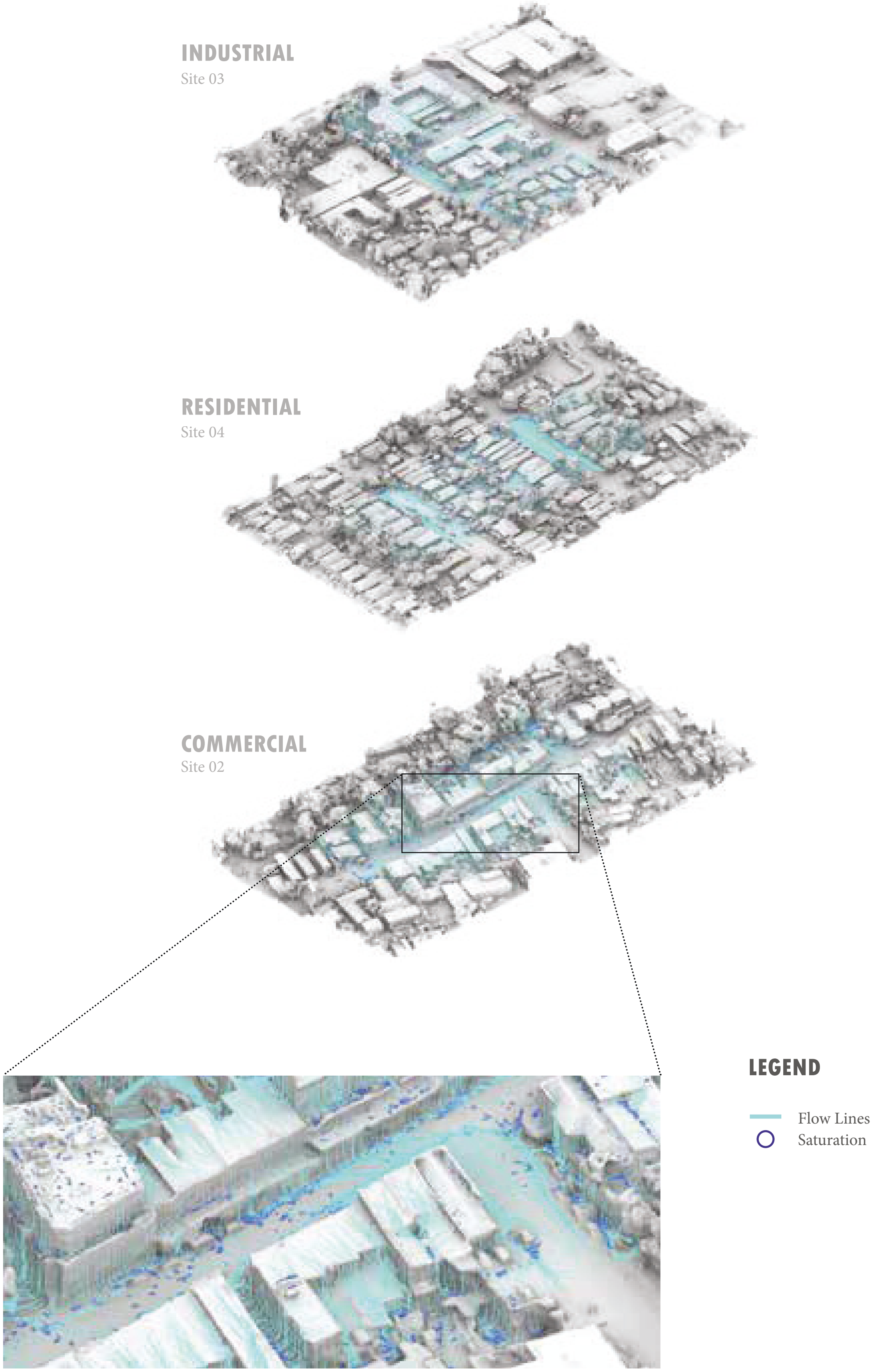


Fig. 07.02.04 Water flow-line simulations across the three example sites in Willoughby, using Grasshopper functionality and 3D point-cloud derived meshes.

Currently, six water catchment areas exist across the Willoughby LGA, with stormwater infrastructure feeding into a network of underground pipes and below-grade channels. Like much of Sydney, stormwater is quickly drained from the local area along hard surfaces with a limited ability to infiltrate into the soil for any ecological function.

Increasing local rainwater retention will decentralise the water supply in Sydney and reduce stress on larger, shared water sources - all whilst decreasing pollution in our environmental water systems.

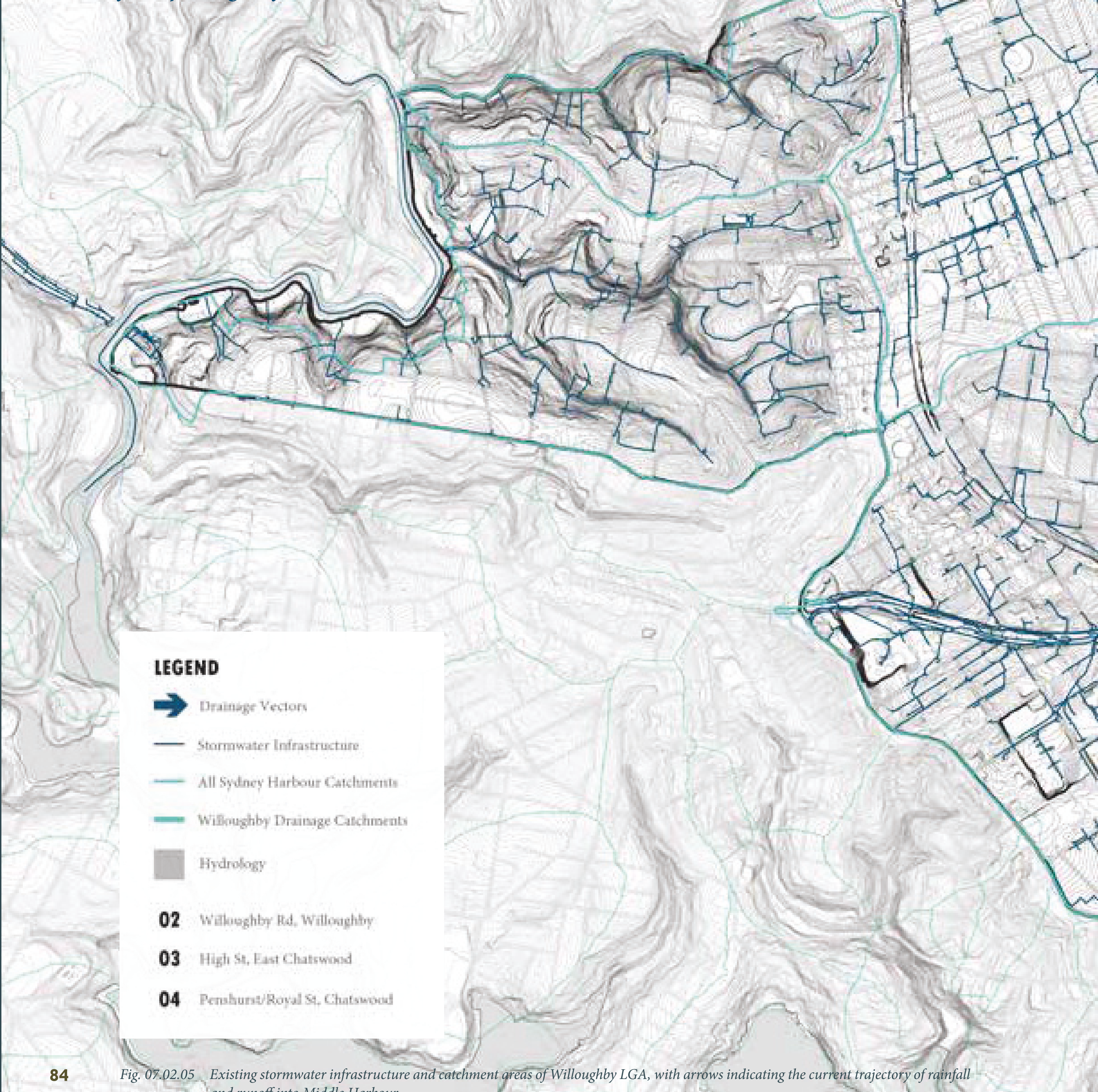
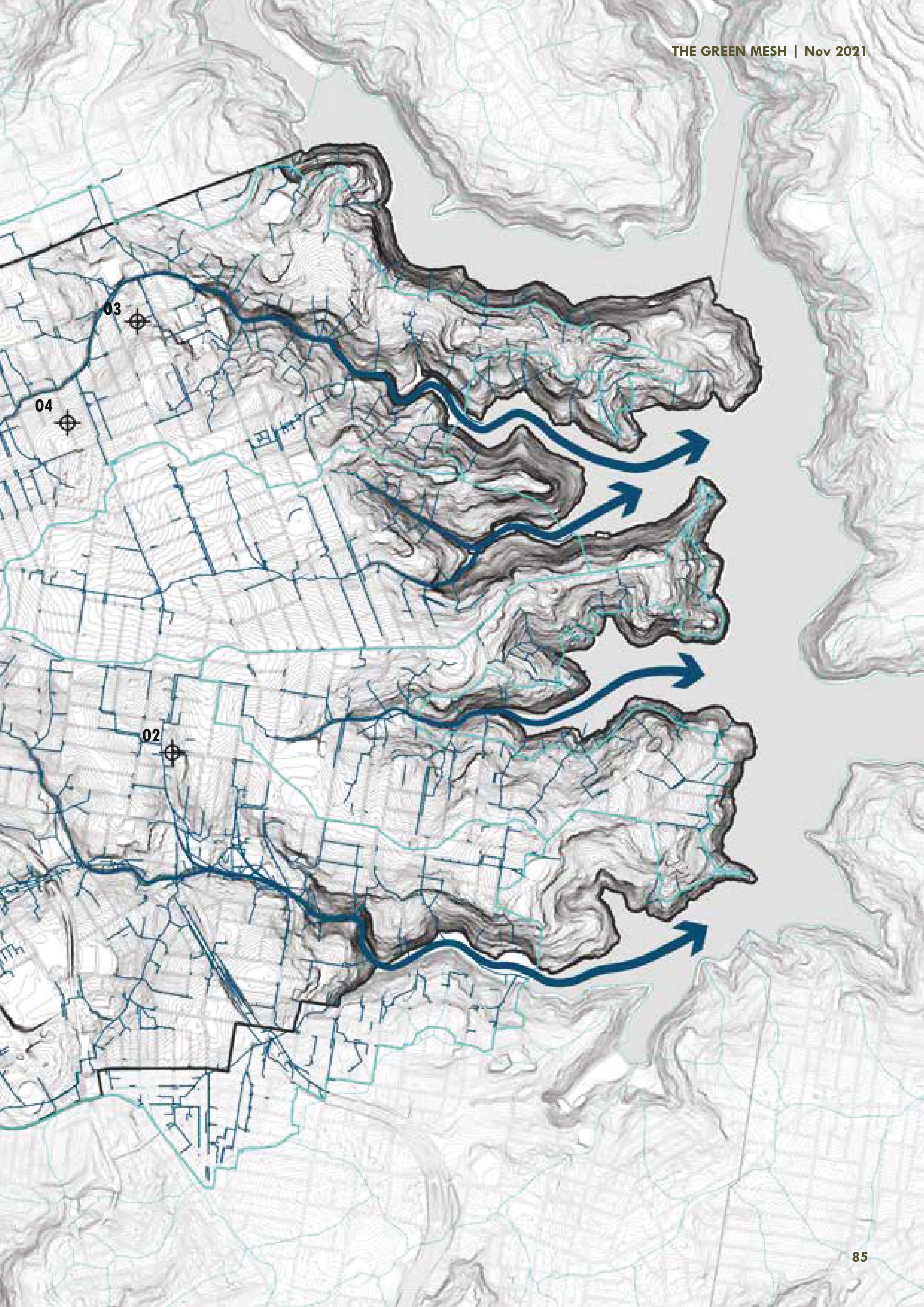


Fig. 07.02.05 Existing stormwater infrastructure and catchment areas of Willoughby LGA, with arrows indicating the current trajectory of rainfall and runoff into Middle Harbour.


03
04
02

SUN EXPOSURE

MICRO-CLIMATE EFFECT

Sunlight is one of the basic requirements for plant growth, triggering a chemical reaction which enables the breaking down of carbon dioxide and water molecules to create the glucose that plants feed on for growth - the process of photosynthesis. The intensity of light is what ultimately influences the rate of photosynthesis, and therefore the growth rate for plants. Various plant and crop species will have a differing requirement for sunlight and temperature, with some preferring full-sun and others thriving in the relative shade. This means that species will ultimately be planted in groupings of similar requirements, and particular grouping will be more ideally suited to certain sun exposure conditions within in a backyard than others.

Sun exposure will furthermore influence a number of other micro-climate factors, such as solar irradiance - effecting both ambient and surface temperatures. In turn, this will also influence considerations such as water evaporation, humidity, and air pressure, with the latter caused by warmer air moving upwards (hot air rises), reducing pressure.

Finally, from the perspective of inhabitation, sun exposure has an influence on outdoor comfort through many of the aforementioned considerations - with the potential to create harsh, hot, urban environments if not addressed in summer months.

SIMULATION RESULTS

Sun exposure simulations were conducted twice for each site, detailing exposed hours across a surface for both winter and summer solstices, when the sun is lowest and highest in the sky, respectively. Weather data for the nearest location available, Observatory Hill, Sydney, was acquired through 'EnergyPlus', and fed into the Ladybug script to ensure accurate yearly weather data inputs and locationally specific sun positions and metrics. Sun path diagrams in Fig. 07.02.06 show the sun positions derived through this data, and used for each simulation.

Results show the distinct difference in sun exposure between winter and summer extremes, with lower winter sun angles producing larger shadows cast from built form and therefore less surfaces achieving a full eight hours of exposure. The higher and more direct summer sun, with less shadows from adjacent buildings, means that ground-level surfaces have around 3-4 more hours of sunlight per day, affecting the nature of vegetation that might be able to grow in these areas, and introducing a seasonal challenge to urban green infrastructure.

Simulation results across Site 04 demonstrate the accuracy and subtle responsiveness that this methodology enables, as changes in slope angle and direction in residential rooftops reveal a fine-granularity in data outputs.

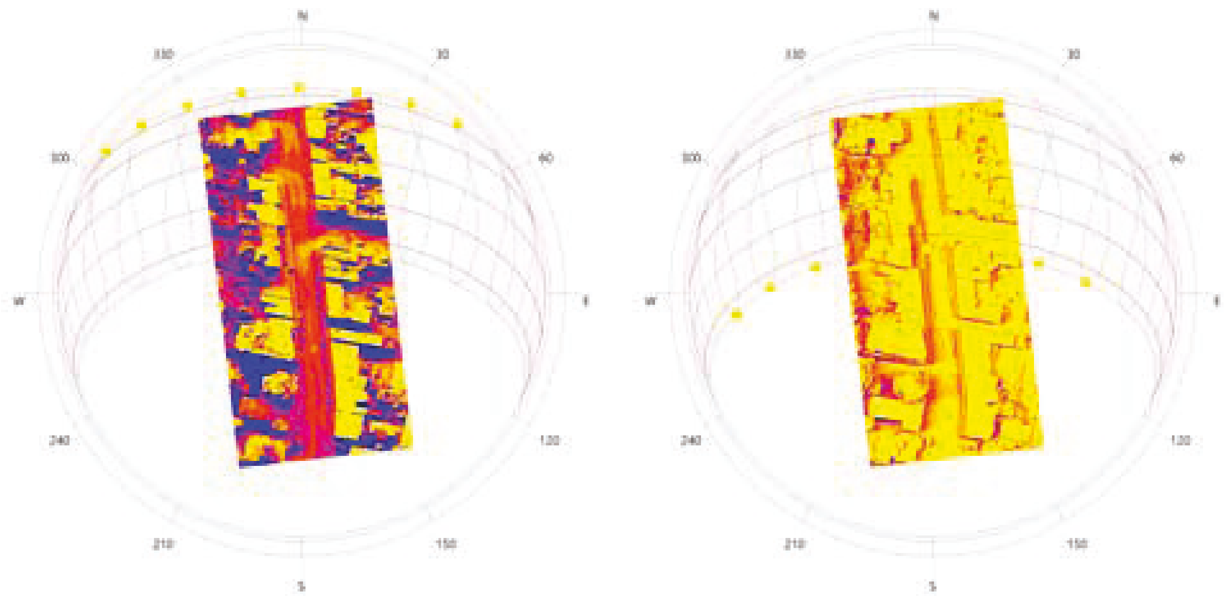


Fig. 07.02.06 Sun path visualisations produced through Ladybug for Grasshopper, using 'Representative Meteorological Year' (RMY) weather data specific to Sydney, acquired through the 'EnergyPlus' website. Winter solstice 9AM-5PM [left], and Summer solstice 9AM-5PM [right].

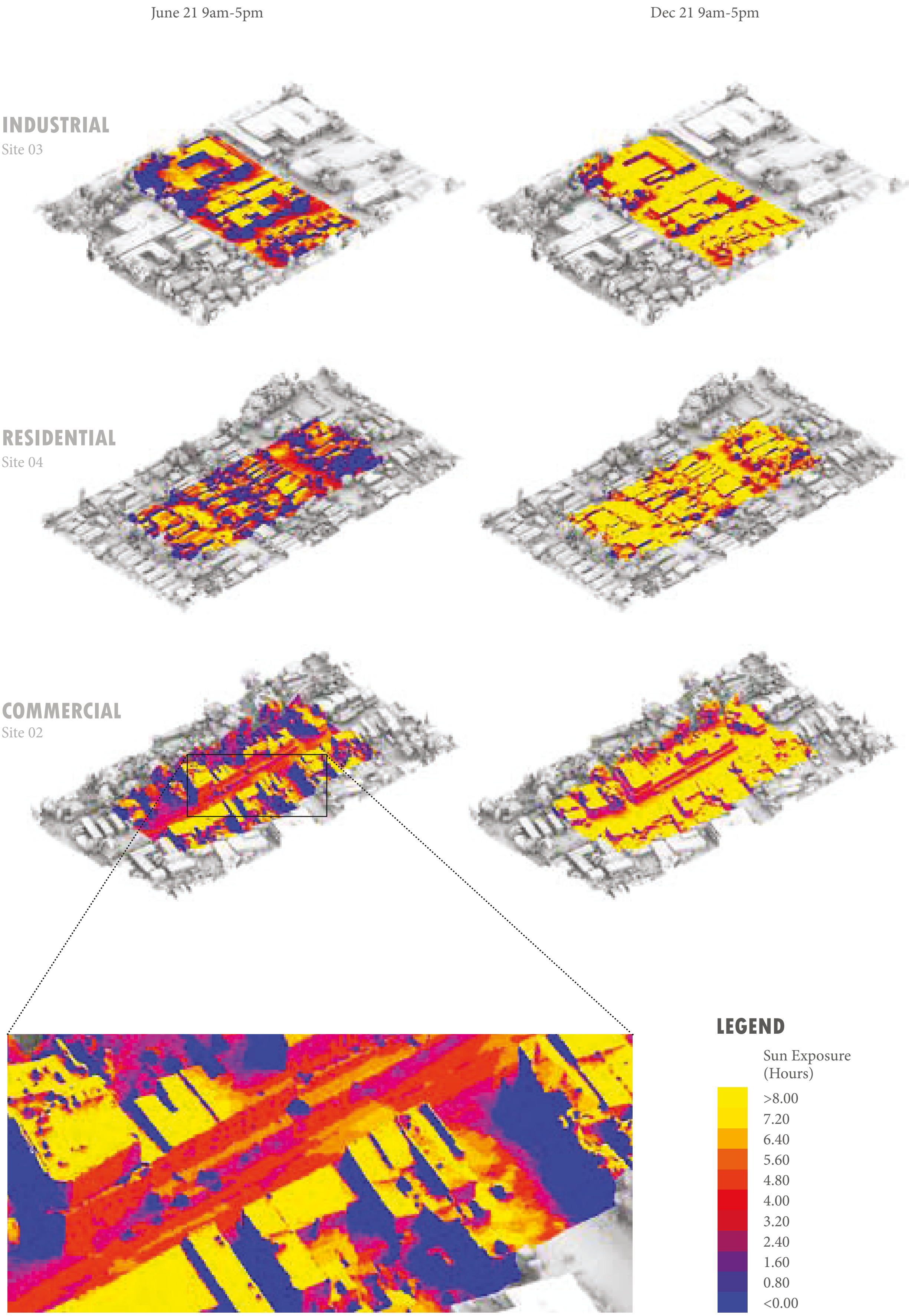


Fig. 07.02.07 Sunlight hours for both Winter and Summer extremes simulated across three example sites within Willoughby. Simulations were done using the Ladybug plugin for Grasshopper.

SOLAR RADIATION AND TEMPERATURE

MICRO-CLIMATE EFFECT

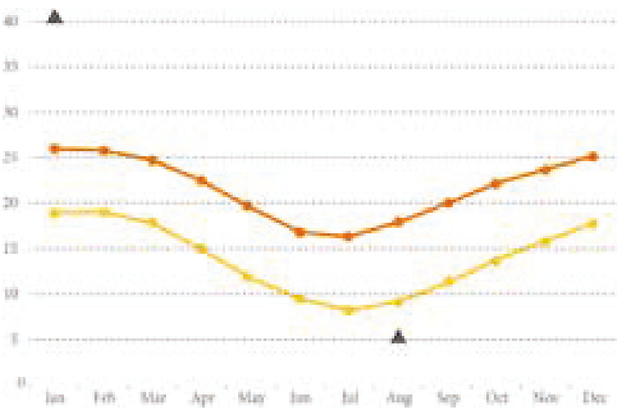
Solar radiation is defined as "electromagnetic radiation emitted by the sun" (Office of Energy Efficiency & Renewable Energy, 2013) and measured in terms of 'irradiance', the radiant flux received by a surface per unit area (kWh/m2). This energy can be captured and converted into other forms of energy such as heat and electricity, both naturally through plants and photosynthesis, and artificially through technologies such as solar panels.

In combination with the resulting effects on air and surface temperature, solar radiation is an important consideration for plant growth and species suitability. Whilst some plants have adapted to surviving in harsh temperatures, with built-in mechanisms for minimising moisture evaporation in these situations, other plants would die if exposed to similar conditions.

From a social perspective, temperature is a crucial indicator of outdoor comfort, overlapping in this area with the effects of sun exposure. In terms of radiation specifically, exposure and absorption should ideally be maximised in winter, and minimised in summer, acting as a natural temperature regulator to decreasing the harsh seasonal extremes.

SIMULATION RESULTS

Once again, Ladybug was used to run these simulations in Grasshopper, with EnergyPlus data providing climate and weather input values. Comparisons between winter and summer results show the effect that the angle of incidence has on the radiation potential of certain surfaces [Fig. 07.02.09]. Two variables can act to change the angle of incidence; the angle of the sun within the sky, and the angle and orientation of the actual surface that sun rays intersect.



Min/Max temperature records (°C) 2020*

Mean max temperature (°C)

Mean min temperature (°C)

*Fig. 07.02.08 Mean max and min temperatures (°C) for closest weather data location, Sydney (Observatory Hill). Data source: Australian Government, Bureau of Meteorology. *As of August 2020.*

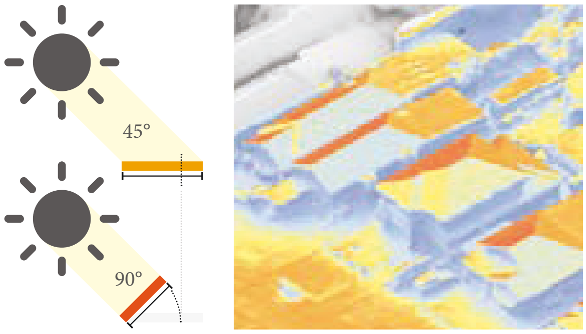


Fig. 07.02.09 The effect that the angle of incidence (degrees) has on radiation potential. Both the angle of the sun, and the surface inselft will influence this. Simulation of winter solar irradiance.

With the angle of the sun much lower in winter, the solar irradiance potential of a horizontal surface will therefore be much lower than the same surface with the summer sun directly overhead at 90°. At this angle, rays from the sun travel a much shorter distance to the ground, and therefore experience less scattering and diffusion, resulting in more concentrated and higher measures of irradiance - therefore compounding the individual effect of angle of incidence.

Assessing the angle of the surface itself, surfaces angled towards the direction of the sun - even when lower in the sky like in Fig. 07.02.09, will experience a greater irradiance potential as the same rays from the sun are concentrated onto a smaller area. With solar panels angled towards the sun, this effect can increase energy generated by 10-20%. Whilst demonstrated in the winter scenario, surface angle is also a consideration for summer as well, with flat roofs for example, experiencing proportionally greater irradiance than in winter.

Ultimately, this methodology allows for the identification of greatest irradiance potential, and hottest potential surfaces - depending on the materiality. This can be used to identify the best location for solar panels, surfaces that would benefit from vegetation as a cooling agent, or primary areas of concern towards to UHI effect.

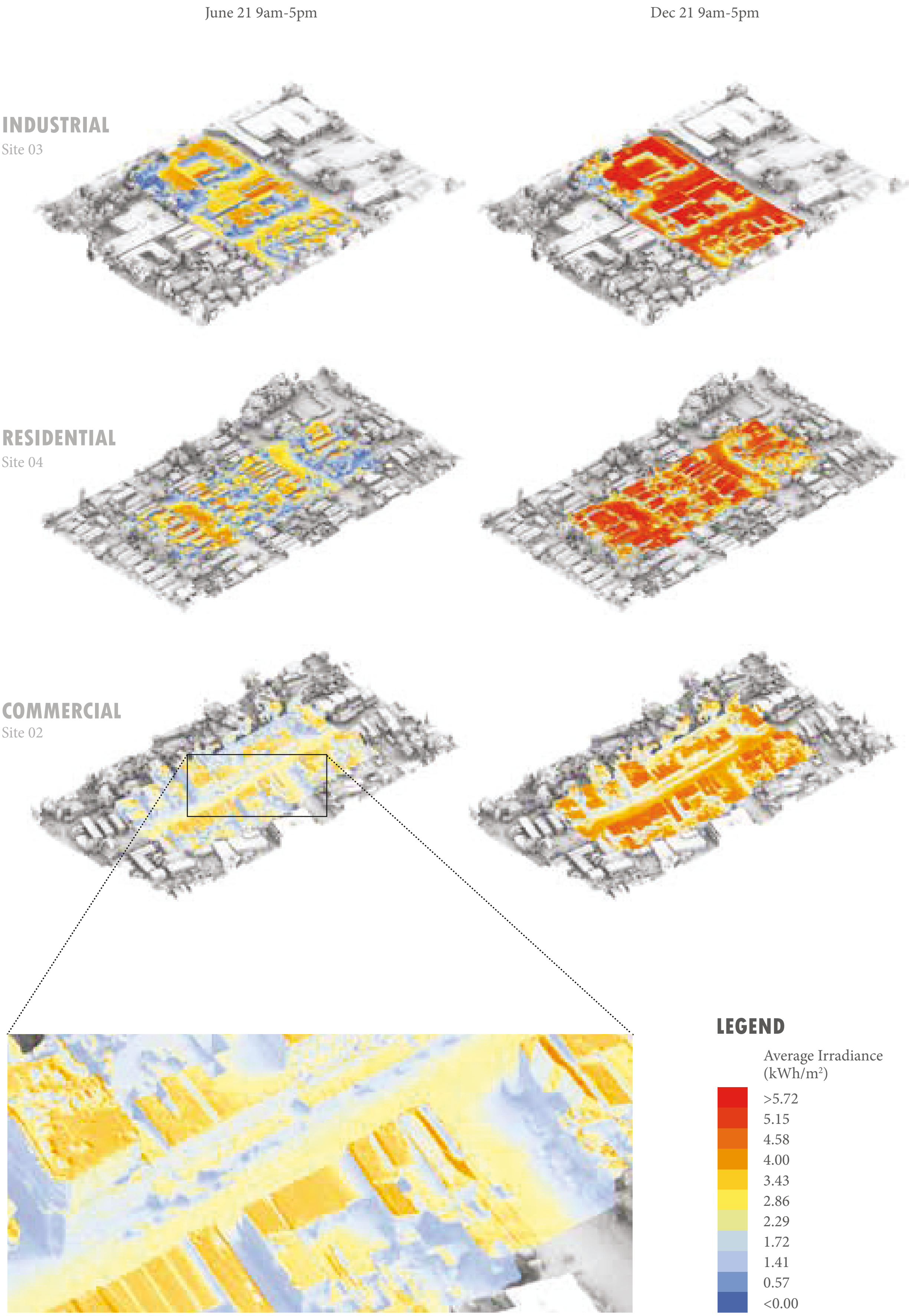


Fig. 07.02.10 Solar radiation simulations for both Winter and Summer extremes simulated across three example sites within Willoughby. Simulations were done using the Ladybug plugin for Grasshopper.

WIND ANALYSIS

MICRO-CLIMATE EFFECT

Wind has a range of effects for both plant stability and growth, surface temperature, and rate of evaporation. Whilst winds up to a certain amount during plant development can be beneficial to the strength of the mature plant, anything greater can cause structural failure in the roots and truck, with the ability to recover from this being entirely species dependent.

Similarly, "wind damage can have major economic impacts on crops, forests and urban trees" (Gardner et al, 2016), with poor species selection or prior analysis of site contributing to this issue. However, "management that is sensitive to the local site and climatic conditions... accounts for the ability of plants to acclimate to their local wind climate" (Gardner et al, 2016). The same notion is true for many other aspects of plant health and climatic suitability, including soil and sun conditions, availability of nutrients, and local insects.

Furthermore, higher winds cause greater levels of moisture evaporation from plants, due to increased rates of transpiration - the water movement through a plant, and its evaporation through leaves, stems and flowers.

"...because of the topography of a high-rise downtown corridor, micro-climate wind speeds can also exceed those found in rural areas."

- Amy Grant (2019)

SIMULATION RESULTS

Ladybug and Eddy3D were used to simulate wind conditions within the photogrammetry models. The former, Ladybug, was used to visualise weather data from EnergyPlus, as seen in the wind rose diagrams below, with the latter, Eddy3D, using the prevailing wind directions and intensities from these diagrams to simulate both winter and summer wind characteristics. Wind was simulated along a plane parallel to the underlying topography, and half-way up the building facades within each model.

Within Site 03 [Fig. 07.02.12], a wind tunnel effect can be seen as the streets and buildings are orientated parallel to the prevailing wind directions for both summer and winter. Whilst high winds can be destructive to plants and vegetation if they have not grown to withstand it, this also presents the opportunity through design to harness the wind for more useful functions such as soil aeration and even wind energy production.

The other two sites feature a range of wind conditions, creating both high and low pressure areas on the facades of buildings, presenting a number of other challenges and knock-on effects to other micro-climate factors.

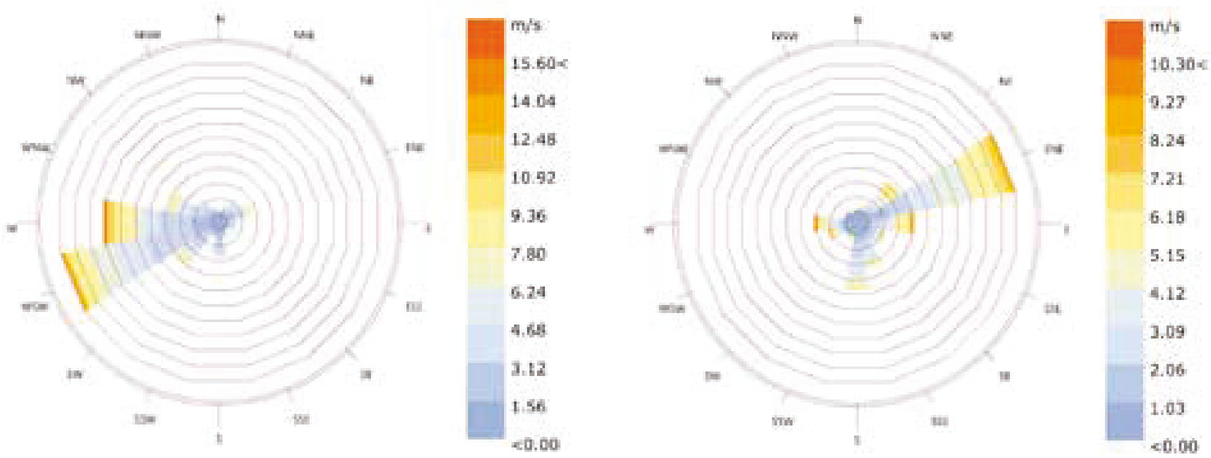


Fig. 07.02.11 Wind Rose visualisations produced through Ladybug for Grasshopper, using 'Representative Meteorological Year' (RMY) weather data specific to Sydney, acquired through the 'EnergyPlus' website - Winter months [left] and Summer months [right].

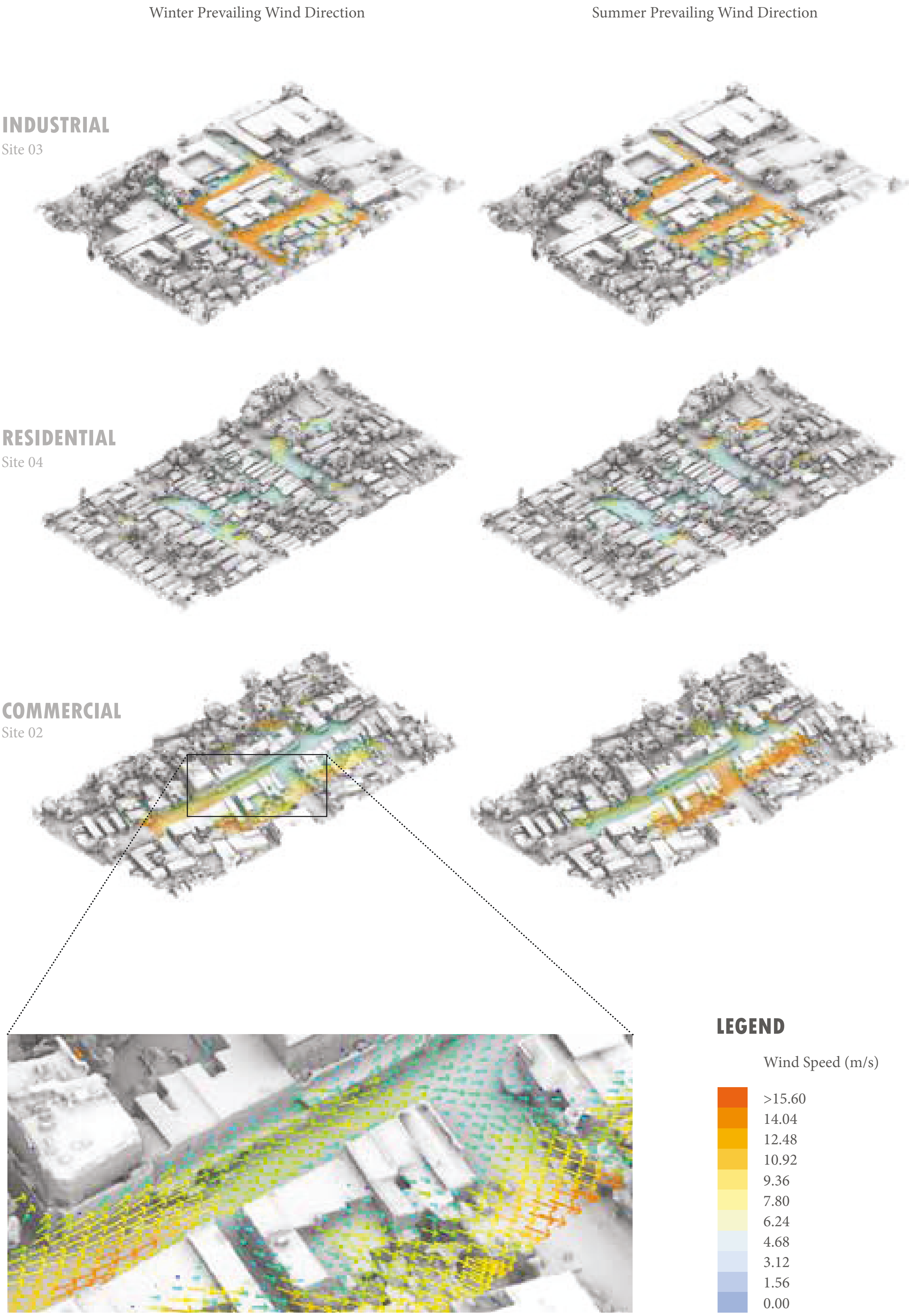


Fig. 07.02.12 Wind simulations using the Eddy3D Grasshopper plugin.

REPLICATION AT A PROPERTY-SPECIFIC SCALE

SIMULATION RESULTS

Shifting in scale from the street to the property, simulation of the key micro-climate factors were replicated for a single residence. Whilst the street-scale was useful in developing and testing this analytical methodology against a wide variety of built form simultaneously, the property scale is ultimately more relevant to facilitating community implementation for individuals within their own property. At this scale, micro-climate considerations for ecological implementations can be more intimately aligned with human aspects of the site, including program, movement, and interaction.

The chosen property was isolated within a broader point cloud dataset, capturing the boundary extents, overhead canopy, and extending out to the street to include council verge. Contextual data external to the property boundary remained important for the simulation process, used particularly for sun exposure and solar irradiance simulations to represent shadows cast from features external to the property such as vegetation canopy and built form. Where applicable, simulations were once again repeated for seasonal extremes of summer and winter, once again showing the innate differences between seasons.

The detail and complexity achieved through these simulations, demonstrated within Fig 07.02.14-16, suggests that this methodology is able to deliver a fine-grain environmental baseline, not only at a broader, street-scale, but also down to the individual property level.

Fig. 07.02.13 Property-specific 3D point cloud data containing ~10 million points.

PHOTOGRAMMETRY BASE DATA

Isometric

Plan

MATERIALITY

Impermeable

- Glass
- Floor Tiles
- Timber
- Pavers
- Brick
- Metal
- Roof Tiles
- Concrete
- Asphalt

Permeable

- Grass
- Planting
- Canopy

- Soil / Leaf Litter
- Stones/Pebbles

Materiality

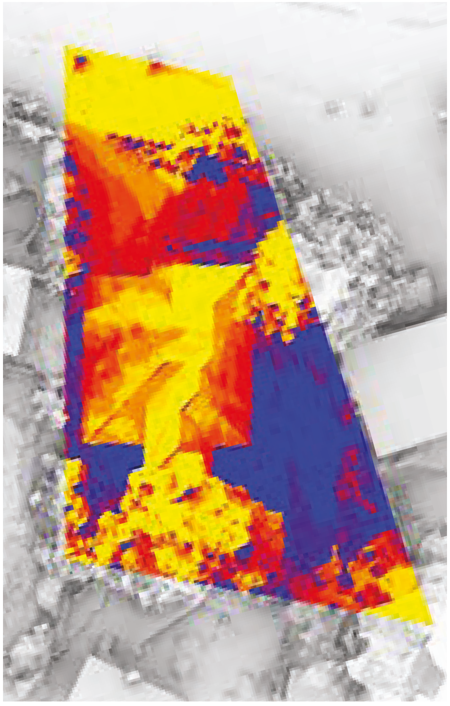
Permeability

Fig. 07.02.14 Property-specific 3D photogrammetry base-data [top], and manual permeability and materiality classification [bottom].

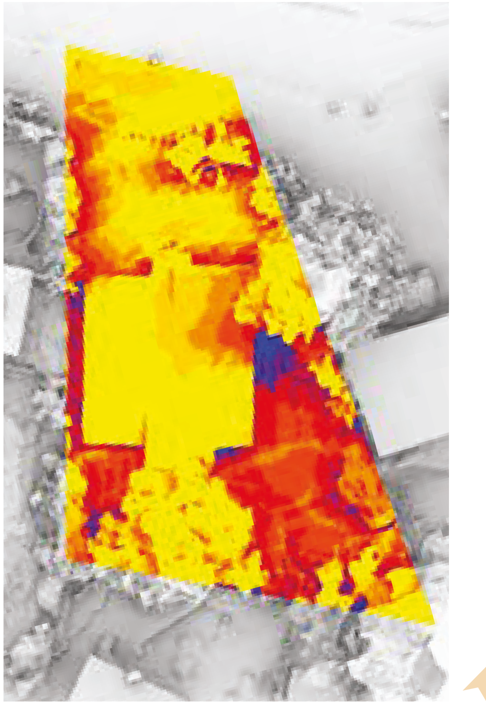
SUN EXPOSURE

(Hours)

>8.00
7.20
6.40
5.60
4.80
4.00
3.20
2.40
1.60
0.80
<0.00



Winter

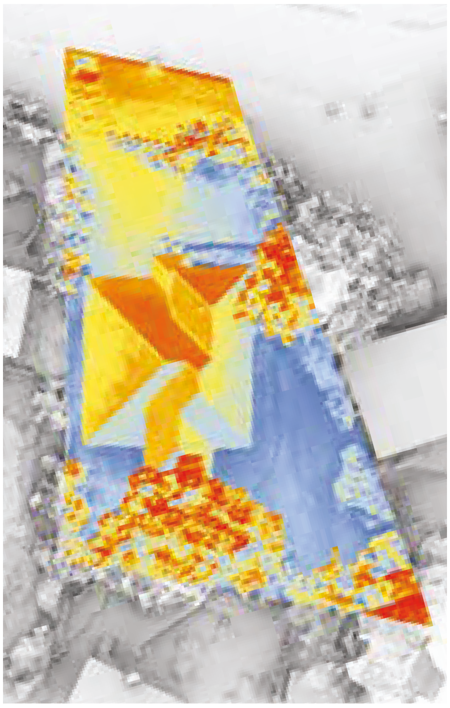


Summer

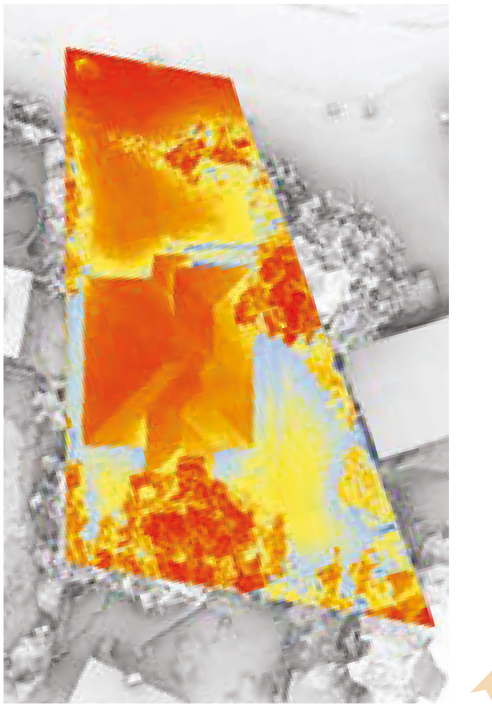
SOLAR IRRADIANCE

(kWh/m^2)

>5.72
5.15
4.58
4.00
3.43
2.86
2.29
1.72
1.41
0.57
<0.00



Winter



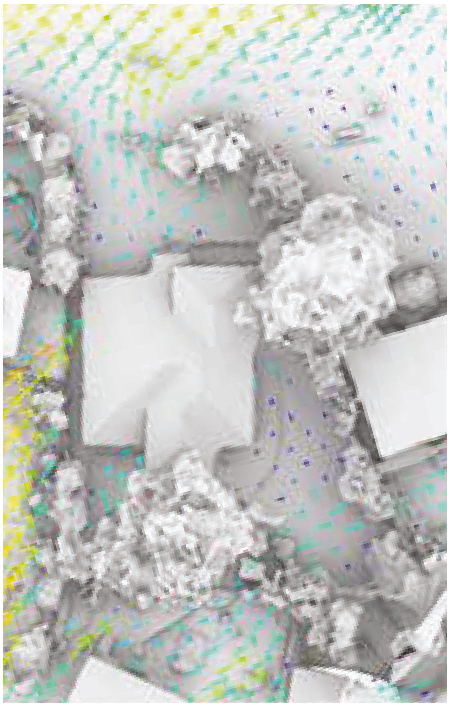
Summer

Fig. 07.02.15 Property-specific sun exposure [top], and solar irradiance [bottom] simulation results.

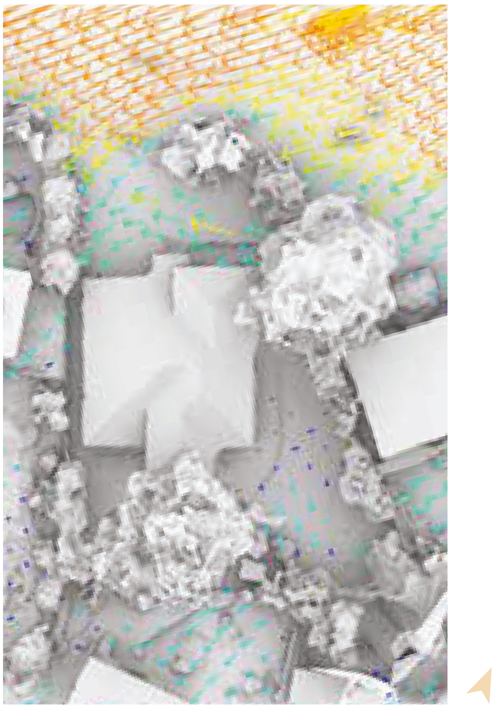
WIND SPEED

(m/s)

>15.60
14.04
12.48
10.92
9.36
7.80
6.24
4.68
3.12
1.56
0.00

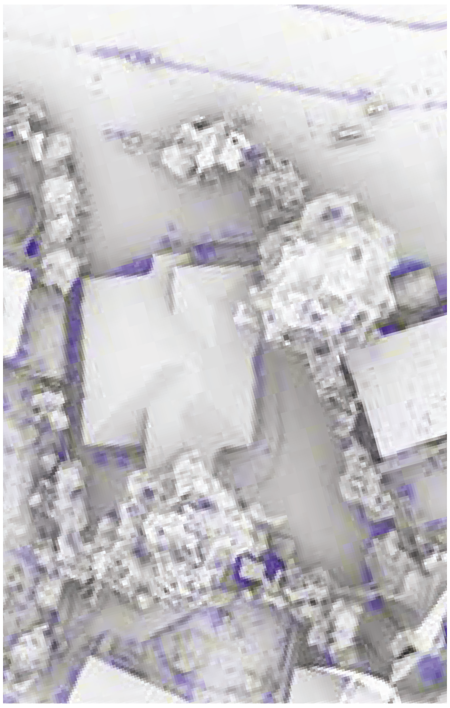


Winter



Summer

WATER FLOW & SATURATION



Water Saturation

Water Flow

Fig. 07.02.16 Property-specific wind [top], and water flow and saturation [bottom] simulation results.

FURTHER PLANT SUITABILITY VARIABLES: SOIL LANDSCAPE

SOIL CONSIDERATIONS FOR PLANTING

Soils have a significant effect on a plant's suitability to particular areas, influencing a number of growth characteristics of which certain plants will be more adapted to than others. These effects range from the growth rate of root systems, where more friable soils (coarse and crumbly) require rapid growth, to the ability for nutrient and moisture uptake (Passioura, 1991). Harder soils, for example, are much harder for root systems to spread and therefore 'forage' for water and nutrients, however their contact with the soil is much greater than that of friable soils, increasing the ability for uptake. Macropores (cavities within the soil that are large enough for roots to grow through) provide an anomaly in this rule, where even in harder soils, roots are able to grow and spread quickly by taking advantage of these pre-existing spaces. Sharing this space within macropore cavities, a variety of microorganisms, symbiotic and pathogenic, either share mutually beneficial relationships, or pose a threat to disease to the root systems, respectively (Passioura, 1991).

Beyond the physical structure of the soils, salinity and acidification are further considerations for the suitability of plants to certain soils, influenced by the mineral and salt content, with effects on the "structure, water movement, and microbial and plant diversity of soils" (Artiola et al., 2019).

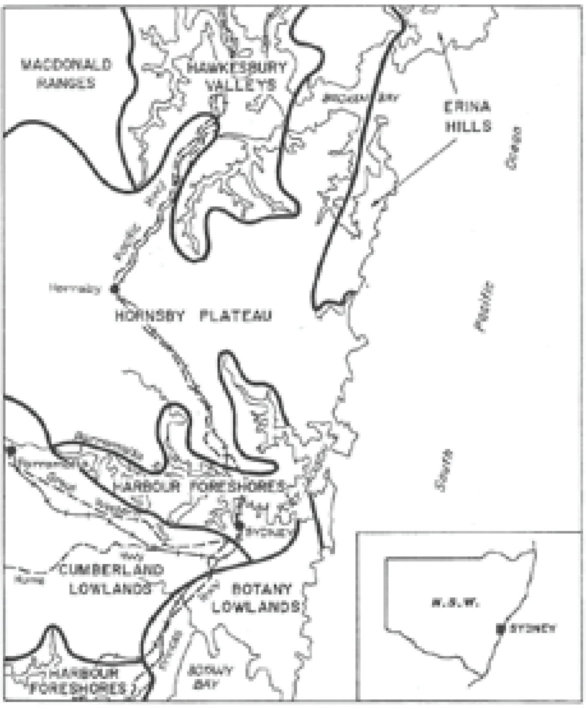


Fig. 07.02.17 Physiographic Regions of Sydney. Source: Chapman and Murphy, 1989

MAPPING SOIL LANDSCAPE

Soils are therefore yet another key consideration for planting into existing soils of backyards, however as outlined previously, a key limitation of point cloud data lies in it's inability to represent underground elements. As such, soil landscape is an area where traditional GIS datasets remain relevant in spatial mapping, and has been used on the following page to represent the soil landscapes of Willoughby LGA.

SOIL LANDSCAPES OF WILLOUGHBY

Willoughby LGA features soil landscapes from the five different geomorphic processes, with distinctly differing soil properties, characteristics, and vegetation qualities to be considered for ecological implementations into existing soils.

The following descriptions correlate to soil landscape mapping in Fig.07.02.19 on the following page.

Residual soils (REXX) are made of remnant material from "in-place weathering of [the] underlying material" (Kuna Raj, 2013). These soils are concentrated throughout the flatter extents and the higher topographies of Willoughby LGA, including the main Chatswood plateau, the Northbridge ridge-line, and ridges of Chatswood West and Lane Cove North adjacent to the Lane Cove River. Vegetation across each of these soil landscapes has almost completely been cleared throughout Sydney (Chapman & Murphy, 1989), once supporting tall open-forests (wet sclerophyll) and open-woodlands (dry sclerophyll), low eucalypt open-forests and woodlands with a sclerophyll scrub understorey.

Erosional soils (ERxx) are produced through a process where "soil and rock particles are worn away and moved elsewhere by gravity, or by a moving transport agent – wind, water or ice." (The Geological Society, n/a). These soils are prominent within the sloped topographies of Willoughby, on the hills below residual soils. Glenorie and Gymea soils, formerly supporting tall open-forest (wet sclerophyll) and sclerophyll woodlands, have since been extensively cleared primarily for urban residential land-uses, with the former also cleared for hobby farms and smaller rural subdivisions. Lambert soils, however, is predominantly uncleared, featuring lower vegetation communities such as open-heathlands, closed-heathlands and scrublands, as well as low eucalypt woodlands.

Colluvial soils (COxx), also called 'Colluvium', are "a superficial deposit transported predominantly by gravity containing <50% of material of >60 mm in size'… comprise[d] of dense, silty sand with many cobbles and boulders" (Parry, 2011). These soils are limited to the peninsulas of Middle Harbour such as Castle Cove, Middle Cove and Castlecrag, as well as the outskirts of Northbridge. The two colluvium found in Willoughby - Hawkesbury Sandstone (COha) and West Pennant Hills (COwp), support open woodlands (dry sclerophyll) and tall open forest (wet sclerophyll) vegetation communities, though with the latter, has been extensively cleared for land-uses ranging from open space, parklands, and reserves, to high density residential development.

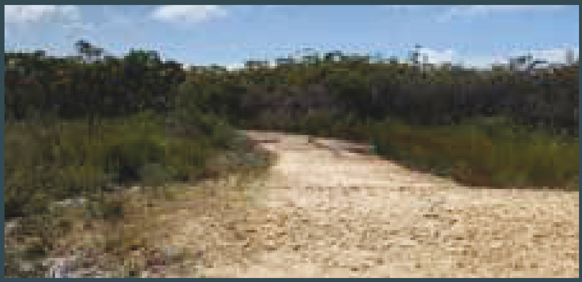
Aeolian soils (ALxx) are created through the "erosion, transportation, and deposition of sediment by the wind, occur[ing] in a variety of environments, including beaches, semi-arid and arid regions (e.g., cold and hot deserts), [and] agricultural fields" (Lancaster, 2005). Within Willoughby LGA, these soils are limited to the shores of the Lane Cove River along the western council boundary, with two varieties within the Quaternary sands geology, either containing parent material from Lane Cove (ALlc), or Deep Creek (ALdc). Vegetation for the Lane Cove soils includes wet sclerophyll forests and woodlands, with a high level of disturbance through landfill and human modification in the past.

Disturbed Terrain (DTxx) includes areas where the "original soil landscape is difficult to identify… [including] reclaimed estuarine flats, quarries, rubbish dumps and major commercial and industrial areas" (Chapman & Murphy, 1989). Classified as 'DTxx', these areas within Willoughby coincide with the industrial land-zoning of Artarmon, lands around the former municipal refuse incinerator built from 1933 to 1934, and sports fields of Artarmon Reserve and Shore School. Vegetation from this classification is almost completely cleared, but may include the presence of opportunist weeds within former commercial and industrial complexes. Other land uses include sporting and recreational areas, quarries and waste disposal sites.

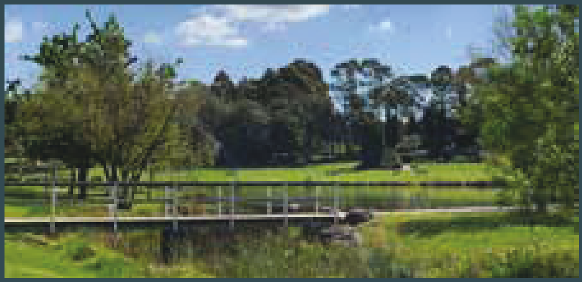
A

B

C



D



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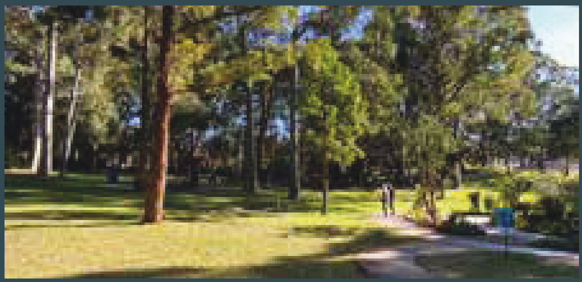


Fig. 07.02.18 Sydney soil and geological landscapes:
A) Birrong Alluvial of Sydney Olympic Park,
B) Hawkesbury Colluvial of Kamay Botany Bay NP,
C) Lambert Erosional of Ku-Ring-Gai Chase NP,
D) Glenorie Erosional of Galston, Sydney, and,
E) Blacktown Residual of Chatswood, Sydney.
Source: Author

Soil conditions have a significant effect on a plant's suitability to particular areas (when planting into existing soils), and will influence a number of growth characteristics of which certain plants will be more adapted to than others.

The implementation of local community nurseries introduces the potential for acclimatised species to be grown, suitable to both the unique climatic and soil conditions of the area.

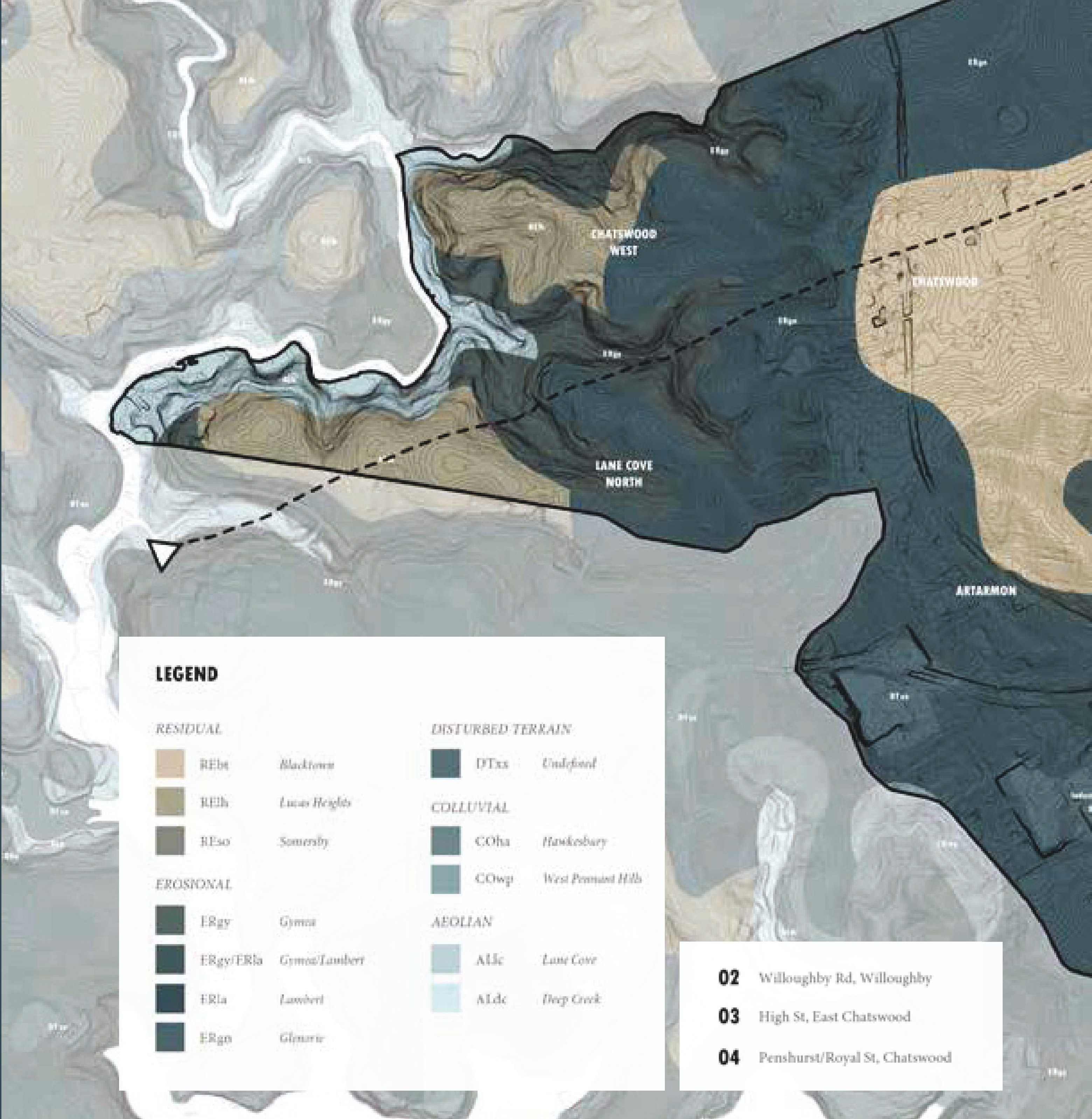
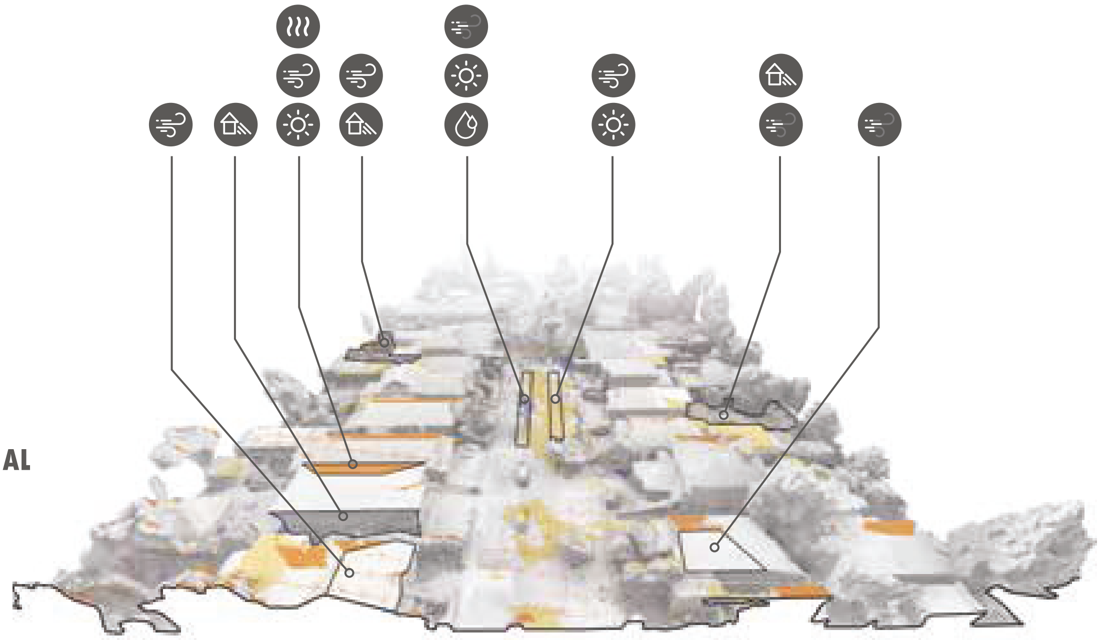


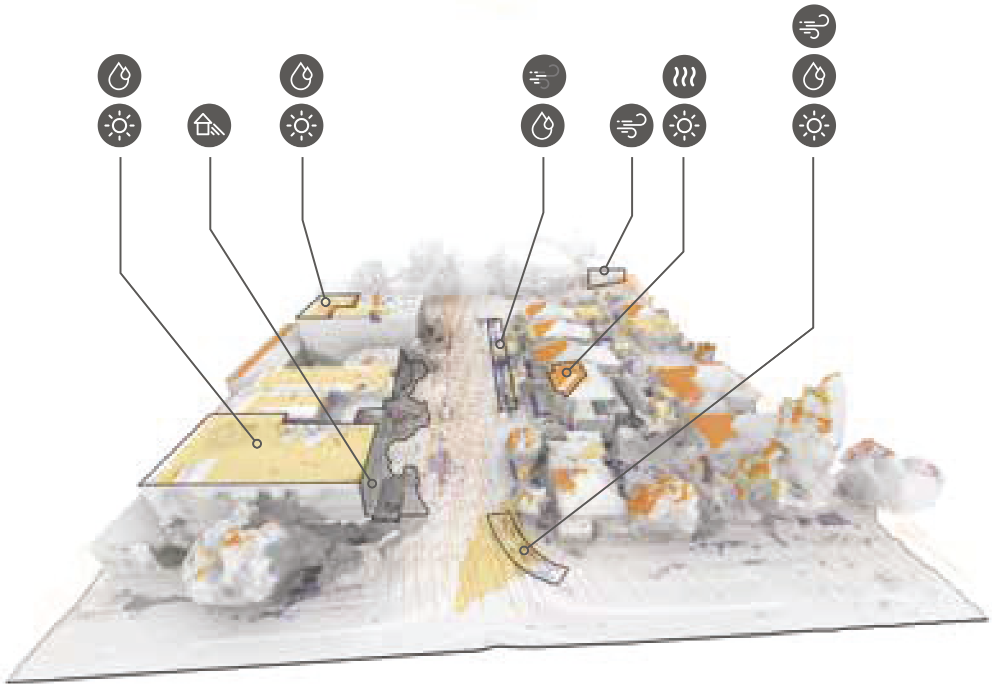
Fig. 07.02.19 Willoughby LGA Soil Landscape mapping and cross-section representing an informed judgment of below-ground geological layering


CASTLE COVE
03
04
MIDDLE COVE
CASTLECRAG
02
NORTHBRIDGE
T LEONARDS
WILLOUGHBY LGA
1:4 VERTICAL EXAGGERATION
6KM

RESIDENTIAL
Site 04



INDUSTRIAL
Site 03



COMMERCIAL
Site 02

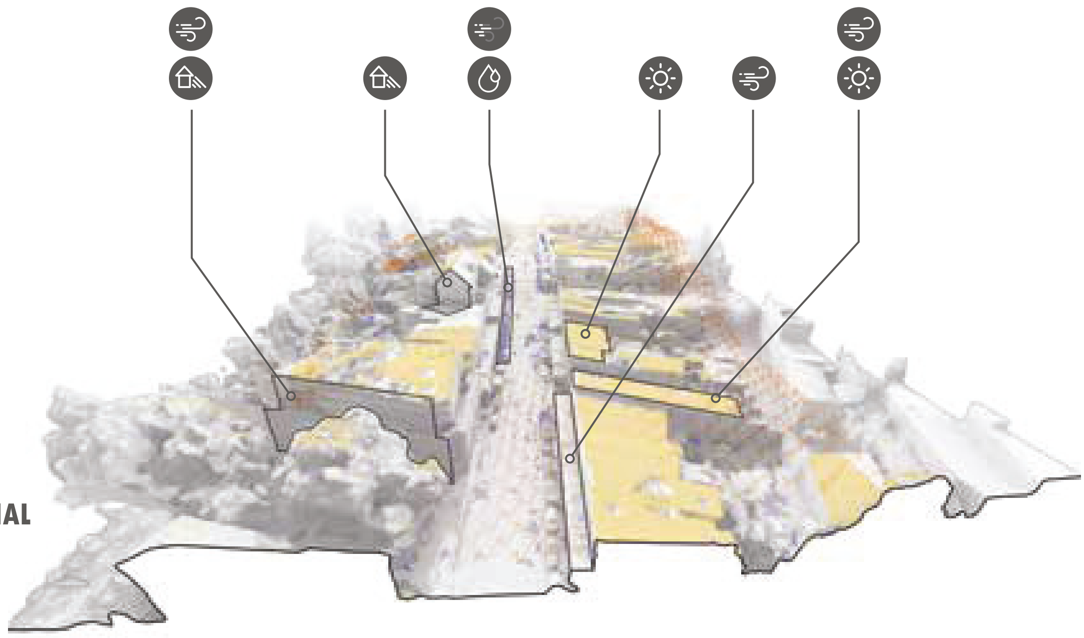


Fig. 07.02.20 Overlaying and distilling of individual micro-climate simulations, recognising a number of micro-climate typologies within areas of varied environmental factors.

DATA CONSOLIDATION

CONSOLIDATED MICRO-CLIMATE CLASSIFICATION

Simulation data was consolidated through an overlay method similar to that developed by McHarg, albeit with several major differences that overcome prior critiques of this process.

The progression from traditional GIS data to new 3D spatial datasets has enabled a novel degree of detail and complexity, enabled through a shift in scale to the street and property level. Overlaying environmental factors at these 'human' scales introduces the possibility for integration with socio-spatial and programmatic considerations - beyond just the tangible environmental GIS layers used by McHarg at a very broad and generalised scale. Ultimately, the more holistic approach enabled by new spatial datasets represents a less deterministic view than that of the overlay method, with inputs and considerations from both the top-down and bottom-up.

Micro-climate data was distilled and consolidated into Fig 07.02.20, represented in 3D to understand both the vertical and horizontal interactions between urban built-form and micro-climate factors. For the purpose of legibility, the main extremes and influences on plant growth were isolated, including full sun exposure and shade, highest areas of solar radiation, water saturation areas, light winds and strong winds. Each scene represents the characteristics and environmental considerations in a winter context, correlating with the socio-spatial analysis in the following section (07.03), which was undertaken in June 2020.

SUMMARY & DESIGN PRINCIPLES

SUMMARY

The results and success of this novel analytical approach proves that new 3D spatial technologies can indeed provide the highly complex, fine-grain environmental baseline that will strategically inform Green Mesh implementation, through responsive ecological interventions. This section of the chapter investigated a number of environmental planting considerations that focused primarily on achieving a methodology for the spatialisation of urban micro-climates, whilst recognising a number of other considerations that lie beyond limitations in either understanding, or the data itself, for the scope of the project.

Sun exposure, solar irradiance, wind and water conditions were each recognised as key individual micro-climatic factors that could be simulated through Grasshopper, spatialisating the intangible. Simulations were demonstrated across two scales, the street and the individual property, illustrating the scalability of this data and the ability to inform and interact with human-scale aspects of place - achieving a more holistic analytical foundation than McHarg's overlay method, whilst setting the scene for a far greater level of site specificity and responsiveness than demonstrated through the mapping of the SGG.

'Materiality' and 'soil landscapes' were also investigated and identified as key plant suitability considerations - yet could not be simulated due to the complexity involved, or the point cloud data limitations, respectively. Therefore, a manual process of materiality classification was used, though with future potential for this process to be automated through more complex algorithms or artificial intelligence (Ai). A more traditional GIS process was used for soil landscape mapping, with the broader-scale characteristic of this process better suited to the nature of geological representation.

DESIGN PRINCIPLES

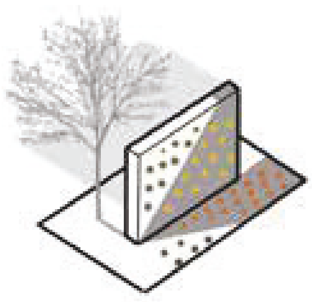
The following Design Principles provide a summary of findings for beneficial physical outcomes related to the theme of each of the four sections in this chapter, starting with urban micro-climate. These principles are intended to inform the physical implementation of the Green Mesh, ultimately producing a combined set of 24 holistic, best-practice principles to support the community in activating the Green Mesh strategy. They seek to promote widespread environmental sustainability and ecological integration, enabling many hands to facilitate efficient and unified environmental action across a large percentage of private lands.

The first six design principles were identified through micro-climate research and simulation testing. As such, these principles deal with the management of natural and environmental resources such as solar energy, wind, and water, and more specifically, how to address current urban challenges which have arisen due to the poor prior management of these factors.

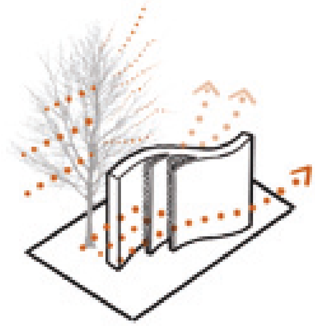
For example, the creation of shade within urban areas through increased canopy cover can lead to lower ambient temperatures, and a reduced impact of UHIs. Wind can be either be harnessed to promote air circulation and further reduce UHIs, or it can be buffered through hardy planting in areas to create a protected micro-climate for more fragile plants or a more pleasant lived experience. Water should be collected and maintained on-site, reducing reliance on centralised water sources such as Warragamba Dam for Sydney. This water can be stored or filtered through suitable vegetation, providing irrigation for green infrastructures and other planted areas. Finally, materiality can be used to support ecological considerations through an increase in surface permeability. Not only can this benefit water infiltration into below soils, providing water to nearby trees and plants, but also promote urban habitat for particular species such as native bees - which live in holes and crevices in tree trunks, logs or timber.

07.02

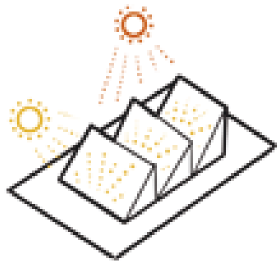
MICRO-CLIMATE & VEGETATION SUITABILITY - DESIGN PRINCIPLES



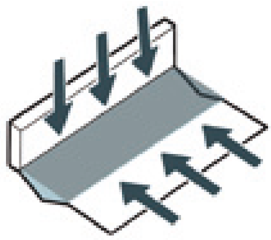
01. INCREASE URBAN SHADE & OPTIMISE PLANT SELECTION TO SUN EXPOSURE



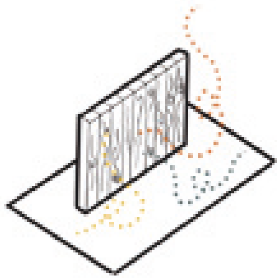
02. HARD & VEGETATED SURFACES FOR WIND BUFFERING OR VECTORING



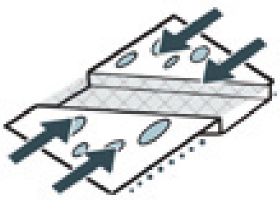
03. UTILISE SURFACES WITH OPTIMAL ASPECT & DIRECTION FOR SOLAR IRRADIANCE



04. LOCATE WATER RETENTION WITHIN NATURAL AREAS OF SATURATION



05. USE NATURAL MATERIALS THAT HAVE GREATER PERMEABILITY & ECOLOGICAL POTENTIAL



06. UTILISE SURFACE PERMEABILITY TO PROMOTE WATER INFILTRATION

01. Target species selection based on sun, wind, water and temperature requirements, along with green infrastructure suitability, whilst increasing urban shade through canopy cover

02. Treatment of wind responds to local needs, either buffering to increase protection and decrease evaporation, or vectoring wind to the benefit of soil aeration and urban air circulation

03. Harness winter solar radiation whilst reducing summer temperature stresses

04. Retain water on-site through swale and bio-retention for use in Green Infrastructure irrigation

05. Use of natural materials to encourage and accommodate species habitation and unplanned ecologies within imperfections

06. Introduce moments of permeable ground surfaces into harsh urban environments to moisten the soil and increase water retention

07.03 Socio-Spatial Interactions through Observation and Place Narrative

INTRODUCTION

A series of social-spatial studies were conducted across the six focus sites chosen within Willoughby LGA, including the three primary focus sites used previously for micro-climate simulation, and three supplementary sites to achieve a diversity of urban and suburban spaces. The aim of these studies was to understand and map the human-scale narrative of each site, represented through the actors and users, the programs and activities, and what urban or micro-climate elements were directly influencing these factors or creating a certain experiential quality. This glimpse into the social dimension and 'lived experience' seeks to offer a 'human' element to the intensity of quantitative simulation data presented in the previous section.

METHODOLOGY

Each of the six sites were observed for two separate 1-hour periods, at different times of the day, to begin understanding how the daily cycle of activities changes throughout the day. Notes and photographs were captured on-site, with annotations and sketches over a 3D birds-eye graphic [Fig. 07.03.01]. Raw field-notes and sketches can be found in Appendix 10.03. Observations focused on pedestrian activity within the space, and their interaction with other individuals and specific urban elements such as fences, bollards, footpaths, crossings, and vegetation. The main circulation paths were identified, with somewhat more interestingly, areas of congregation revealed, prompting thought on how small-scale green infrastructure interventions could be integrated into these situations to benefit both human program, and non-human ecologies.

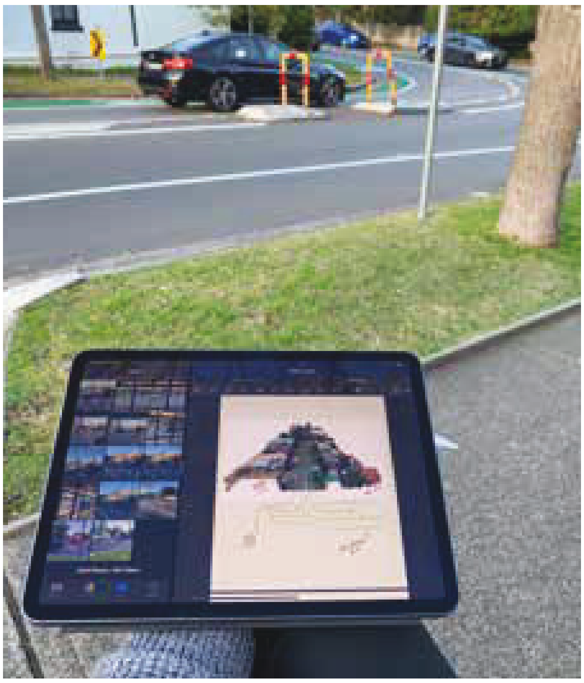


Fig. 07.03.01 Field observations were recorded digitally, annotated over 3D transect models and site photos. Raw field-notes are documented in the appendix.

"One of the things that strikes me about urban data and analytics are the remarkable blind spots... the lived experiences and the stories that are often missing into those [datasets]..."

- Chris Gibson (2020)

Spatial outcomes from this process were then superimposed on micro-climate mapping to identify any patterns or correlations, intending to reveal the urban conditions that subconsciously influence social interaction and behaviour - and therefore what conditions could be targeted specifically through the Green Mesh to promote liveability and sustainable human activities and programs.

This methodology is communicated through narrative and spatial mapping on the following pages, with a 'web of interactions' summarising the identified links between actors, programs, physical features, and experiential qualities (both positive and negative), in Fig. 07.03.09.

ACTORS AND PROGRAMS

As one of two main focuses of social observation on-site, 'actors and programs' represent the visible and directly evident individuals, demographics, activities and interactions that occurred. This was not only intended to establish an understanding for the specific requirements of the public domain at each site, but also as an initial point of focus to lead on to further discoveries.

The full list of observed actors and programs can be found in the appendix [Fig. 10.03.02-03], detailing the site/s where they were recorded, and at what time of day. With each site also associated to a specific land-use zone, this enables an understanding of how these actors and programs change through various times of the day when the site studies were undertaken, and whilst also reflecting how land-zones affect program as well.

EXPERIENTIAL QUALITIES

Experiential qualities are the intangible human reactions and emotions, both positive and negative, that are provoked through the inputs of all five senses in response to the surrounding environment. These invisible qualities, that subsequently influence the subconscious decisions and behaviours of actors on-site, can only be identified through being present in place, and have been communicated through written narrative. Once again, the 'web of interactions' reveal the connections to actors, programs, and physical features that lead to these experiential qualities in Fig. 07.03.09.

LIMITATIONS

The scope of on-site socio-spatial analysis was limited by both the relatively short duration of this research project, and the fact that this topic represents just one of many other components that have gone into the Green Mesh. Link some of the other components, socio-spatial analysis could itself form it's own research project to commit the maximum amount of time - however the initial exploration within this chapter is rather a 'proof-of-concept' used to develop the holistic methodological approach at an earlier stage.

Due to these limitations, particularly with the time limitation, it was recommended in early milestone feedback that a passive method of socio dimension studies should be adopted (as reflected through the chosen methods of this chapter rather than active communication with residents through surveys or interviews. The latter would have consumed too much time in developing the studies themselves, scrutinising them through an ethics lens, dispersing them to the community, and then waiting for or gathering responses. With more time, this approach could be used to gain a better insight into the usage of private lands that could be fed into the Green Mesh.

As with many scientific processes, repetition was used for each site in order to ensure results captured a broad range of scenarios, however, a final limitation were the COVID-19 lockdown restrictions that were lifted just before these studies were conducted, in the last two weeks of June, 2020. As such, it is recognised that a degree of abnormality may have been captured within socio-spatial analysis, due to diminished pedestrian activity in the streets and public spaces, social distancing restrictions, and other restrictions on public interaction and movement.

A series of social observation studies were conducted across the six focus sites within Willoughby LGA. Locations for these studies were varied to reflect a range of land-zone and built form characteristics, and subsequently the programs and users active within each.

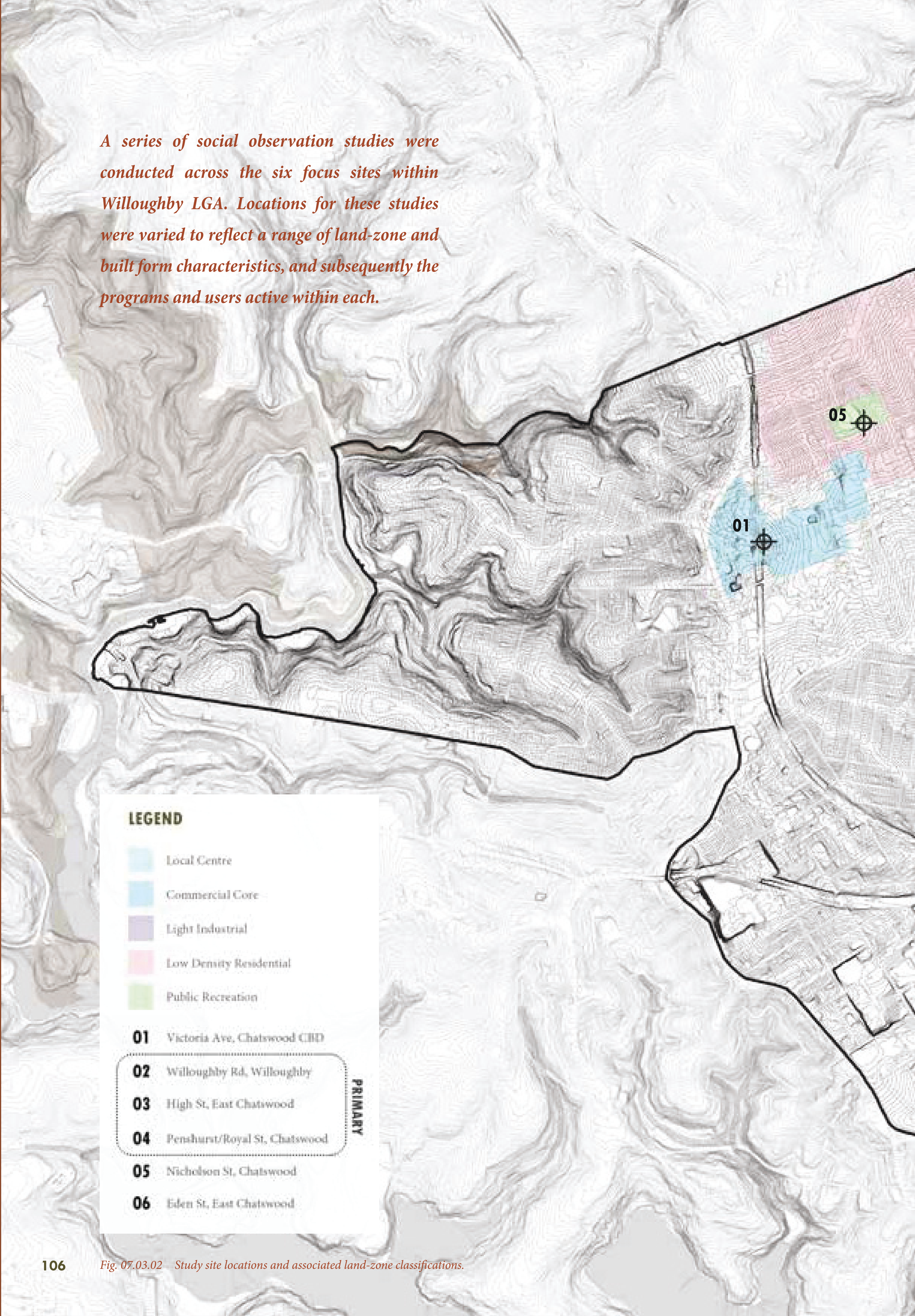
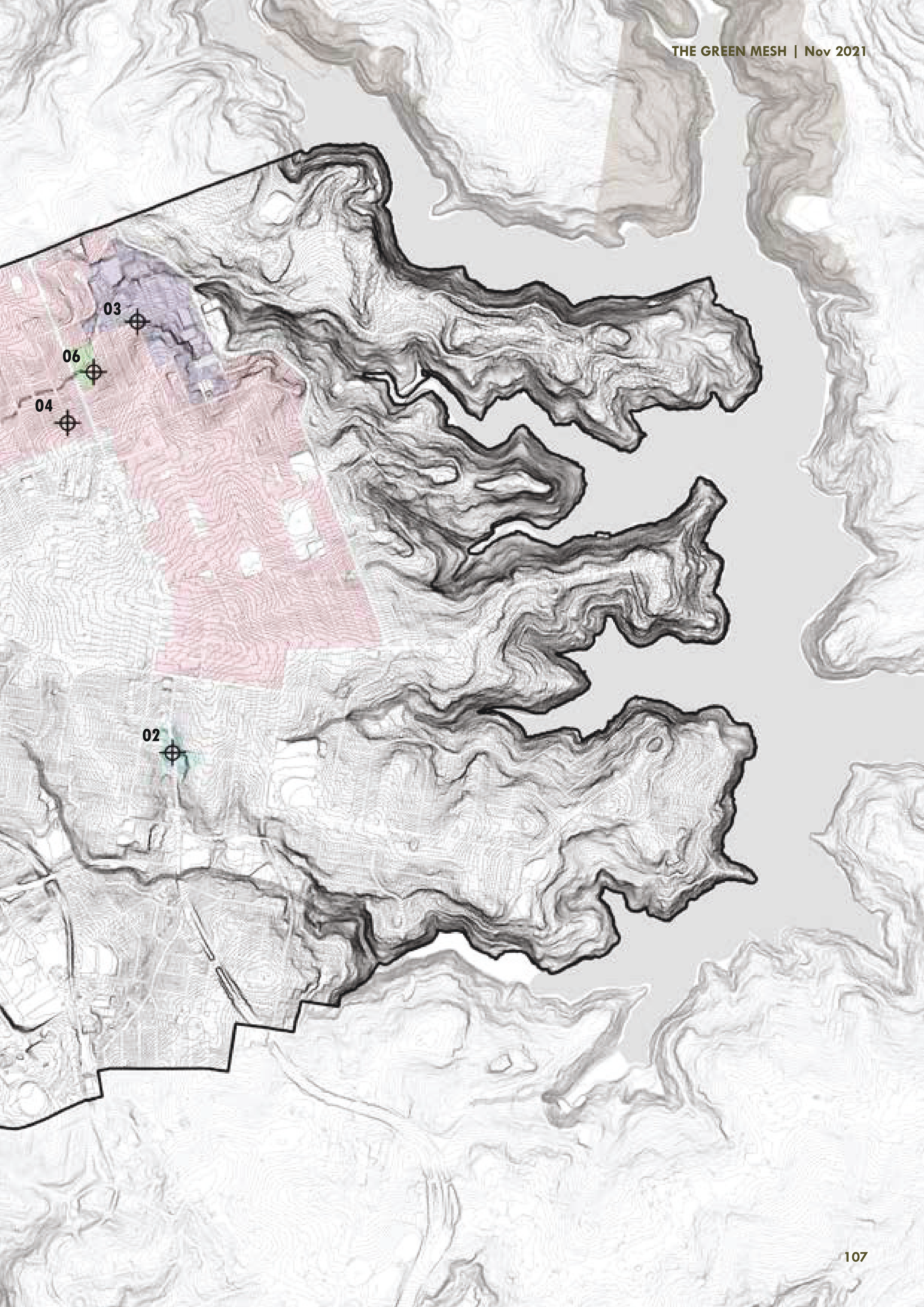


Fig. 07.03.02 Study site locations and associated land-zone classifications.


03
06
04
02

WILLOUGHBY RD, WILLOUGHBY

NARRATIVE OF SITE

Morning breaks. An orange gradient fills the horizon, contrasting a deep green backdrop of trees both near and far. Overhead, criss-crossed streaks of power-lines drape messily across the quiet road. Perfectly still within in the crisp, cool winter air.

Fig. 07.03.03 Site photos. Source: Author

Joggers and cyclists, in groups of two and three, make the most of the vacant footpaths at this hour, only halted as they intersect the main-street and it's increasing activity of commuter traffic, buses, vans and small trucks. They come to a stop at the lights, jogging on the spot, gathering their breath, and preparing for their turn to cross the street. They occupy their time by small, fleeting conversation within their group as the lights turn green, and their journey resumes. Underfoot, they transition from concrete to asphalt, to the safety of concrete once again, whilst contained either side by brick, metal and glass buildings - their 'enclosure' within the hard, man-made public realm, with movement dictated by a system of painted lines, signs and signals to keep both vehicle and pedestrian in check. Small hints towards nature and the natural environment are, similarly, contained within concrete pots and forced to morph and conform under the solid overhead awnings that cast the ground in shade.

The morning moves on, exercise gives way to the morning commute, as school-kids and office workers take their place in the streets. Local cafes are the first shops to open, offering relief off from the busy street, and beginning to draw an audience. Some customers spend time sitting, often alone in thought and contemplation, whilst others join the growing congregation at the bus stop nearby. The monotony of their day-to-day commute forces their gaze downwards towards their phones, as they wait, silently, for their scheduled bus to arrive. Before long the bus pulls up, and the crowd is once again reduced to zero.

A small local centre located along busy Willoughby Rd, enclosing pedestrians, cyclists and vehicles within it's containment of hard, impermeable materialities - with only fleeting or distant links to nature and ecology.

By the afternoon, still too early for office-workers to return, school-kids, construction workers, and younger families occupy the streets. Mothers and fathers accompany their eager kids, scootering along the footpaths, whilst to the side, a lone construction-worker appropriates a closed shop-front's doorstep as improvised seating, waiting by the street for a delivery of tools or materials. To his front, along the street, a constant turnover of cars park in the spaces along the road. Their drivers visit adjacent shops or pick somebody up, before driving off once again. Those that leave their vehicles in a rush, take their chance to cross the middle of busy street, using the cyclical pause in traffic at the lights to their advantage. Those that stay in their vehicle, keep an eye out for their passenger to arrive, taking part in spontaneous conversation with people they know who might walk past. Meanwhile, cyclist maneuvers through the now busy street, though unlike in the morning, this cyclist is not out for exercise but is instead delivering food. The volume of cars causes them to be cautious along the street, hugging the curb as they navigate parked cars, traffic lights, and bumps in the road surface.

Fig. 07.03.04 Willoughby Rd, Willoughby - Local Centre, pedestrian movements and stationary locations, with size of the latter indicating quantity of pedestrians.

HIGH ST, EAST CHATSWOOD

NARRATIVE OF SITE

A long, downhill stretch precedes a sweeping, 90 degree corner onto High St in East Chatswood. Delivered around this bend, a constant stream of cars encounter, navigate, and intersect pedestrians and road crossings, cyclists and cycle lanes. The latter, hesitantly maneuvering within the short, narrow section of dedicated cycle path, as traffic crosses into it, cutting the sharp bend. They proceed along a long, straight stretch of road, perfectly symmetrical, and flanked either side by a narrow nature strip of carefully mown lawn. Populating the otherwise 'barren' grassy patches of lawn, trees of all different shapes and sizes stand sporadically, struggling for water with the poor soils and limited runoff they receive.

Regular disruptions in these lawns are created by hard, concrete driveways, accessing a mix of original, historic and contemporary houses of residents as they prepare for the day. On the opposite side of the road, an eclectic mix of light industrial warehouses and mismatches commercial uses - automotive workshops, fitness gyms, gardening shops, and an animal hospital. The road as the boundary between residential, and industrial/commercial, facing-off to one another like a last-stand.

Fig. 07.03.05 Site photos. Source: Author

Light industrial warehouses oppose residential houses along the threshold of High St, East Chatswood. High winds are funnelled through the downward sloping street, as pedestrians, cyclists, and vehicles move and interact.

As the morning progresses, the actors are revealed, joining the early industrial workers. Parents load their kids into cars and leave for the school drop-off, pet-shop customers lead their cats and dogs in for a checkup, and a group of young men march their way to an 8am gym class. At a slower pace, the footpaths either side facilitate the morning strolls, and casual day-outings beginning to commence. Across the road, a woman seeking to cross the street, glances up and down, waiting for a break in the constant stream of cars. She takes an opportunist break in the flow, making it half-way across to the isolated and exposed centre island. The solid concrete and bright red and yellow painted metal construction revealing signifying its only functional purpose. By this time, a man heading the other way happens across the same island. They stand, distanced from one another, yet both marooned within the same urban island - once again waiting for their moment to complete the crossing.

Further down the street, residential homes give way to office-style glass facades, whilst industrial buildings become asphalt council parking, and a vacant lot. Spontaneous vegetation occupies cracks and creases in the former concrete slabs still evident across the site. Sunlight bathes these slabs, unobstructed from any nearby buildings, as the site sits, unmaintained, dilapidated, and proliferated by weeds.

Oblivious, commuters are drawn to adjacent bus stops - small congregations of school-kids and office workers, waiting patiently, dormant, for their buses to arrive. Some of them, anxiously peering up the street for the hope of its imminent arrival, whilst slow-moving traffic backs up from traffic lights down the road. Idle delivery vans, tradesman's utes, commuter cars, and small trucks each contributing to the unpleasant noises, smells and sounds of this experienced within the street.

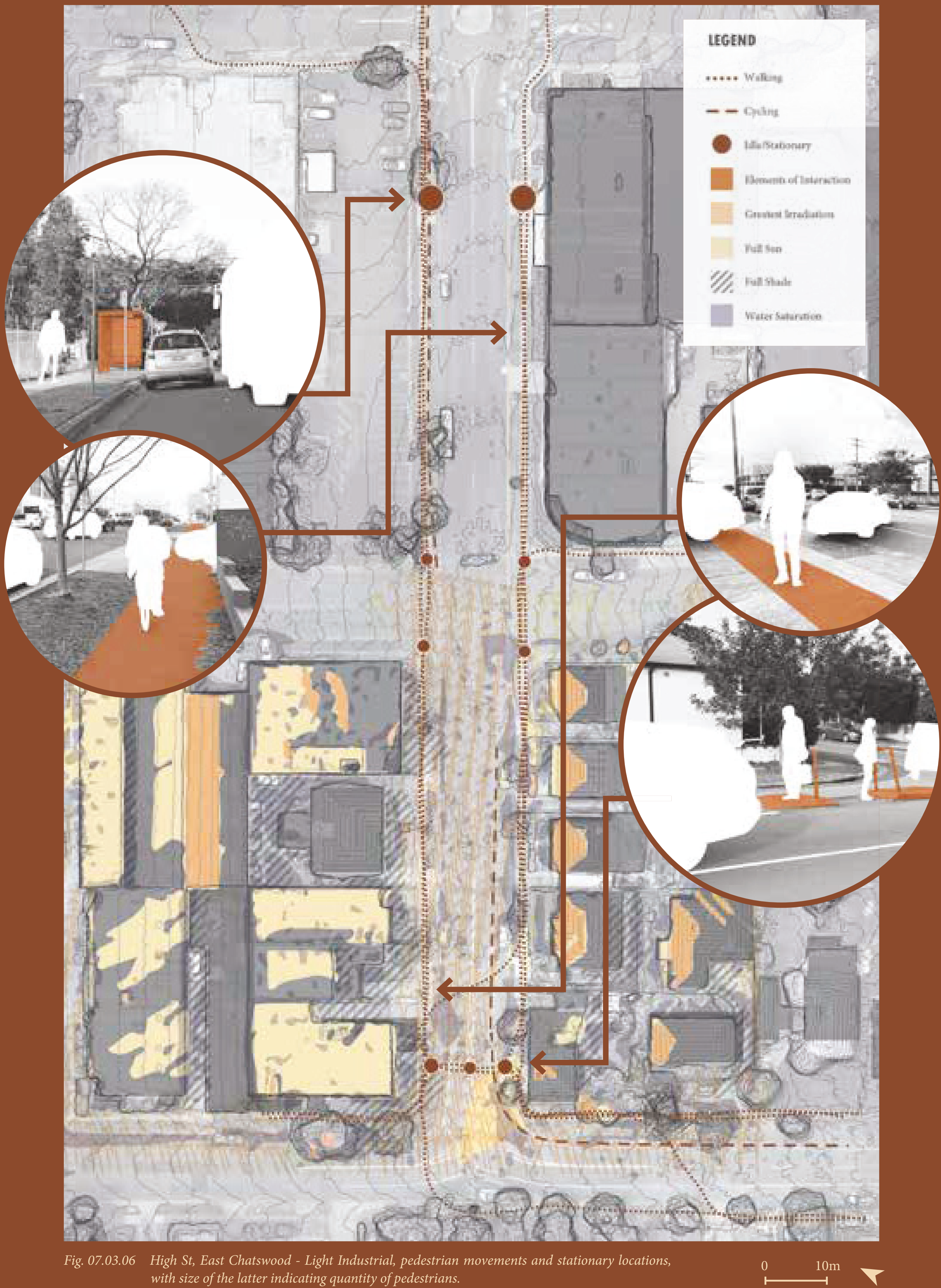


Fig. 07.03.06 High St, East Chatswood - Light Industrial, pedestrian movements and stationary locations, with size of the latter indicating quantity of pedestrians.

ROYAL ST, CHATSWOOD

NARRATIVE OF SITE

An early-morning shower casts a glossy sheen over this quiet, residential street. Cars, parked stationary, line the generous grassy verges dotted with vegetation of all shapes and sizes. Tall evergreen trees, with their dense, leafy canopy overshadow the thick, woody deciduous trees below, with their bare branches having shed for the winter. Their roots making the most of the light rainfall, as it filters through the canopy, through the grass, and into the soils below. Beyond the reaches of these soils, however, this rainfall follows a vastly different journey. The hard, harsh asphalt and concrete surfaces, impermeable, collect this water on their surface. Assisted by the engineered slope of the street, surface water is funnelled into neat streams along the gutters and underground, yet distanced from any roots or biological life by the solid, man-made pipes. This runoff, including road pollutants and debris collected along the way, find their exit into one of many local creeks and streams.

Further evidence of human activity within these streets, old furniture forms neat stacks on the verges, accompanied by broken wheelbarrows and heaters, used mattresses and rolls of carpet, and an assortment of smaller items, waiting for council collection. Before long, the stillness of this scene is broken by short animations of life. A lady walks her two inquisitive dogs, sniffing the grass on their journey along the path. A man wheels out the garbage bin, and a family of school-kids reluctantly follow their mother out to the car. The occasional delivery-van or vehicle makes its way along the street, searching for an address, or a suitable place to park.

One car pulls in to the kerb, taking the time to straighten up and adjust. After a short time, a lady steps out, a resident, making her way to the front door of her original brick home. Her attention is drawn as she lifts her head and greets her friendly neighbour, with a brief acknowledgment turning into a lengthy chat, and her movement across the verge coming to a stop at the white picket fence that bounds the property. As they speak, the soft winter sun emerges, casting dappled shade across the path, bringing with it a playful dance and a mesmerizing warmth.

Several doors up, two men enjoy a coffee as they overlook from their sun-bathed front patio. Enjoying the peaceful bird song and hush of wind through the trees in which they sit, their tranquility suddenly disrupted by the mechanical grind of lawn-mowers and hedge trimmers. A council crew, starting their days' route maintaining street vegetation - their highly choreographed and efficient motions making quick work of sculptures in which they create. Before long, they've loaded their truck once again and hurry off to their next destination.

Fig. 07.03.07 Site photos. Source: Author

A quiet, leafy residential street on a steady slope. A stormwater channel collects runoff at the lower end, whilst a mix of occasional joggers, dog-walkers and school-kids occupy the street during the morning, with fleeting moments of movement from front-door to car.

Fig. 07.03.08 Royal St, Chatswood - Low density residential, pedestrian movements and stationary locations, with size of the latter indicating quantity of pedestrians.

0 10m

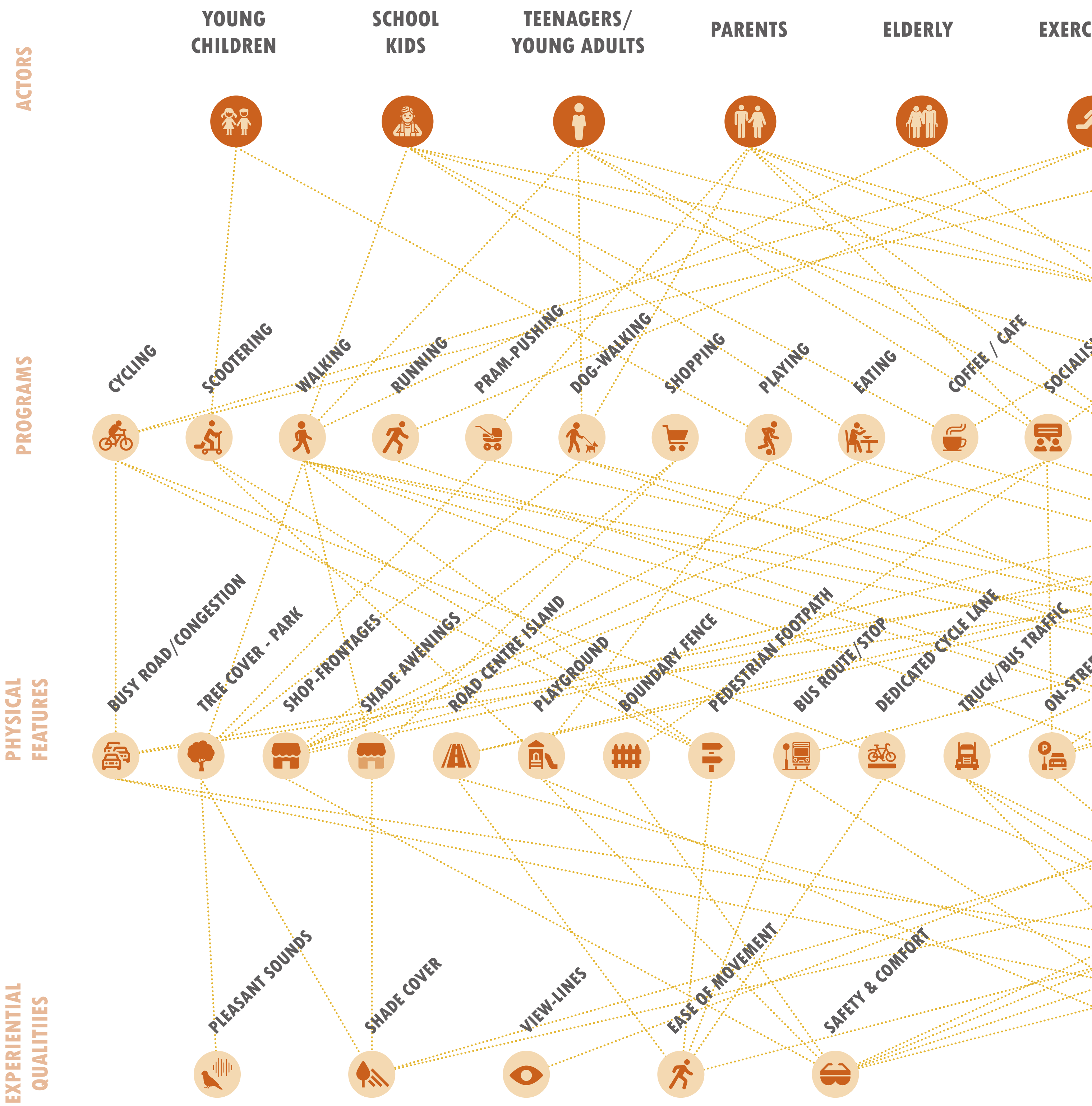
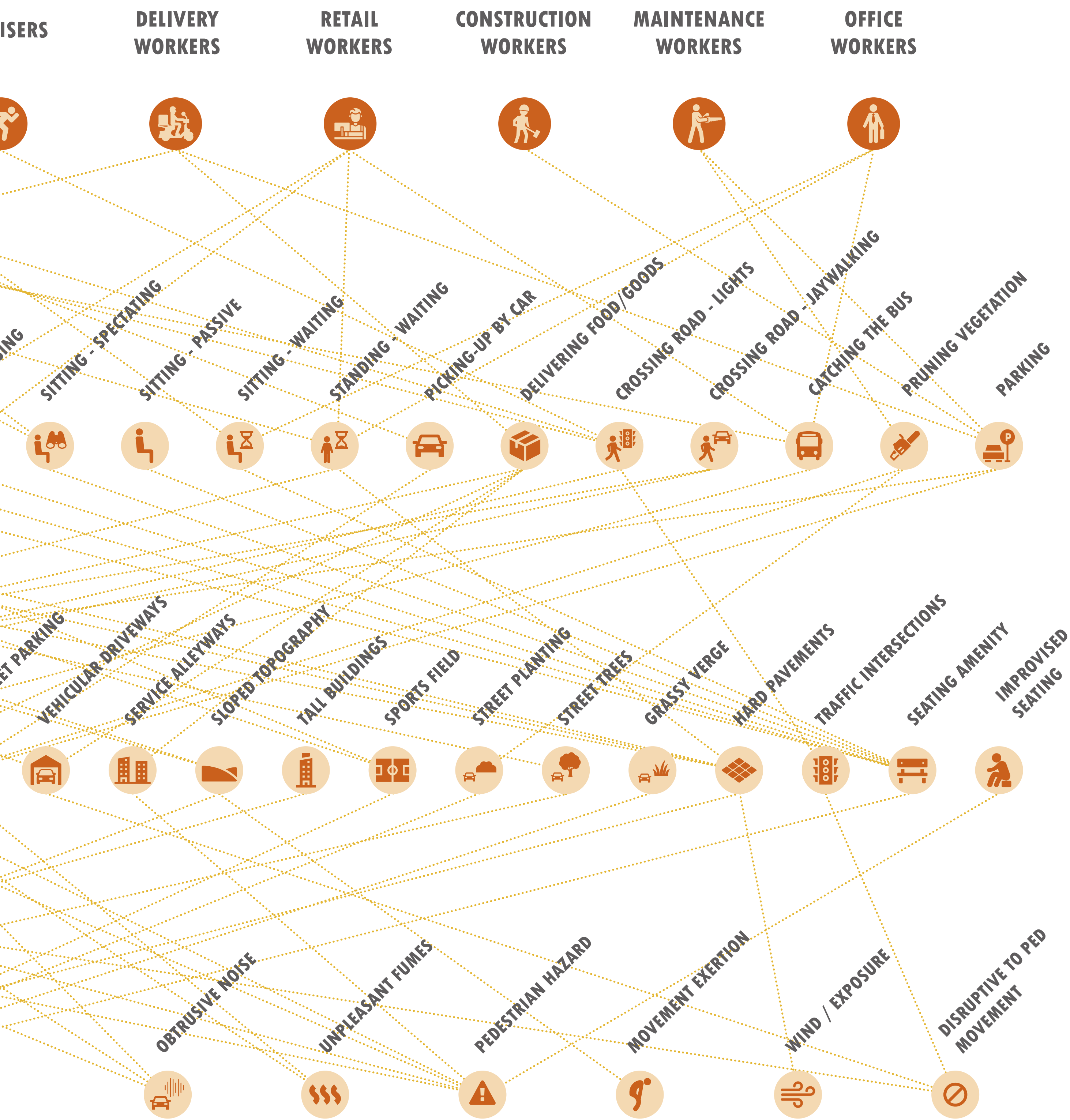


Fig. 07.03.09 *A summary of the socio-spatial interactions observed throughout Willoughby LGA. Within the time and capacity constraints of the project, site-studies were undertaken in Winter, 2020, within the months of June - July.* ***Raw site observation data is documented in appendix 10.03.***


DELIVERY WORKERS
RETAIL WORKERS
CONSTRUCTION WORKERS
MAINTENANCE WORKERS
OFFICE WORKERS
SITTING - SPECTATING
SITTING - PASSIVE
SITTING - WAITING
STANDING - WAITING
PICKING-UP BY CAR
DELIVERING FOOD/GOODS
CROSSING ROAD - LIGHTS
CROSSING ROAD - JAYWALKING
CATCHING THE BUS
PRUNING VEGETATION
PARKING
VEHICULAR DRIVEWAYS
SERVICE ALLEYWAYS
SLOPED TOPOGRAPHY
TALL BUILDINGS
SPORTS FIELD
STREET PLANTING
STREET TREES
GRASSY VERGE
HARD PAVEMENTS
TRAFFIC INTERSECTIONS
SEATING AMENITY
IMPROVISED SEATING
OBTRUSIVE NOISE
UNPLEASANT FUMES
PEDESTRIAN HAZARD
MOVEMENT EXERTION
WIND / EXPOSURE
DISRUPTIVE TO PED MOVEMENT

SUMMARY & DESIGN PRINCIPLES

SUMMARY

Six sites were observed over two, one-hour periods during different days and at different times, with each site chosen due to their distinctly varied character as hypothesised by their range of land zoning typologies. The main aim of this fieldwork was to gain an understanding of the social and human dimensions of each site, whilst at the same time, recognising any subconscious behaviours instigated through micro-climate factors or landscape elements.

In the end, landscape elements were observed to have a far greater apparent influence on the movement and behaviours of the individuals inhabiting these urban areas, with micro-climate factors being less evident in their influence, for the times of day that each area was observed. As these spaces would be the busiest during morning and evening peaks, these were the most common times of day that I used for the observation. At this time of day, it is likely that influences of the sun, for example, are much less relevant as, during these winter months, sunrises are later and sunsets are earlier, with an overall reduced exposure to sun throughout all sites, as one example of micro-climate influence.

Pathways, as a landscape element, were observed to have the greatest influence on the movement of individuals through the site, with outlying instances of people departing from footpaths mainly to cross a road, or access a parked vehicle. Furthermore, man-made elements such as bus-stop shelters as well as informal and formal pedestrian crossings were the most common places for individuals to stop and congregate.

DESIGN PRINCIPLES

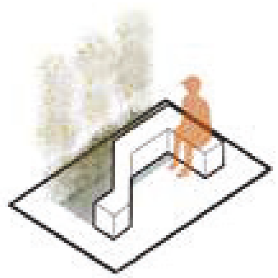
A further six design principles were established through socio-spatial observations, dealing with the topic of human interaction, and opportunities for the integration of ecologies within everyday activities. A product of analysis undertaken within the public realm, these principles are catered more towards council-implemented strategies, however is also applicable to publicly-owned land for shared community facilities, or community-based initiatives for private developers.

These principles range from specific opportunities for ecological integration into existing objects and structures in which people may be waiting at or interacting with in the public realm - such as bus stops and pedestrian crossings, to considerations for active transport and wayfinding to connect people to community Green Mesh facilities. One such example, local community nurseries would provide the opportunity for shared engagement between community members, with the unified goal of growing native or productive species for transplanting into nearby gardens. Whilst acting to raise awareness of the Green Mesh strategy within local communities, nurseries would also produce locally-acclimatised vegetation and provide support for each and every community member regardless of their financial situation, age, or ability - with the potential for sponsorship support from commercial nurseries. Urban beekeeping, another form of urban agriculture, can be applied within both private backyards as well as community facilities, supporting bee populations whilst pollinating the mesh of local wildflower or productive gardens.

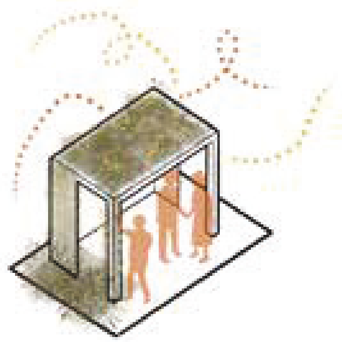
Fig. 07.03.10 Site 02, Willoughby Rd. Source: Author.

07.03

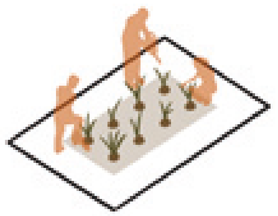
SOCIO-SPATIAL ECOLOGICAL OPPORTUNITIES - DESIGN PRINCIPLES



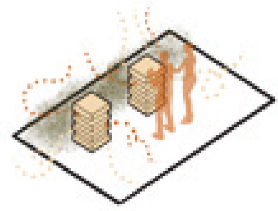
07. ECOLOGICAL SPACES FOR PEOPLE AND GATHERING



08. INTEGRATE ECOLOGICAL FUNCTION WITHIN COMMON PUBLIC ELEMENTS

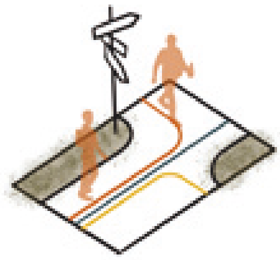


09. LOCAL NURSERIES TO PROMOTE A SENSE OF COMMUNITY AND SHARED RESPONSIBILITY



10. URBAN BEEKEEPING TO FACILITATE POLLINATION AND ATTRACT PREDATORS

11. ACTIVE TRANSPORTATION PATHS INTEGRATED ALONG LINEAR WILDFLOWER MEADOWS



12. WAY-FINDING AND SIGNAGE TO CONNECT PEOPLE WITH THE GREEN MESH

07. Vegetated urban spaces to facilitate small gatherings and congregation, connection to nature and awareness of natural resources

08. Small-scale urban agriculture within bus shelters and at pedestrian crossings, to occupy people whilst waiting

09. Community nurseries to educate and grow locally acclimatised plant stock, promoting a sense of community ownership and enthusiasm within tight, local neighbourhoods

10. Urban beekeeping to introduce and promote the pollination of flowering vegetation and broader ecological function

11. Active transportation cycle paths along urban wildflower meadows to promote a constant connection to nature, whilst supporting bee, butterfly, and native bird movement

12. Ground markings and signage used for wayfinding to community nurseries, urban micro-agriculture farms, and active transportation

07.04 Ecological Case-Studies informing the Vegetation Matrix

INTRODUCTION

This section of the chapter presents several case-studies of ecologically diverse and significant sites throughout Sydney, including wildlife protection areas, parklands, reserves, nurseries, and green infrastructure projects. The aim of this fieldwork was to understand and identify vegetation species to create a Vegetation Matrix, informing species selection of the Green Mesh. As a result, hundreds of native and exotic species have been distilled and classified into one of seven planting typologies, each offering a unique ecological or programmatic opportunity for public and private ecological implementations.

The Vegetation Matrix forms a crucial component of the Green Mesh, linking between qualitative micro-climate data and the physical implementation of suitable vegetation species within backyards. Selected species' are detailed by their micro-climatic growing preferences, and can therefore be directly associated with simulation data presented in 07.02. This establishes a highly responsive methodology for strategically locating certain plant species within a backyard or lot, ensuring their suitability to where they're planted, and the possibility for this 'tool' to be used by community-members within the Green Mesh platform.

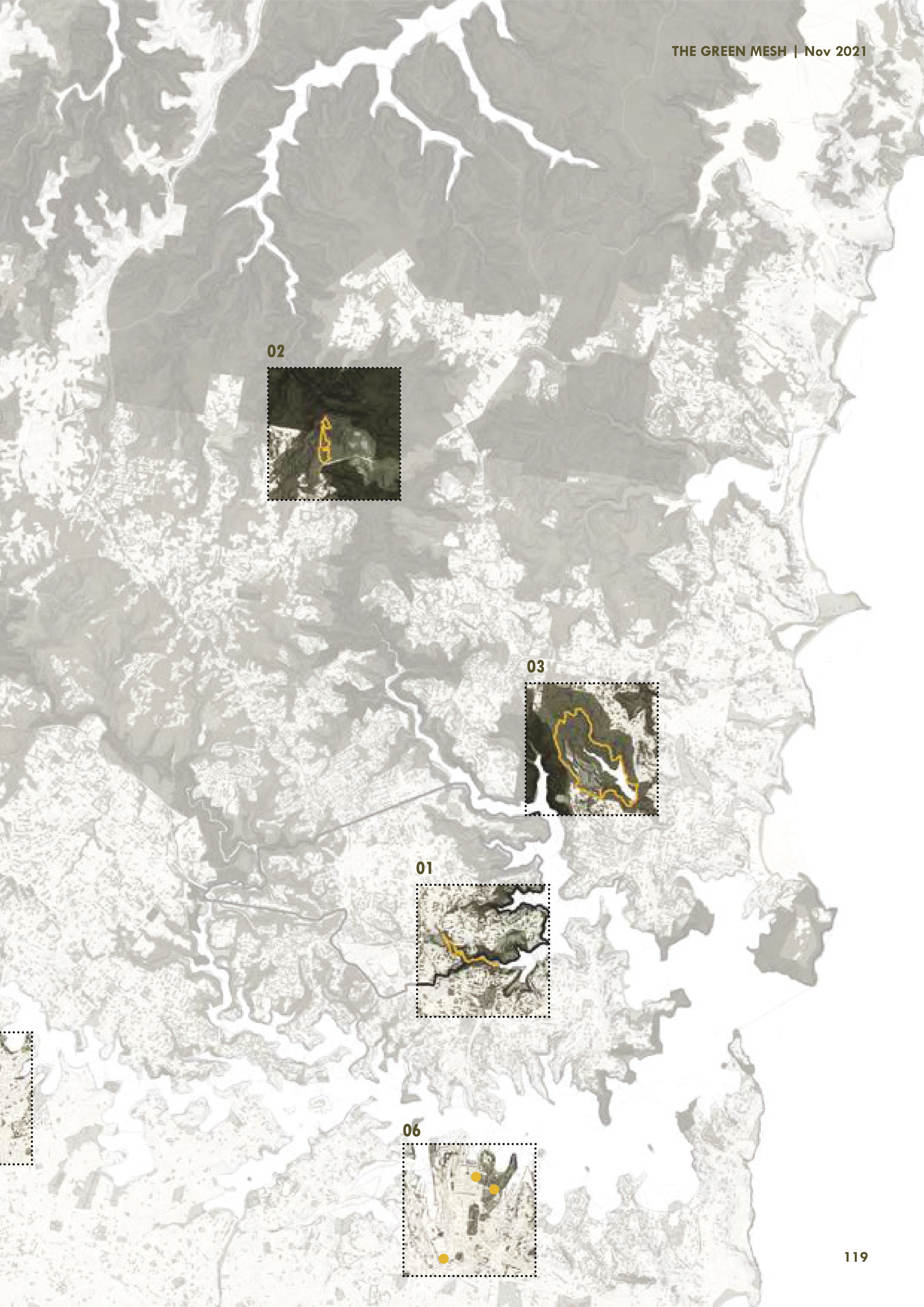
Responding to the unique ecological considerations between different LGAs, the Vegetation Matrix is a component of the Green Mesh that can be tailored and adapted from place to place. LGAs will therefore have the ability to include specific locally threatened species within their unique matrix, encouraging communities within their area to plant these species and establish an ecologically restorative urban and suburban landscape.

Case study sites are located in Fig. 07.04.01 adjacent.

"A lack of proven plant species suited to Australia's harsh climate is one barrier to the uptake of green infrastructure in this country... [with plants needing to] withstand stresses of high temperature, wind and water deficit while providing good vegetation cover"

- Perkins et al, (2012)

Fig. 07.04.01 Local Ecological Case Study Sites


02
03
01
06

01. FLAT ROCK GULLY, NORTHBRIDGE

4.43km
87m Elev. Gain

Willoughby LGA features a range of diverse vegetation communities suited to different landscapes, soil conditions and sun exposure. The higher ridges of Chatswood, Willoughby (suburb), Artarmon and Naremburn feature a clay-rich, fertile soil, formerly occupying extensive Blue Gum High Forests of which only scattered remnants remain, due to the clearing of land for urban development. Vegetation include Gums, Blackbutt, Turpentine, Smooth-Barked Apple, Sydney Peppermint, Red Mahogany and a range of understorey heath and bush shrubbery. Sandstone is dominant throughout lower creek lines, gullies and tidal flats, along with ridges close to Middle Harbour and the Lane Cove River. These environments feature Gums, Bloodwoods, She-Oaks, Banksias and Wattle, and a range of ferns, Coachwood, Swamp Oak, Common Reed, Rushes and Paperbark, respectively (Willoughby City Council1, n/d). Amongst these diverse vegetation communities, three particular communities are classified as threatened; Saltmarsh (Estuarine Complex), occurring around the median tide level within low energy, brackish environments; Blue Gum High Forest, occurring along ridge lines now occupied by housing and road developments; and finally, Sydney Turpentine-Ironbark Forest, a transition zone occurring on downslope areas of shale derived soil (Willoughby City Council[4], 2015). These communities have seen significant fragmentation as a consequence of urban development, with "nearly 90% of the land [that] has been cleared for development" (Willoughby City Council3, n/d), not only having an adverse effect on the resilience and health of these individual remnants, but also on the habitat connectivity and quality for approximately "200 species of native vertebrate animals" (Willoughby City Council[3], n/d).

Flat Rock Gully represents 14ha of this remnant forest, along a creek-line that captures rainwater runoff from surrounding suburbs of Artarmon, St Leonard's, Crows Nest, Willoughby, Naremburn, Northbridge, and Cammeray. Along with a diversity of natural and cultural heritage, the area of bushland is also a Wildlife Protection Area, home to native and migratory fish, birds, reptiles (such as Water Dragons), frogs, macropods (including Wallabies) and marsupials (including Bandicoots). Furthermore, Flat Rock Gully is also a (non-continuous) habitat linkage connecting numerous local parks, with a dominant Hawkesbury Sandstone geological foundation. The vegetation community dominant for this area, Coastal Sandstone Foreshore Forest, consists of large trees, predominantly Smooth barked apple (Angophora costata), along with small trees and shrubs including Sweet pittosporum (Pittosporum undulatum), Cheese tree (Glochidion ferdinandi) and Blueberry ash (Elaeocarpus reticulatus), above a shrub layer and ground cover consisting of ferns, rushes and grasses (Willoughby City Council[2], 2018).

As illustrated by Fig. 07.04.03, this relatively short tributary to Middle Harbour features a vastly changing character along it's extent. From the upper-end (A) through to it's exit (E), Flat Gully Creek not only gets wider as more water is collected, but a significant amount of pollution and rubbish is collected too (B). Evidently, infrastructure is in place to prevent this pollution from making it further down the system (C), leading to cleaner waters in downstream.

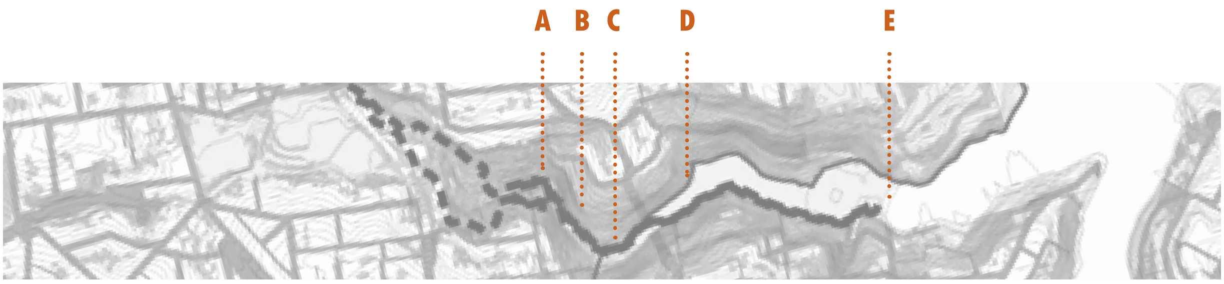
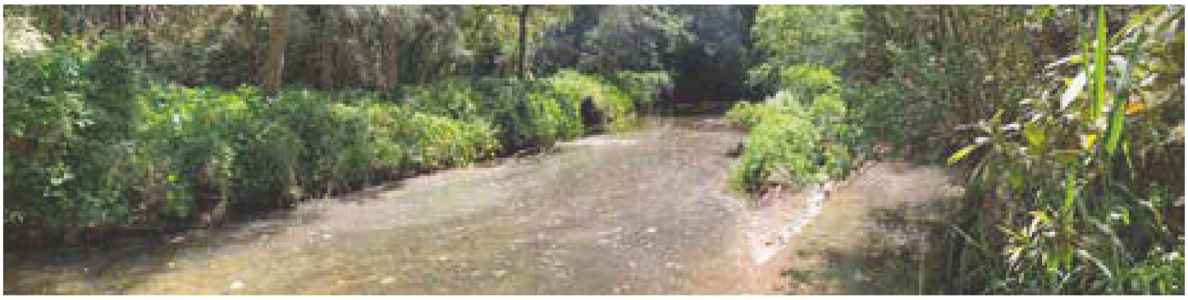


Fig. 07.04.02 Locations of key changes along the creek, aligned with images on adjacent page.

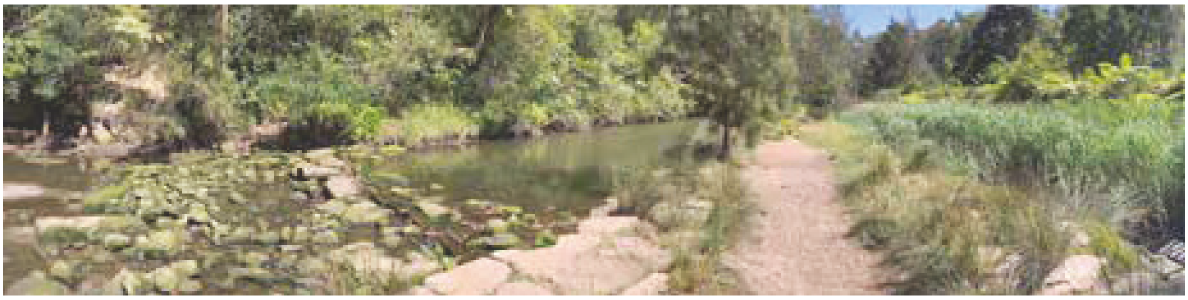
A

B



C

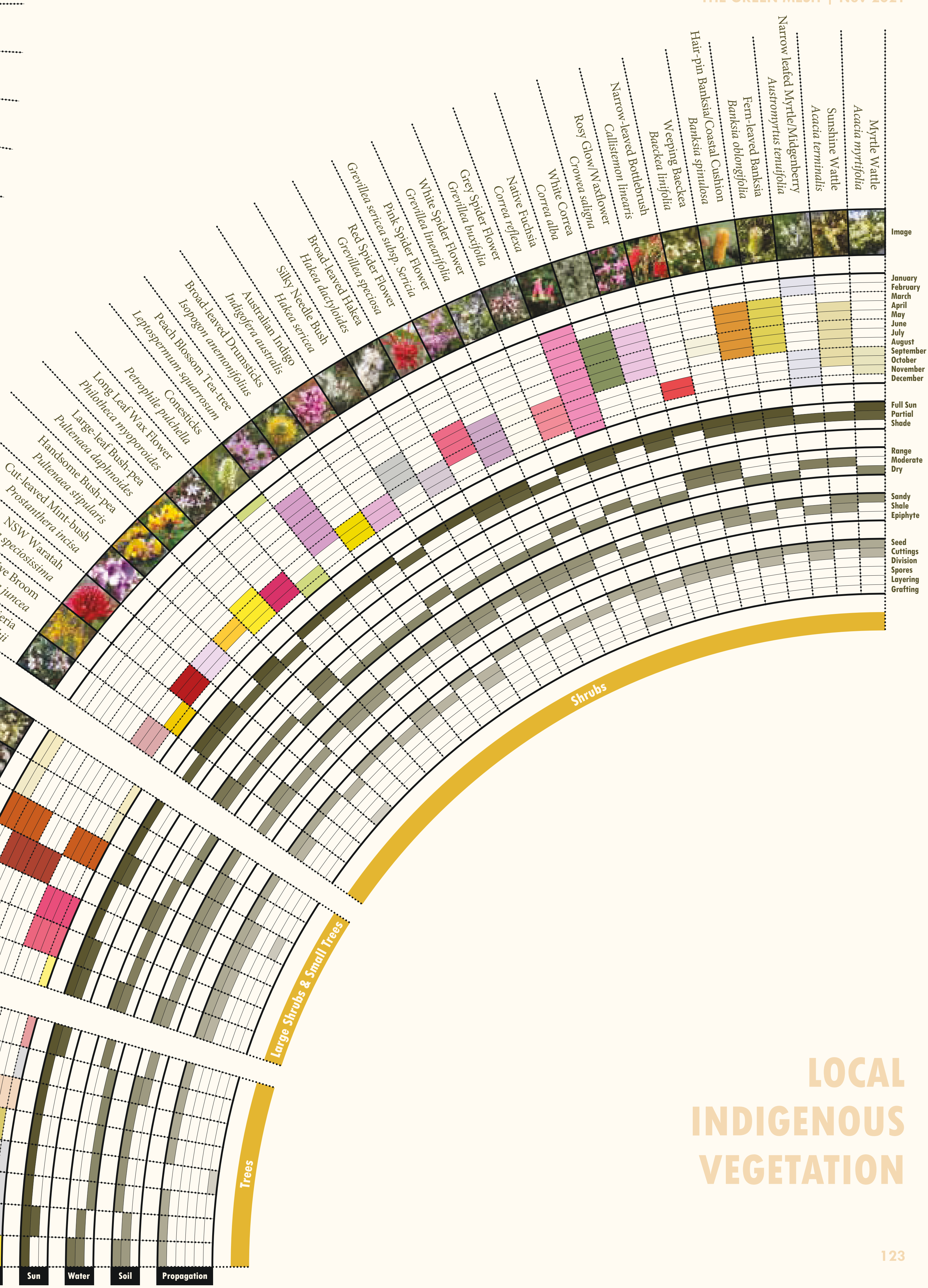
D



E

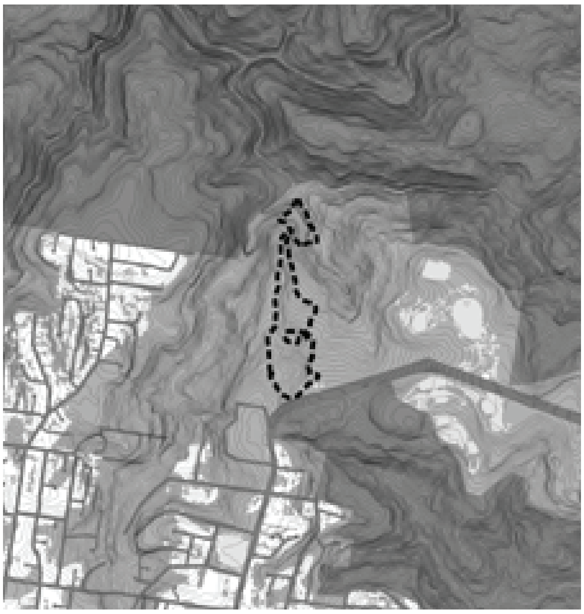
Fig. 07.04.03 Rainwater runoff from local suburbs of Artarmon, St Leonard, Crows Nestm Willoughby, Naremburn, Northbridge and Cammeray wash into Flat Rock Creek as it gradually swells from A through D, to where it exits into Middle Harbour at E. Pollution and rubbish seen in B is collected at C to try and clean the water before it reaches the harbour. Source: Author, 2020.

Fig. 07.04.04 Vegetation Matrix for Indigenous Australian Plants suitable for planting in backyards. Data source: Willoughby City Council (n/d)[5]. Additional plant information sourced through; GardensOnline (n/d), Gardening With Angus (n/d), Plant This (n/d), Australian Native Plants Society (Australia) (n/d), PlantNET (n/d), Atlas of Living Australia (n/d), Wrigley. W. J. and Fagg. M. (2013), Fairley. A. and Moore. P (2010).



LOCAL INDIGENOUS VEGETATION

02. KU-RING-GAI WILDFLOWER GARDEN



3.89km
159m Elev. Gain

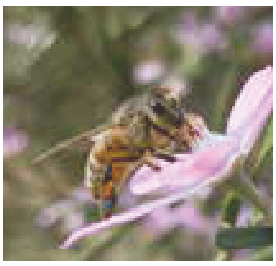
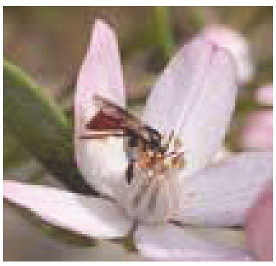
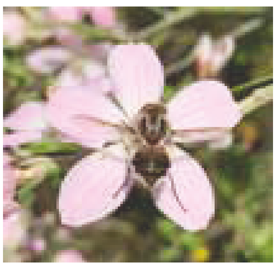
Ku-Ring-Gai Wildflower Gardens are located adjacent to the Ku-Ring-Gai National Park in Sydney's north. It features 123ha of native and wild gardens, established in 1968 with the purpose of growing "plants from all parts of Australia for preservation and public display" (Ku-Ring-Gai Council, n/d). As such, my site visit to the gardens in early Spring 2020 aimed to inform the basis of native vegetation within the matrix, with a specific focus on flowering vegetation that would offer valuable ecological habitats for bees, butterflies and other pollinators.

As an extension of the same ridge-line on which Willoughby LGA is located, Ku-Ring-Gai council features many of the same ecological communities, climatic characteristics, and threatened species to that of Willoughby to its south. Two threatened ecological communities in particular are featured within the wildflower gardens; Duffys Forest and Coastal Upland Swamp, including 18 threatened species of flora and fauna. In addition to these communities, the wildflower gardens include a diversity of environments from heathlands to tall forests, sandstone outcrops, ponds, gullies and waterfalls - monitored and maintained by rangers and volunteers from the Australian Plants Society. These vegetation communities demonstrate a range of strategies for attracting and supporting native fauna, replicable through backyard planting.

These strategies and benefits include:

- Planting local native species' that are adapted to the soils and climate of the area, which therefore require less maintenance than exotic species.
- Planting to attract a wide diversity of birds, bees, butterflies and other wildlife, supporting the co-existence between flora and fauna. This can be achieved through a variety of colourful flowering species, as well as nectar producing plants.
- Establishing a range of opportunities for shelter, including hollow logs, flat and overhanging rocks, dense shrubbery, and nesting boxes.
- Providing a variety of vegetation heights and covers, including trees, shrubs, ground covers, and grasses. This will support wildlife through shelter and nesting opportunities. Invertebrates may also nest in leaves, stems, decaying matter at ground level and the root system.
- Mulching your garden with leaf litter and prunings to discourage weed growth and retain water.

(Source: Ku-Ring-Gai Council[2], nd)

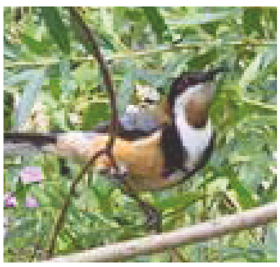



Fig. 07.04.05 A variety of bees, other insects, and bird species observed at Ku-Ring-Gai Wildflower Gardens, attracted to the native vegetation species of the gardens - 8 September 2020. Source: Author, 2020.

Fig. 07.04.06 The display of freshly collected native flower specimens at the Ku-Ring-Gai Wildflower Gardens - Australian Plants Society North Shore Group, taken 8 September 2020 at the start of Spring. Source: Author, 2020.

Illustrating the diversity of native flowering vegetation, volunteers from the Australian Plants Society maintain and update a daily display of fresh flower specimens taken locally within the gardens (shown above). Specimens are identified and labeled, providing a dynamic display of colour and seasonality through the inclusion of genera including Epacris, Westringia, Acacia, Pittosporum, Boronia, and more. Colours range from light to dark pinks, through to whites, yellows and reds, each contributing to the biodiversity of fauna that are potentially attracted.

Implementation of many of these native species into backyards is supported by the on-site nursery, providing locally acclimatised and seasonally-specific vegetation stock. Plants are propagated by staff through using local seeds and cuttings, preserving adaptations specific to the area whilst maintaining genetic diversity (Ku-Ring-Gai Council, n/d).

Fig. 07.04.07 Native australian bees emerging from their hive within the Wildflower Gardens

03. MANLY DAM, ALLAMBIE HEIGHTS

9.10km
219m Elev. Gain

"Manly Dam Reserve has over 300 native plant species and 18 different orchids. It includes various vegetation communities like bloodwood, scribbly gum, silvertop ash, stringy bark, red gum, peppermint woodlands and heath species of banksia, grevillia and hakea to name but a few." - Roberts et al, 2019

Located adjacent to Willoughby LGA, on the opposing side of Middle Harbour, Manly Dam Reserve is a 377ha state park and protected bushland amongst residential areas of North Balgowlah and Allambie Heights. Created by the damming of Curl Curl Creek in 1892, the water body is the largest freshwater lake in Sydney, supporting 300 native plant species (Roberts et al, 2019), animals, and a number of threatened species, amongst various human recreational and leisure activities.

Traditionally, the area was a valuable source of materials for the local Gayemagal people, allowing them to make tools, fishing nets, gum or glue, medicine, weapons, shields, coolamons and canoes… [as well as] material for spiritual practices and ceremony" (Roberts et al, 2019). It also provided a significant source of food including "grubs, honey, sweet bool from the flowers, possum, snake, goanna, wallaby and the fresh water resources of ducks and water hens and their eggs, freshwater yabbie, mussels, turtle and fish" (Roberts et al, 2019). Evident to the Aboriginal activities of the area, are the "76 known Aboriginal sites on the shores [of Middle Harbour]… a combination of rock shelters, middens and rock art" (Visit Sydney Australia, n/d). Along with Manly Dam, these sites are located throughout Castle Cove, Castlecrag, Middle Cove, and Northbridge – all suburbs within Willoughby LGA.

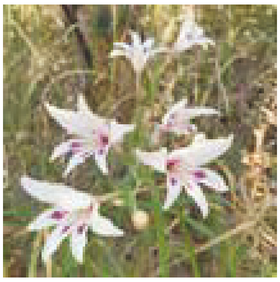
Since European settlement, Manly Dam has seen "historical significance for it's role in the historical development of Sydney's water supply… [along with] technical significance… for its pioneering strengthening methodology which was developed for this dam… [and] local aesthetic value." (NSW Office of Environment & Heritage, n/d).

Due to this cultural and environmental significance, whilst being in close proximity to residential properties and urban runoff, my visit to Manly Dam Reserve provided additional diversity to the selection of flowering species along with those from Ku-Ring-Gai Wilflower Gardens. The management of ecosystems at Manly Dam provides an example of how in spite of increased urban stresses such as weed infestations and excess nutrient pollution (the product of fertiliser runoff, road surface pollutants, spills and leachate from old tip sites further up the catchment), native vegetation and ecologies can thrive and provide valuable habitat to a wide range of animals and insects.

Species from Manly Dam Reserve and Ku-Ring-Gai Wildflower Gardens were consolidated into the 'Native Flowering Vegetation' component of the Green Mesh.


Flannel Flower
Actinotus helianthi


Sago Flower
Ozothamnus diosmifolius


White Marianth
Rhytidosporum procumbens


White Spider Flower
Grevillea linearifolia

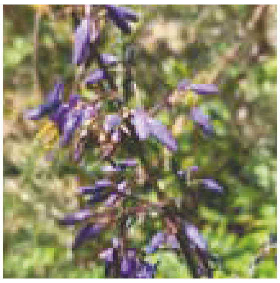

Red Spider Flower
Grevillea speciosa

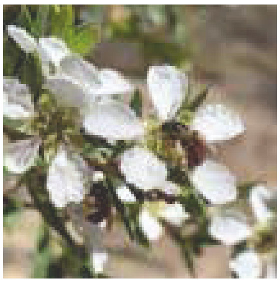

Christmas Bells
Blandfordia grandiflora


Darwinia
Darwinia procera


Heathy Parrot Pea
Dillynia retorta


Silky Purple Flag Iris
Patersonia sericae


Paroo Lily
Dianella caerulea


Pink Tea Tree
Leptospermum squarrosum


Sunshine Wattle
Acacia terminalis

Fig. 07.04.08 A variety of observed flowering vegetation species [top], and Manly Dam and surrounding bushlands [bottom]. Source: Author, 2020.

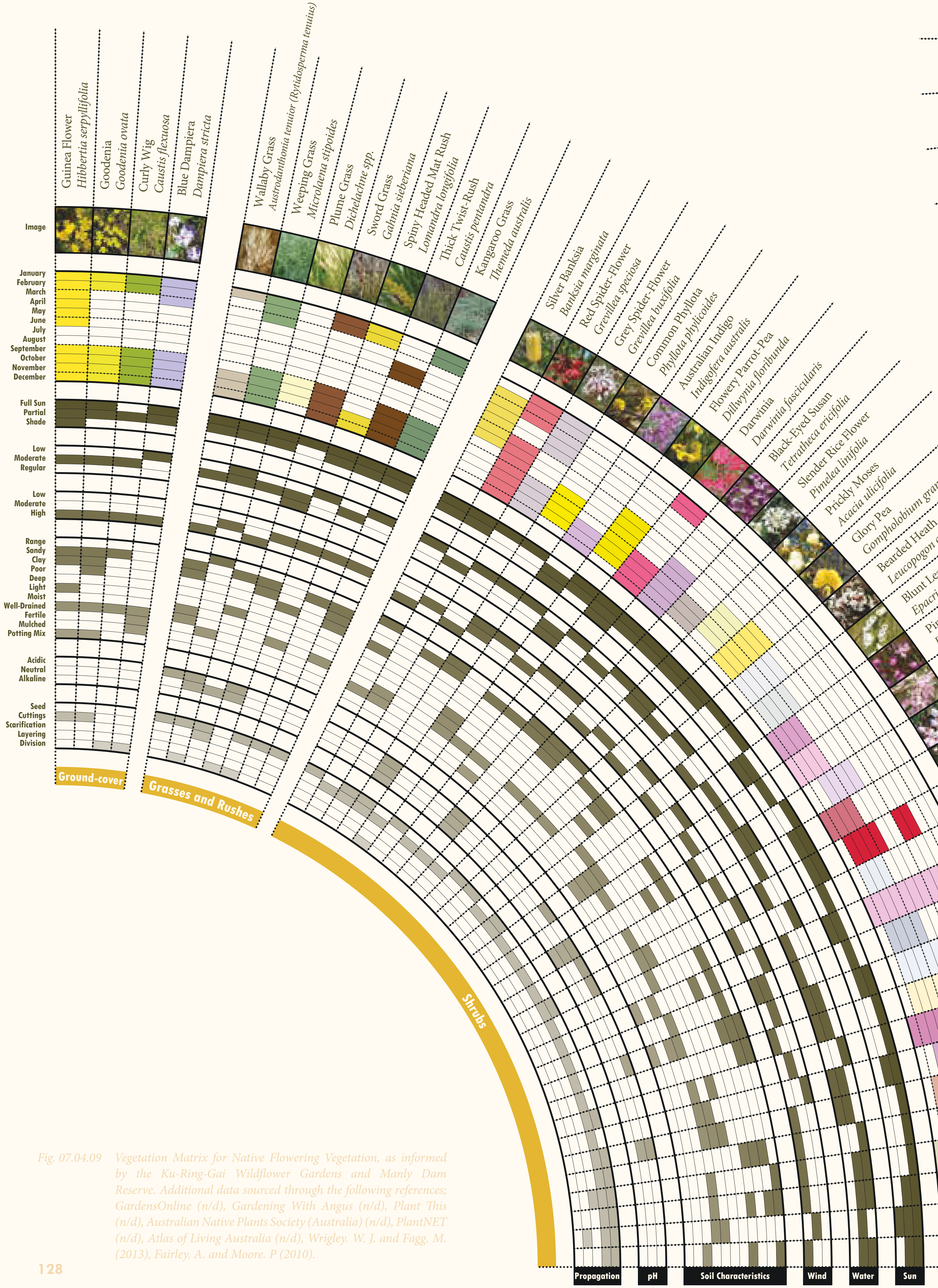


Fig. 07.04.09 Vegetation Matrix for Native Flowering Vegetation, as informed by the Ku-Ring-Gai Wildflower Gardens and Manly Dam Reserve. Additional data sourced through the following references; GardensOnline (n/d), Gardening With Angus (n/d), Plant This (n/d), Australian Native Plants Society (Australia) (n/d), PlantNET (n/d), Atlas of Living Australia (n/d), Wrigley. W. J. and Fagg. M. (2013), Fairley. A. and Moore. P (2010).

NATIVE FLOWERING VEGETATION

04. FAGAN PARK ECO GARDEN, GALSTON

3.91km
59m Elev. Gain

A site visit to the Fagan Park Eco Garden in early Spring of 2020 revealed a number of co-interactions between the flora of the gardens, and numerous insects including European Honey Bees, Australian native bees, and butterflies. Of particular interest for my visit to these gardens were the 36 species of garden-suitable fruit species on display, along with its general displays of sustainability practices that can, once again, be implemented in backyards. Whilst not only introducing a variety of productive vegetation into the Green Mesh vegetation matrix, this also brought foreword a number of relatively easy and inexpensive ways that individuals within the community can start with small sustainability initiatives, that would compound in effect if extensively adopted throughout an LGA, or indeed, metropolitan Sydney.

Fagan Park is a landscape architect-designed public parklands, featuring a regional playground, and international gardens located in Hornsby Shire, Sydney. In 1980, the 70-acre land was donated to the Department of Lands, with Hornsby Shire Council as the sole trustee for the park, and a landscape architect was appointed soon after, turning the rolling grasslands into ornamental displays of Australian, Chinese, Japanese, Mediterranean, Dutch, North American and South American Gardens, collectively called the 'Gardens of Many Nations'.

The Fagan Park Eco Garden was established in 2000, operated by Hornsby Shire Council. The Eco Garden seeks to showcase a variety of techniques that support sustainability principles and are easily replicated in your own garden, revealed throughout your exploration of the gardens, and communicated through signage and descriptions. The Eco Garden features a display of 36 garden-suitable species of fruit, a four-season vegetable garden, and composting demonstration, along with a range of garden-bed typologies from 'No-Dig Gardens' and 'Wicking Beds', to 'Herb Garden Spirals' and 'Mandala Gardens'.

NO DIG GARDENS AND WICKING BEDS

Constructed above-ground, 'No-Dig Gardens' [Fig. 07.04.10-A] are made of several layers of organic matter that rot down into nutrient-rich living soil. Due to their above-ground nature, these gardens can be built over existing garden beds or lawns, where the soils are too poor or thin for adequate planting, or where shallow services or infrastructures exist beneath the ground. Soils can be tailored to the desired vegetation intended to be planted.

Wicking Beds [Fig. 07.04.10-B] use a PVC pipe or similar, within a coarse aggregate layer beneath the growing medium, to retain and self-water the vegetation in soils above. Water is drawn up through the plants' root systems through the capillary function when needed, with its retention below the soil limiting evaporation to create a highly water efficient irrigation solution.

HERB GARDEN SPIRAL AND MANDALA GARDENS

The 'spiral' shape of herb spirals maximises the extent of edge planting within a garden bed, creating a range of growing conditions within one spot and ensures accessibility for the harvest or watering of productive species. Herb spirals are subsequently highly productive garden beds, that are also highly space efficient.

Mandala, or 'keyhole' gardens [Fig. 07.04.10-C], are circular garden beds broken up by a path that allows access to the inside of the garden-bed. Similar to herb spirals, Mandala gardens make it easy to access all species within the bed for watering or harvest, with the additional capacity for a central sprinkler to be installed and used with no waste around the edges.

PERMACULTURE GUILD AND NATIVE VEGETATION

A permaculture guild is a group of plants, animals or insects, that work cohesively to ensure their survival, mimicking the function of natural ecosystems within nature. Within this structure, 'companion' plants will usually surround a main fruit-tree or other type of tree as the centre-piece.

The use of native vegetation within gardens is a way to facilitate the development of local permaculture guilds, through the existing interactions between local flora and fauna, who may use the vegetation for food or shelter. A variety of vegetation heights and layering from ground-covers, to shrubs and trees will best reflect a natural setting, whilst creating linear planted areas will facilitate the movement and protection of native fauna along corridors.

A

B

C

D

Fig. 07.04.10 (A) No-Dig Garden, (B) Wicking Bed, (C) Mandala/ Key-hole garden-bed, and (D) used tyres recycled into planting containers. Source: Author, 2020.

CROP ROTATION & PEST MANAGEMENT

Preventing pests and disease is important for the longevity and yield of productive vegetation in particular. Productive species planted within the same garden bed should not be from the same vegetation family two years in a row, and should therefore be rotated annually. Healthier soils are thus more resilient to pests and disease. Furthermore, companion planting can be used to attract native predatory insects such as dragonflies and lady-beetles, to control any pest insects from becoming a problem, and reducing the need for harmful chemicals and pesticides. Additionally, barriers such as fencing, netting or bags can be used to prevent pests, and as a last resort, homemade remedies or certified organic sprays may be used.

'ADAM' COMPOSTING & WORM FARMING

Composting is the process of creating a nutrient-rich soil compound through the breaking-down and decomposition of green or brown nitrogen-rich materials, by living organisms. Green, organic materials include kitchen food scraps, fruit and vegetables, coffee grounds and tea bags, along with garden waste such as fresh grass clippings and manure. Brown, dry compost materials include straw and sugarcane mulch, dry leaves and grass clippings, cardboard and paper. Using a combination of these materials for composting will produce the best result, along with a combination of both fast and slow composting materials. Adding compost to garden soils will not only increase the nutrient-content of the medium, but also increase the water holding capacity and overall structure of the soils. For the healthiest compost, aeration should be encouraged through turning over the compost regularly, whilst moisture should be kept up whilst not bing saturated. The four principles – Aliveness, Diversity, Aeration and Moisture, make up the acronym 'ADAM'.

In addition to composting, worm-farms are a cheap and easy to maintain to convert vegetable and fruit scraps into a valuable fertiliser material.

PONDS

Ponds provide habitat diversity for native flora and fauna, a cool refuge to fauna on hot days, and a visually calming and relaxing feature to a backyard. They can influence the immediate micro-climate of a garden, providing a cooling effect, and an area for the harvesting of aquatic productive species such as water chestnut.

RESOURCE SUSTAINABILITY

Re-using and recycling old materials, for example by turning fence palings, packing pallets, old pavers, or tyres into planting containers [Fig. 07.04.10-D], propagation boxes for seeds, or garden-beds, is a cheap and sustainable way to both create beds for planting, and reducing common waste.

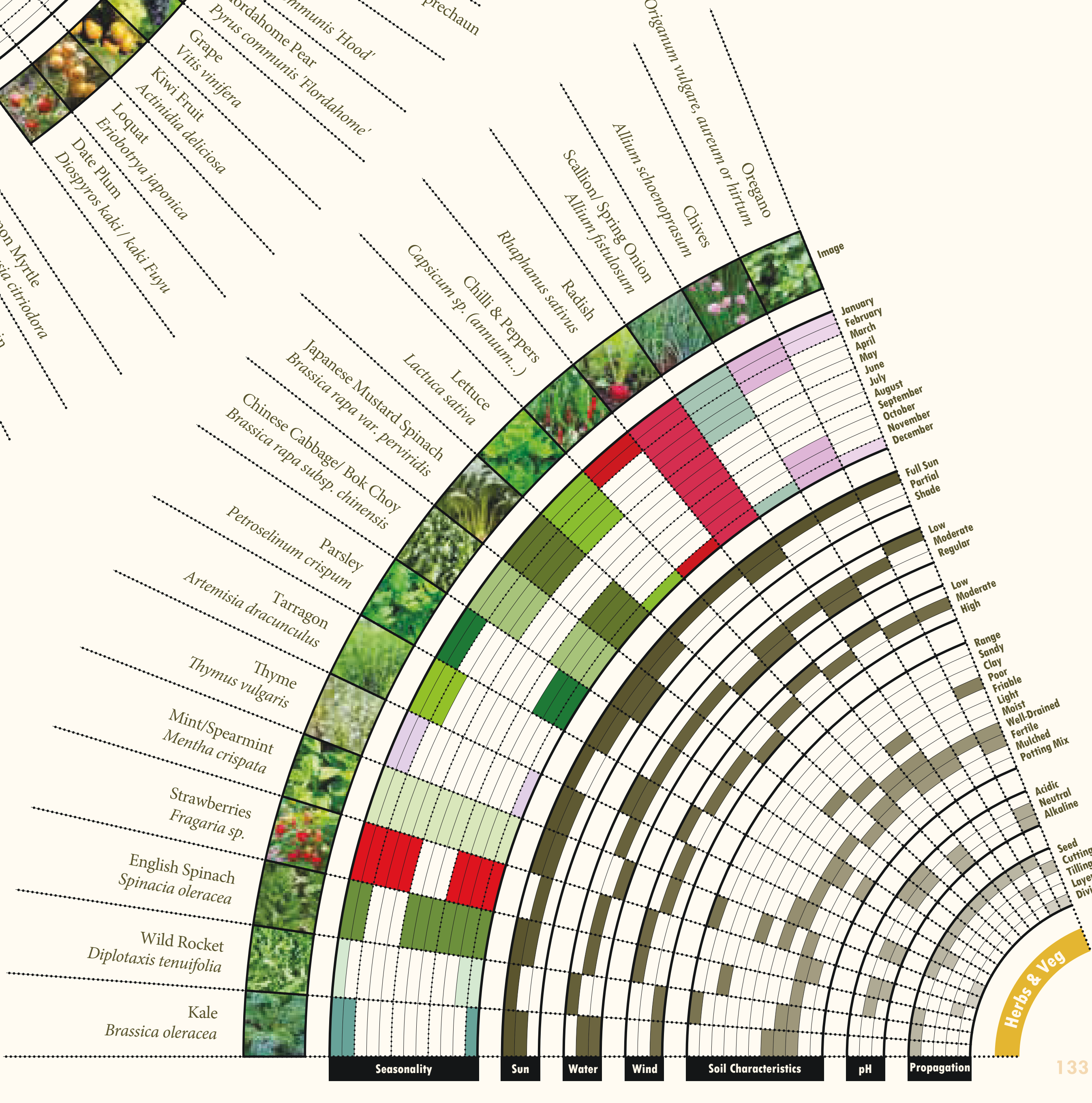
Furthermore, in a climate of periodic drought and water scarcity, rainwater harvesting, if done collectively and widespread, can significantly reduce peak stresses and dependencies for a centralised water supply system, such as large dams like Warragamba for Sydney. The retention of water on-site, through the collection from rooftop runoff into water tanks (as grey-water), or an increase in ground permeability for absorption, will also reduce stormwater runoff and the subsequent pollution of waterways. Shifting to grey-water for all residential garden watering can reduce household mains water consumption by up to 30% (J. Byrne et al, 2015).

From the perspective of species selection, growing plants with similar growing requirements, particularly for watering, prevents over or under watering and overall saves on water wastage. Using local indigenous species suited to the local climate, and mulching gardens to reduce evaporation will both also lead to savings in water consumption and wastage.

Finally, implementations within the landscape surrounding a house, to reduce heat gain in summer and heat loss in winter, through features like planted windbreaks, can also save up to 25% on heating costs and energy usage. Solar panels can also be utilised to either feed sustainable energy back into the grid, or used and stored on-site for a variety of household applications.

Fig. 07.04.11 *Vegetation Matrix for Productive Species, including exotics, as informed by the Eco Gardens at Fagan Park. Additional data sourced through the following references; GardensOnline (n/d), Gardening With Angus (n/d), Plant This (n/d), Australian Native Plants Society (Australia) (n/d), PlantNET (n/d), Atlas of Living Australia (n/d), Wrigley. W. J. and Fagg. M. (2013), Fairley. A. and Moore. P (2010).*

EXOTIC & PRODUCTIVE VEGETATION



05. BICENTENNIAL PARK WETLANDS, SOP

6.23km
52m Elev. Gain

Bicentennial Park is located within Sydney Olympic Park, 12km from Sydney CBD, on landfill and a former abattoir site remediated for the Sydney 2000 Olympic Games. These days, whilst the various parklands and stadiums of Sydney Olympic Park continue to be used as a venue for concerts, sporting events, and festivals, significant effort has been put in to protect a diversity of fauna, including many shore-birds that are either permanent residents to the reclaimed wetlands, or migrate seasonally from parts of Asia and North America. With its intensive industrial history, resulting in a range of terrestrial pollutants and contaminants, along with the revitalisation of these environments through habitat creation and wetland flora, Bicentennial Park therefore provides an opportunity to inform both phytoremediation species, as well as wetland, pond and aquatic species, within the Green Mesh vegetation matrix.

Over several decades, particularly throughout the 1960s-70s, Sydney Olympic Park was the site of both legal and illegal landfill operations, becoming a dumping ground for both residential and industrial waste. A study conducted in 1991 through the creation of boreholes within a 50m grid, revealed contaminants ranging from power station ash, demolition rubble and asbestos, to domestic garbage, industrial hydrocarbons and dredging material from the Parramatta River (Sydney Olympic Park Authority, 2014). An allocated $137 million was provided by the NSW Government to commence remediation works across the 160ha site from 1992-2001, with a clean up program excavating contaminated soils and undergoing specialised treatment procedures. As a result, whilst the majority of landfill remains on-site today, this waste is capped beneath large mounds that protect the soils and open spaces above them from becoming contaminated.

With between 40-60 million litres per year of leachate (contaminated waste water that seeps through these capped landfill mounds and presents a potential threat to nearby ecologies), sustainable methods of bioremediation have been employed to treat these contaminated waters. Phytoremediation and bioremediation are the process of using plants or living microorganisms, respectively, to absorb, consume or uptake contaminants within the soil, water or air. As is the case for Sydney Olympic Park, this process is vital for the reclamation of former industrial or dumping grounds in particular, for their transition into a new function. Within Sydney Olympic

Fig. 07.04.12 Inter-tidal Coastal Saltmash environment of the Sydney Olympic Park. Source: Author, 2020.

Park, this leachate contains ammonia which is a toxic product of waste degradation, broken down through the bioremediation process by denitrifying bacteria within a vertical flow wetland (Sydney Olympic Park Authority, n/d). Furthermore, whilst this process may be used within the Green Mesh as a strategy within industrial lands, phytoremediation for the uptake of harmful metals, petroleum and diesel byproducts, and chemicals, can be used as well.

Through the implementation of this remediation work, the former contaminated lands of Sydney Olympic Park were able to be used as the site for the Sydney 2000 Olympic Games, supporting a range of sporting arenas and other supporting infrastructure, along with its continued use today through residential development, and ecologically significant wetland, mangrove, and creek habitats. These environments protect a range of fauna such as a variety of local and migratory shore-birds, reptiles, fish, and several threatened frog species at the former brick pit quarry now becoming a flooded sanctuary off-limits to people but observable through a raised ring walkway.

HABITATS

Powells Creek Fishway connects the various pond habitats within Bicentennial Park, to the mangroves and broader Parramatta River, supporting a diversity of wildlife through the dense reeds and low shrubs along its banks, and submerged rocks breaking up the flow of water to create slower moving environments for small fish and crustaceans. Of these vegetation species, Phragmites (Phragmites australis), is the most dominant species, common throughout tidal waterways with higher salt levels and used by the Aboriginal people to create rafts, baskets and ornaments from its leaves and stems. These reeds not only help stabilise the banks, reducing erosion, but also provide a sheltered environment for juvenile fish to develop and grow, with these species of fish using the fishway to move between salt water into these protected fresh water nurseries.

Adjacent to the Parramatta River, the inter-tidal mangrove ecosystem provides further habitat through a 'forest' of specially adapted mangrove trees, using their aerial roots (pneumatophores) to extend above the tidal line to breath, and their leaves to excrete excess salt to cope in the saline environment. The low-lying, damp and muddy environment of the mangroves, dominated in Sydney Olympic Park by the Grey Mangrove species in particular (Avicenna marina), provides further habitat to fish, prawns, crabs and mollusks eating detritus that is broken down by bacteria and fungi.

Fig. 07.04.13 Observed vegetation within and around the wetlands environment of Bicentennial Park. Source: Author, 2020.

Fig. 07.04.15 Intertidal Mangrove habitat connected to the Parramatta River. Source: Author, 2020.

Finally, the artificial wetland environment of Sydney Olympic Park, the Coastal Saltmarsh, provides habitat and retreat to a range of local and migratory shore-birds, land-dwelling insects and spiders, and marine creatures such as crabs and mollusks. The intertidal nature of this ecosystem has a large influence on the water birds that inhabit the wetland, with differing preferences for both tidal pattern and water depth. As such, the implementation of a 'tidal gate' to both release water from, or allow water in from Parramatta River, tailors the conditions for specific shore-bird species present at any given season or time. These tidal flows are not only required in the establishment of habitat boundaries for the separation of different species, but also dictates the nutrient levels and in-flows, preventing the formation of 'algae mats' through the build-up of stagnant nutrients. These algae mats are harmful to the wetlands and fauna species, creating an odor as they decay. With this ongoing maintenance, the wetlands provides an annual breeding grounds for more than 15 migratory shore-bird species, moving from Japan, Siberia and Alaska across the East Asian-Australasian Flyway between the months of September through to April.

Within the context of the Green Mesh, and the variety of residential, commercial and industrial built-form environments it seeks to inform ecologically, it is more likely for the potential of freshwater ponds and small freshwater wetland environments, rather than the majority of highly-saline environments of Sydney Olympic Park. Even so, there have been a wide range of important ecological functions, interactions and characteristics identified within this case study, to inform the pond and wetland vegetation matrix, along with a specialised matrix for the remediation of former industrial sites with high levels of contaminants. The use of reed species can not only help stabilise soils and river banks, but provides shelter to a range of fauna species, and the potential for water filtration and treatment. Within an urban environment,and along roadways, a range of bioswales are used already to filter water runoff from roads within the process of Water Sensitive Urban Design (WSUD), though as is evident within this site visit, there is a far greater potential for the ecological function of these systems in a broader context.

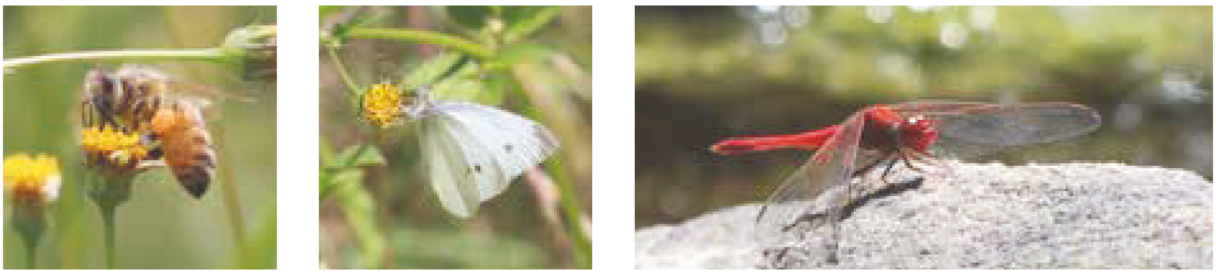
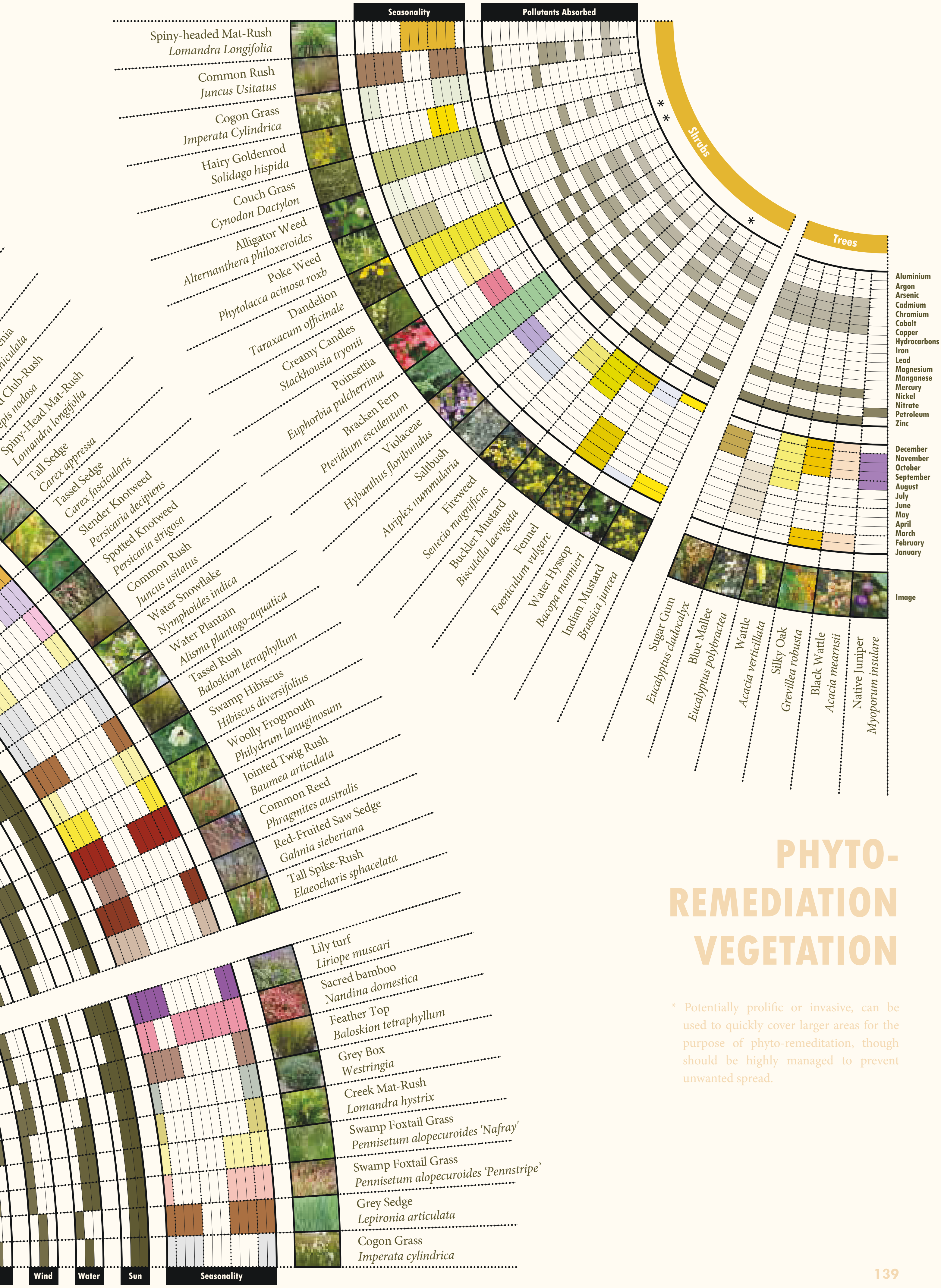


Fig. 07.04.14 Invertebrates observed within Bicentennial Park: [Left] Western Honey Bee (Apis mellifera), [Middle] and Cabbage White butterfly (Pieris rapae), [Right] Red Arrow (Rhodothemis lieftincki). Source: Author, 2020.

Fig. 07.04.16 Masked Lapwing (Vanellus miles) [bottom], along with a range of other native and introduced bird species, including the Superb fairywren, Silver Gull, Australian White Ibis, Black-winged Stilt and Magpie Lark, seen within the man-made Coastal Saltmarsh wetlands environment of Sydney Olympic Park. Source: Author, 2020.

WETLAND & POND VEGETATION

Fig. 07.04.17 Vegetation Matrix for specialty plants for pond and wetland environments, water filtration, and phytoremediation. Source: Australian Plants Society NSW, and Sydney Olympic Park Authority.



PHYTO-REMEDIATION VEGETATION

* Potentially prolific or invasive, can be used to quickly cover larger areas for the purpose of phyto-remeditation, though should be highly managed to prevent unwanted spread.

01. The Calyx Green Wall

02. 1 Bligh St, Sydney

03. One Central Park, Sunken Courtyard

SIGNIFICANCE

Green Walls and Vertical Gardens are becoming more and more popular within commercial and residential contexts. As such, numerous innovative systems exist across a range of scales that facilitate the planting of species to create these green infrastructure typologies. The 'Green Wall Suitable' component of the Vegetation Matrix seeks to establish a sub-set of planting species particularly suited to vertical planting, whether it be within a pot-based system, hanging vines, or tiled modules. As usual, these species are detailed down to their flower or foliage colour, seasonality, propagation method, and micro-climate preferences in correlation with simulation data.

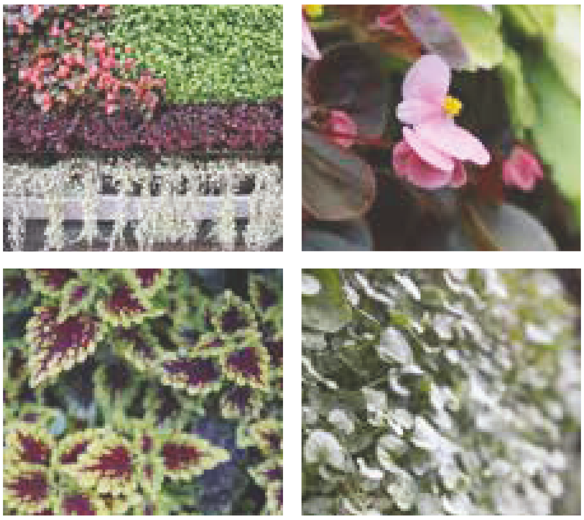


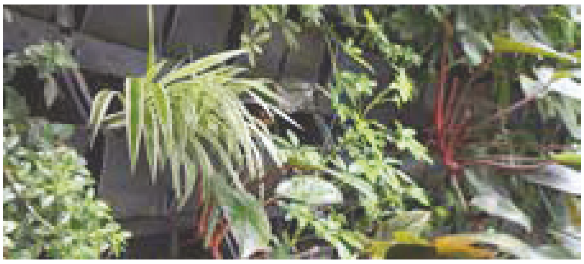
Fig. 07.04.18 Planting details of The Calyx Green Wall. Source: Author.

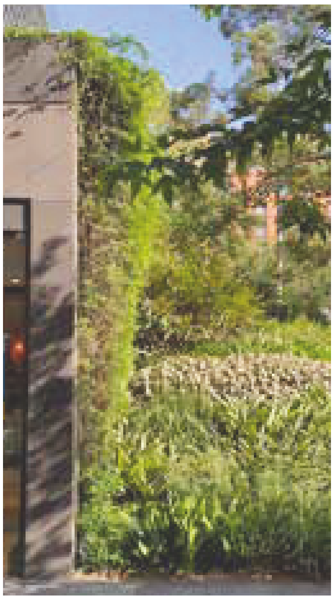
01. THE CALYX GREEN WALL

Located within Sydney's Royal Botanic Gardens, The Calyx features a multi-use exhibition space with an extensive 50m interchangeable green wall – one of the largest of its kind in the southern hemisphere. Utilising the G-Sky Versa Wall shelf system, the green wall holds over 18,000 potted plants, irrigated by 5 independent systems, and uses 2,000 drippers along 300m of irrigation line. These individual pots allow horticulturalists to design colour arrangements through a cell-based, colour by numbers process, whilst furthermore, incorporating a simple and easy method of swapping out groups or individual plants when transitioning between exhibitions.

Two of these exhibitions; 'Pollination' (2018) and 'inBLOOM' (2020), helped inform a number of species within the 'Green Wall Suitable' component, including a range of native and exotic flowering species. Both exhibitions had a focus on the role of colour in prompting human physical and emotional responses, as well as non-human affects in attracting pollinators. Colours including reds, yellows, and purples for example, are common attractors for native birds, bees, wasps, and butterflies, whilst greens and blues have human health benefits in lowering stress and regulating sleep cycles, respectively.

'Pollination at The Calyx' featured a display of Dichondras, Syngoniums, and Heucheras populated throughout the green wall, with 'inBLOOM' adding Begonias and Alternantheras to this mix, each with a range of colour variations to provoke the desired effect.





02. 1 BLIGH STREET, SYDNEY

1 Bligh Street is an innovative and sustainable office high-rise within Sydney's CBD, featuring a 42m long commercial living wall at the ground floor lobby entrance. Within the concrete city, this living wall promotes sustainability and connection to nature, irrigated by recycled water from the tower, and providing visual amenity to the adjacent coffee bar/cafe.

At 9.7m high, and a total area of 337m^2, this living wall holds 11,300 plants - a mix of tropical and water-loving plants, including 27 species of ferns, lilies, and ground covers suited to the low-light, high wind conditions created by overshadowing and a wind-tunnel effect of the high-rise city context. Plants are contained within geo-textile boxes filled with light-weight potting mix & polystyrene balls. The plants themselves grow within this medium, and through cuts in the geo-textile fabric which providing further surface area for the plants to grow and expand in order to further populate the wall.

The planting selection used, in contrast to The Calyx's focus on colour variation, is completely monotone. Instead, the planting palette establishes variation through pattern and texture of the foliage and leaves, whilst the green colour wash promotes mental health benefits through stress-relief and a boost in concentration. From an micro-climate perspective, the plants produce a cooling-effect on localised air temperatures through the process of evapotranspiration from the foliage, with the curved undulation of the wall creating a number of further micro-climates.

03. ONE CENTRAL PARK, SUNKEN COURTYARD

In addition to the widely-renown One Central Park vertical garden, created in collaboration between Ateliers Jean Nouvel and PTW Architects, planting throughout the ground-plane also included the internal foyer, a sunken courtyard and atrium planting. Each typology brought with it a number of micro-climatic challenges such as wind speed and sun/shade conditions, and light lux levels for indoor spaces, addressed through testing and technical development to ensure planting success.

The sunken courtyard, featuring a planted stairway connecting to adjacent Chippendale Green, utilises steel wires to establish 'tensile trellis' hanging gardens, connecting between lower and upper level planting. This system provides support for a variety of vine species - including Chinese Wisteria, Star Jasmine, Native Sarsaparilla, Wonga Wonga Vine and Madagascar Jasmine, as well as climbers - Kangaroo Vine, Passion Flowers and Orange Trumpet Creeper, and scrambling vegetation - Bougainvillea, Lade Banks Rose and Cape Honeysuckle. These plants are able to populate on their own as they grow and expand, with some species requiring a soil growing medium from which to begin growth. This medium can be positioned at the top or bottom of the tensile cables for growth either upwards or downwards.

GREEN WALL SUITABLE VEGETATION

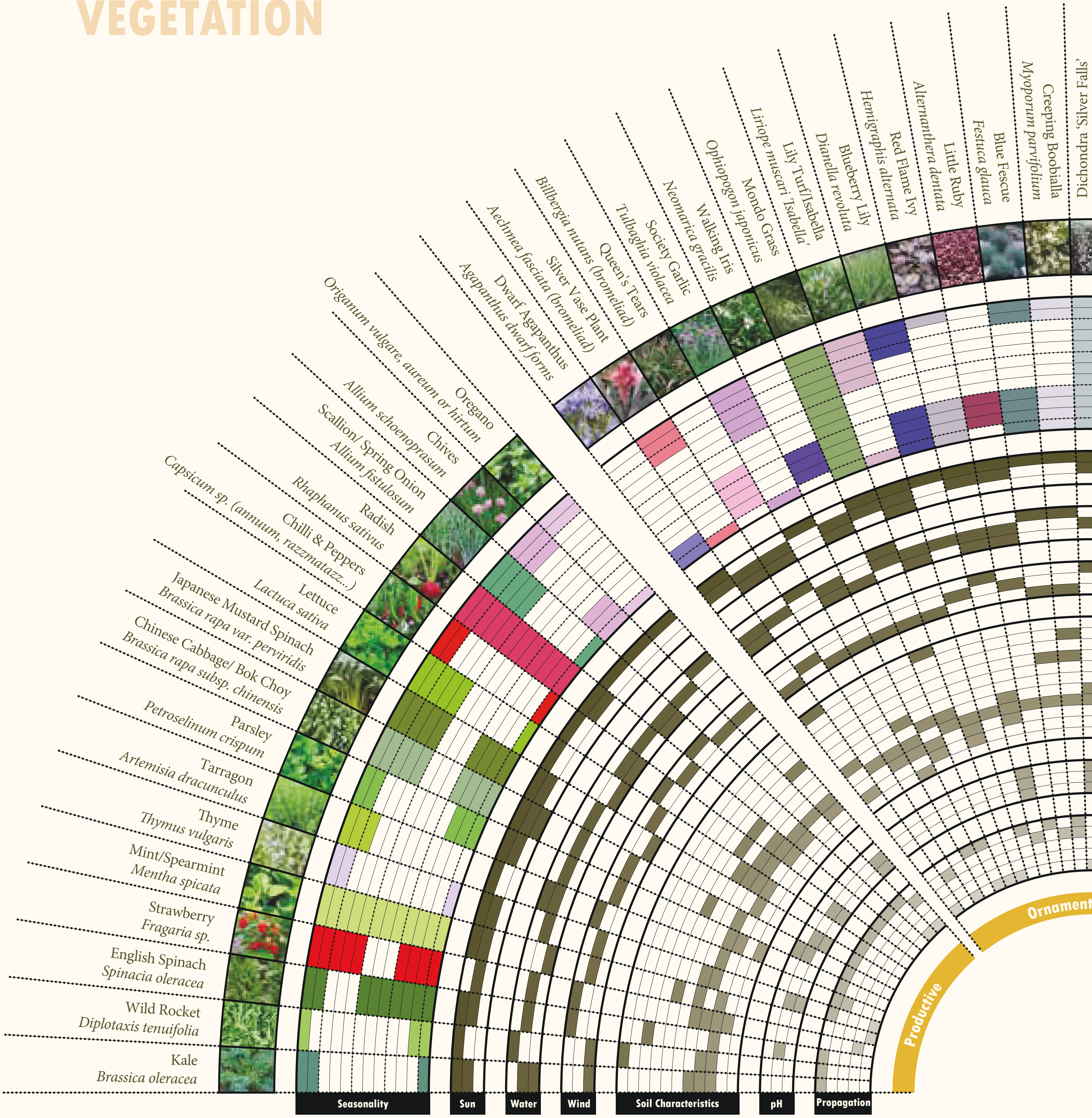
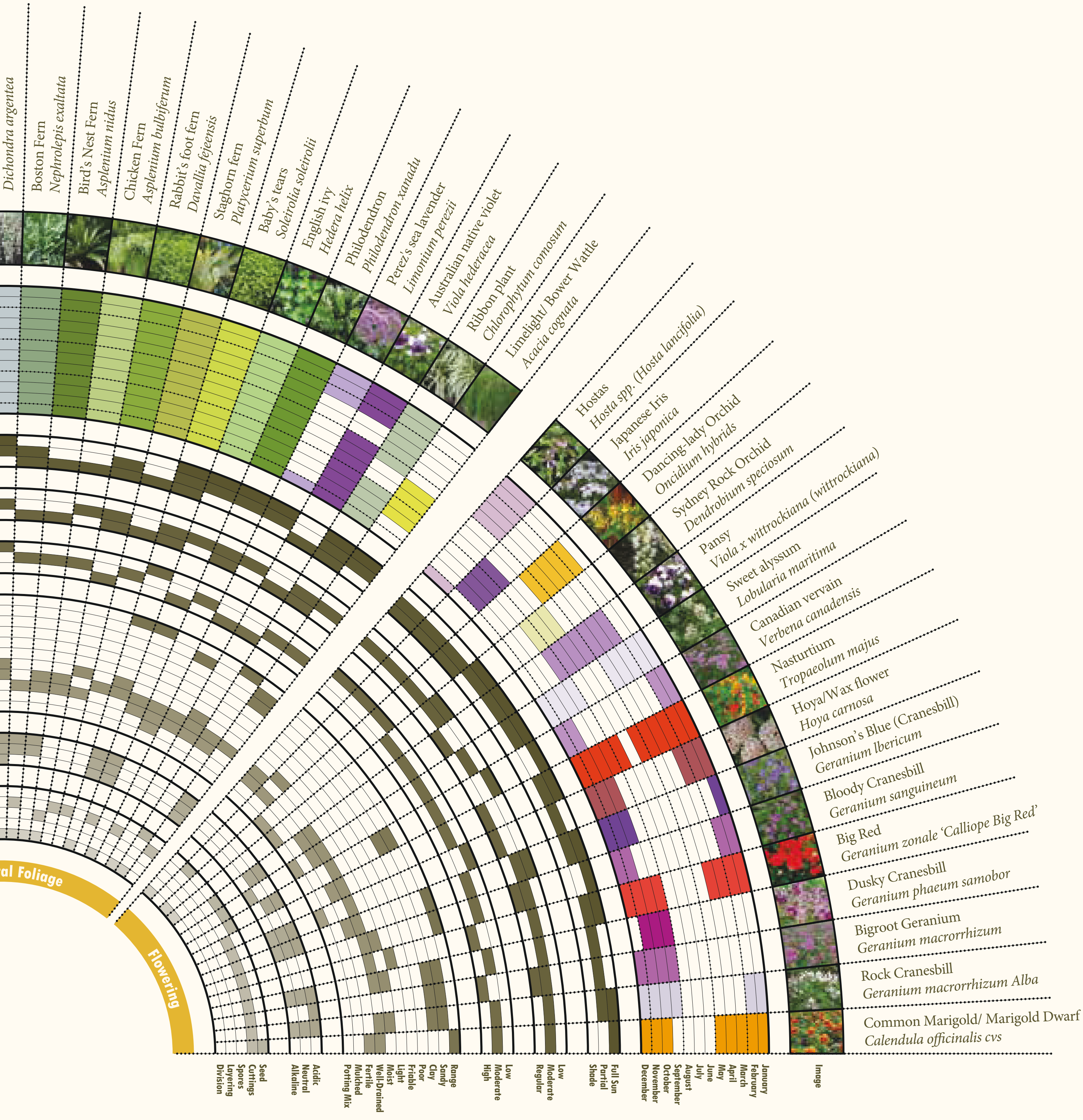


Fig. 07.04.19 Vegetation Matrix for Green Wall Specific Species. Data sourced through the following references; GardensOnline (n/d), Gardening With Angus (n/d), Plant This (n/d), Australian Native Plants Society (Australia) (n/d), PlantNET (n/d), Atlas of Living Australia (n/d), Wrigley. W. J. and Fagg. M. (2013), Fairley. A. and Moore. P (2010).


Dichondra argentea
Boston Fern
Nephrolepis exaltata
Bird's Nest Fern
Asplenium nidus
Chicken Fern
Asplenium bulbiferum
Rabbit's foot fern
Davallia fejeensis
Staghorn fern
Platycerium superbum
Baby's tears
Soleirolia soleirolii
English ivy
Hedera helix
Philodendron
Philodendron xanadu
Perez's sea lavender
Limonium perezii
Australian native violet
Viola hederacea
Ribbon plant
Chlorophytum comosum
Limelight/ Bower Wattle
Acacia cognata
Hostas
Hosta spp. (Hosta lancifolia)
Japanese Iris
Iris japonica
Dancing-lady Orchid
Oncidium hybrids
Sydney Rock Orchid
Dendrobium speciosum
Pansy
Viola x wittrockiana (wittrockiana)
Sweet alyssum
Lobularia maritima
Canadian vervain
Verbena canadensis
Nasturtium
Tropaeolum majus
Hoya/Wax flower
Hoya carnosa
Johnson's Blue (Cranesbill)
Geranium Ibericum
Bloody Cranesbill
Geranium sanguineum
Big Red
Geranium zonale 'Calliope Big Red'
Dusky Cranesbill
Geranium phaeum samobor
Bigroot Geranium
Geranium macrorrhizum
Rock Cranesbill
Geranium macrorrhizum Alba
Common Marigold/ Marigold Dwarf
Calendula officinalis cvs
al Foliage
Flowering
Seed
Cuttings
Spores
Layering
Division
Acidic
Neutral
Alkaline
Potting Mix
Mulched
Fertile
Well-Drained
Moist
Light
Friable
Poor
Clay
Sandy
Range
High
Moderate
Low
Regular
Moderate
Low
Shade
Partial
Full Sun
December
November
October
September
August
July
June
May
April
March
February
January
Image

SUMMARY & DESIGN PRINCIPLES

SUMMARY

Case studies undertaken within this chapter, including on-site investigation and species identification, have resulted in a series of seven planting typologies that together, create an informed and diverse vegetation matrix associated with the plant suitability factors established through the micro-climate simulation in 07.02.

This matrix, whilst relevant to Willoughby in particular, also contain elements relevant to backyards throughout the broader context of Sydney, with the intention that the specific local vegetation community requirements and characteristics of different LGAs can be accommodated and implemented accordingly. These vegetation typologies range from native, flowering plants that will attract a range of pollinator insects and birds, subsequently attracting larger prey animals and establishing greater biodiversity and ecosystem connectivity, to exotic productive vegetation species, which, whilst also attracting pollinators, allow for urban agricultural practices and the decentralisation of our food production systems to reduce the stresses of intensive mass-agriculture.

Extensive research into the hundreds of selected species within the combined matrix, with each species detailed by micro-climate preference in addition to flowering colour, seasonality, and propagation method, enables a highly responsive strategy for locating species uniquely suited to the simulated micro-climate characteristics of certain areas of a garden. This autonomous methodology will be fed into the Green Mesh framework to inform physical implementation by the general public, facilitating the proliferation of ecologically valuable garden planting throughout backyards, and in turn, stitching together remnant vegetation fragments throughout Sydney.

DESIGN PRINCIPLES

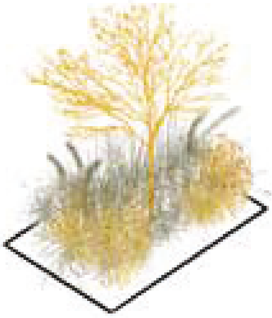
A number of implementation strategies observed through case-studies and site visits informed the six design principles that deal with vegetation and sustainability. These include garden-bed typologies, considerations for insects and other fauna, and resource sustainability practices including solar energy and water harvesting, recycling, and composting. Fagan Park Eco Garden was the primary source for many of these principles, as it was specifically set-up to inform backyard implementations, in common with the goals of the Green Mesh.

Planting strategies represented through these principles include a number of realistic, DIY garden-bed typologies, including no-dig gardens, wicking beds, herb spirals and mandala gardens. These garden-beds aims to maximise the use of space whist maintaining accessibility for harvesting herbs or maintaining vegetation. Co-dependency groups encourage diversity in species, and co-beneficial interactions between these species. Co-existence can also be incorporated into flora-fauna interactions, with certain vegetation species can be used to attract native insect predators to naturally control pests. Similar to large-scale wildlife corridors, fauna can also be accommodated through backyard vegetation corridors that provide shelter and nesting potential, whilst facilitating movement and protection from garden to garden.

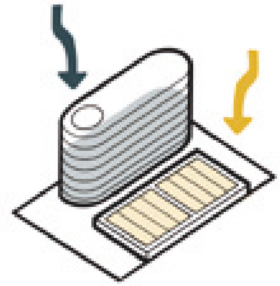
Resource sustainability is also addressed through these principles, encouraging the recycling of common waste materials such as tyres and timber scraps, and the use of existing rainwater harvesting methods, and solar panels. In combination with principles from the micro-climate section, solar panels can be positioned in response to the surfaces and roof aspect with the greatest solar irradiance potential, providing an easy method for determining the ideal location for solar panels. Several ideas for recycling common materials were demonstrated within Fagan Park Eco Garden, and can also be used within the Green Mesh in creating small garden beds whilst minimising garbage.

07.04

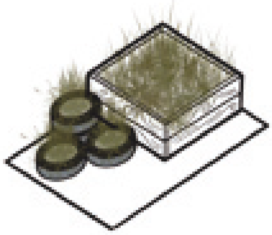
LOCAL ECOLOGICAL CASE STUDIES - DESIGN PRINCIPLES



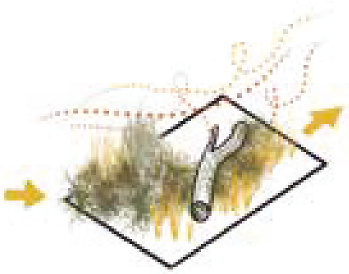
13. PLANTING IN CO-DEPENDENCY GROUPS



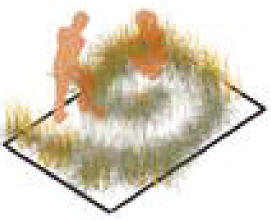
14. RESOURCE SUSTAINABILITY



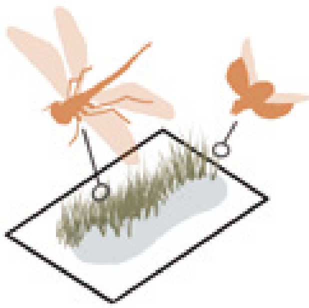
15. REDUCE WASTE, RECYCLE COMMON MATERIALS



16. FAUNA HABITAT AND VEGETATION CORRIDORS



17. A DIVERSITY OF GARDEN-BED TYPOLOGIES



18. NATIVE INSECTS FOR PEST MANAGEMENT, ORGANIC WEED & DISEASE MANAGEMENT

13. Group plants in co-dependency groups, incorporating 'permaculture guild' strategies, and plants that will benefit native birds and bees.

14. Incorporate rainwater harvesting, wind-breaks to save energy consumption, solar energy and water permeability within surfaces to retain water on-site.

15. Utilise compost and worm-farm systems, mulching of organic material, and recycling common materials such as timber pallets to make garden beds.

16. Accommodate native fauna through backyard vegetation corridors, with a range of shelters, vegetation heights, nesting sites, and ponds.

17. Implement a range of garden-bed typologies from No-Dig Gardens, Wicking Beds, Herb Spirals and Mandala Gardens.

18. Practice crop-rotation within productive gardens, encourage native insect predators through plant selection, and utilise planting to filter polluted/contaminated water.

GREEN MESH
VEGETATION MATRIX

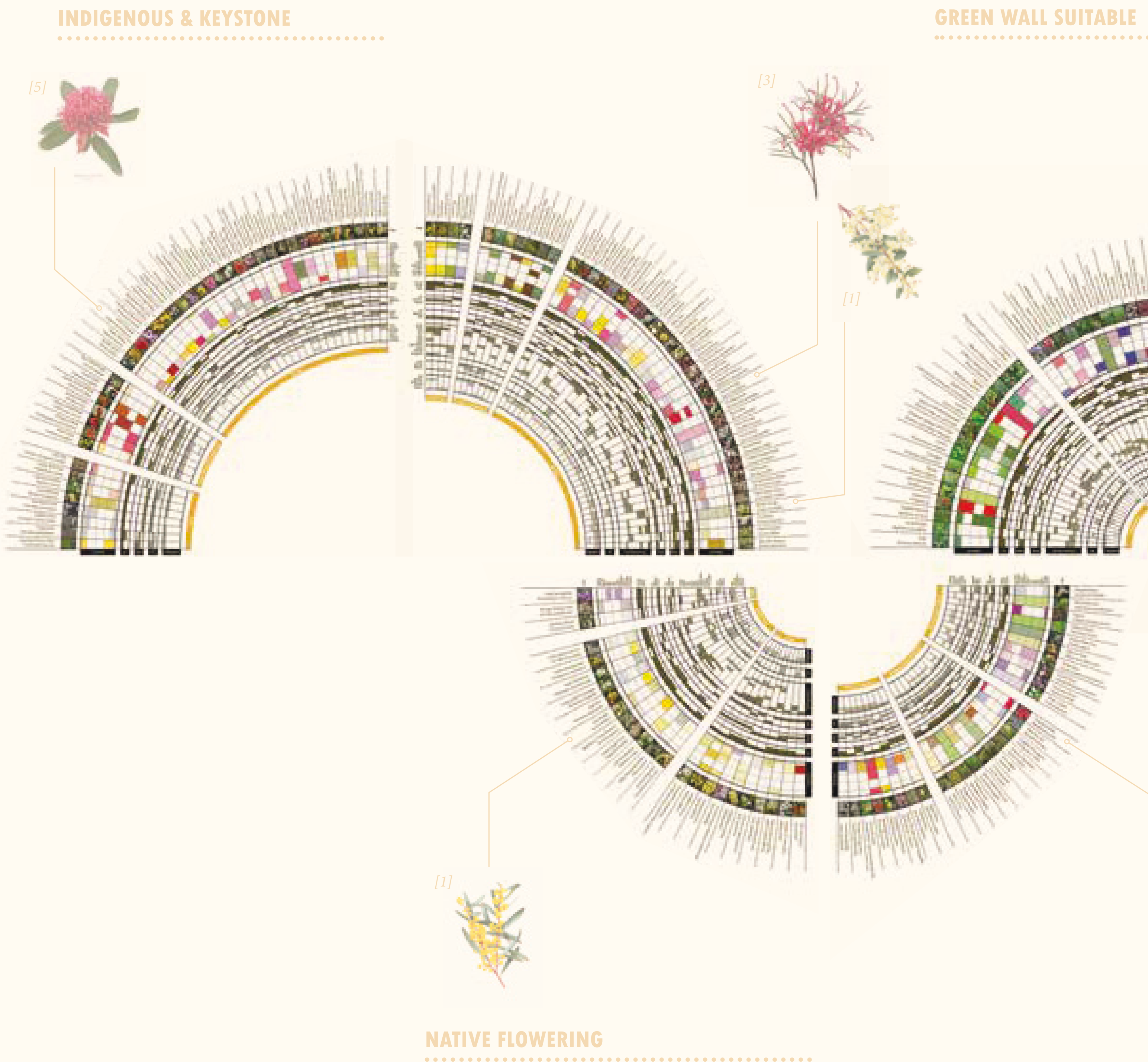
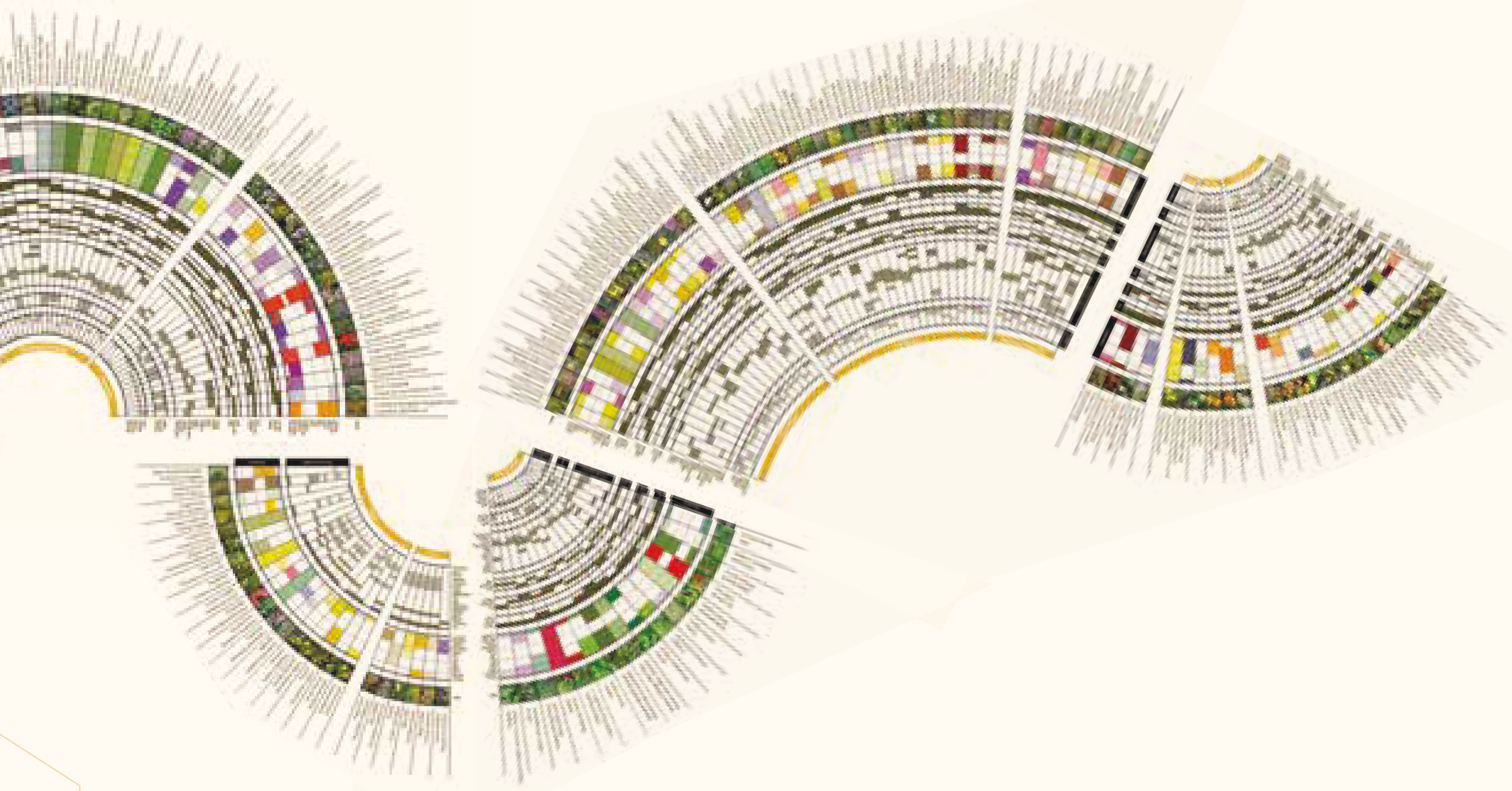
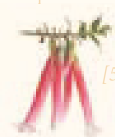


Fig. 07.04.20 Consolidated vegetation matrix covering a series of six vegetation typologies with a variety of ecological and human functions, and associated planting preferences specifying sunlight, water, wind and soil characteristics, along with propagation methods.

WETLAND & AQUATIC





[5]

REMEDIATION

PRODUCTIVE

PRODUCTIVE

Illustration Credits: [1] Heidi Willis (2017), [2] Cheryl Hodges (n/d), [3] Sketchbook Designs (n/d), [4] Joseph Henry Maiden (1859 - 1925), [5] Maurice Hayler (n/d)

07.05 The Physicality of Planned and Unplanned Urban Vegetation

INTRODUCTION

Urban vegetation can be classified as either 'planned' or 'unplanned', with the former referring to intended green implementations such as parklands and built infrastructure, and the latter referring to spontaneous and unintended plant growth that opportunistically establish under particular conditions. Either classification has potential to offer a range of urban habitats and micro-climate benefits - not only supporting a insects and other fauna such as birds, but also in addressing urban challenges that affect human health and wellbeing.

This topic of the chapter seeks to incorporate planned and unplanned urban vegetation typologies within the Green Mesh, by understanding the particular physical characteristics which enable each respectively. Whilst green infrastructure typologies, falling within the 'planned' category, are widely resolved and documented, the unique opportunity is to integrate ways to harness the spontaneity of unplanned vegetation, driving the autonomous dispersal and proliferation of vegetation.

These uniquely adapted urban vegetation species continue to arise through "the interacting forces of urbanization, globalization, and climate change... [creating plants] remarkable for their ability to grow under extremely harsh conditions" (Del Tredici, 2014). This enables spontaneous vegetation to grow in soils and micro-climates poorly suited to the growth of regular plants. The interface here between plant adaptation and the physical urban environment raises the potential of the biomorphic city concept, where the city can be built and designed to accommodate natural seed dispersal and proliferation to provide a restorative function to native ecologies.

"The plants that appear spontaneously in urban ecosystems are remarkable for their ability to grow under extremely harsh conditions—most notably in soils that are relatively infertile, dry, unshaded, and alkaline" - Del Tredici (2014)

SEED DISPERSAL

Seed dispersal is one of the primary functions that enable spontaneous vegetation. There are three main methods of dispersal; "anemochory, hydrochory, and zoochory... dispersal by wind, water, and animals, respectively" (Brittanica, n/d). External environmental forces, such as the heat of bushfires (particularly with many Australian species), can instigate the autonomous function of seed dispersal within native plants.

Dispersal by animals in Australia mainly occurs within larger mammals - foxes, swamp wallabies and wallaroos through ingestion, and other mammal species that have had contact with seeds and transported them on their fur, including various species' of grasses (Royal Botanic Gardens, n/d). Ants play a significant role in local seed dispersal, attracted to food bodies within the vegetation, called eliasomes, acting in a similar way how flowers attract bees, butterflies and native birds through nectar. Such insects and animals play a crucial role in pollination, facilitating the reproduction of flowering vegetation through the movement of pollen between male and female flowers.

Fig. 07.05.01 Unplanned vegetation as seen down a service alley-way on-site, off of Willoughby Rd, Willoughby. Source: Author

Fig. 07.05.02 Aphaenogaster ants dispersing bloodroot seeds. Source: Alex Wild

POLLINATION

Bees are a crucial part of ecosystems all around the world, with "nearly 90% of the world's wild flowering plant species depend[ing], entirely, or at least in part, on animal pollination, along with more than 75% of the world's food crops and 35% of global agricultural land" (United Nations, n/d), at the same time, promoting the biodiversity that forms the basis for a resilient system. Significant declines in bee populations have been experienced globally in the past 10 years, caused by large-scale agriculture, disrupting foraging distances and introducing "sub-lethal stresses" such as chemicals and pesticides that disrupt brain functionality of bees and impair their natural behaviour.

"nearly 90% of the world's wild flowering plant species depend, entirely, or at least in part, on animal pollination, along with more than 75% of the world's food crops and 35% of global agricultural land" - United Nations (n/d)

Urban beekeeping has become increasingly popular in recent years, in the form of rooftop hives of the traditional European Honey-Bee, or the provision of 'bee-hotels' to attract one of many thousands of native, solitary bee species. With bees and other fauna such as flies, beetles, moths, butterflies, wasps, ants, native birds and bats being such crucial pollinators for the majority of plants, a successful implementation of urban green infrastructure will rely on the habitat creation and accommodation of such pollinators.

Furthermore, with many of these insects and animals also contributing to ecologies through seed dispersal, integration and accommodation of such species urban ecologies will not only allow a diversity of vegetation to grow and flourish, but also spread and proliferate, within a framework that allows for such spontaneity and autonomy.

UNPLANNED URBAN VEGETATION CASE STUDY: HONG KONG

Prior fieldwork undertaken in Hong Kong, a comparative photographic study of urban vegetation, was revisited and re-analysed to understand the physical characteristics of surfaces that enable these instances of vegetation to establish and grow. The ultimate aim of this study was to accommodate these physical characteristics into the Green Mesh strategy in order to facilitate the autonomous proliferation of spontaneous vegetation, where vegetation does not need to be planted, but will eventually self-seed and establish independently (provided the right conditions are established).

Throughout Fig. 07.05.03-06, a range of wall typologies were investigated, with the key facilitating properties to each instance noted within the points below. Through this process, several common classifications began to emerge. Firstly imperfections within vertical wall surfaces such as cracks, holes, and ledges were observed to enable vegetation to grow. These imperfections were often areas of water saturation, and where seeds and nutrients could possibly collect in order to facilitate germination. Secondly, species' specific characteristics that enable climbing, utilising pad structures within the plant to grip onto vertical surfaces, whether they be smooth or rough, along with aerial roots that are able to cover urban walls. Finally, is urban guerrilla vegetation through human activity, or a lack of maintenance. This results in small-scale, improvised vegetation implementations within public spaces that were not necessarily authorised, along with the growth of mosses across damp wall surfaces, due to poor maintenance.

01. Vegetation established in cracks, holes, and gaps providing something for plants to grip onto

02. Self-attaching vegetation species gripping to concrete, tiles and other relatively smooth surfaces

03. Vegetation clinging to ledges where water tends to collect

04. Vegetation attached to objects, particularly climbers on pipes and wires

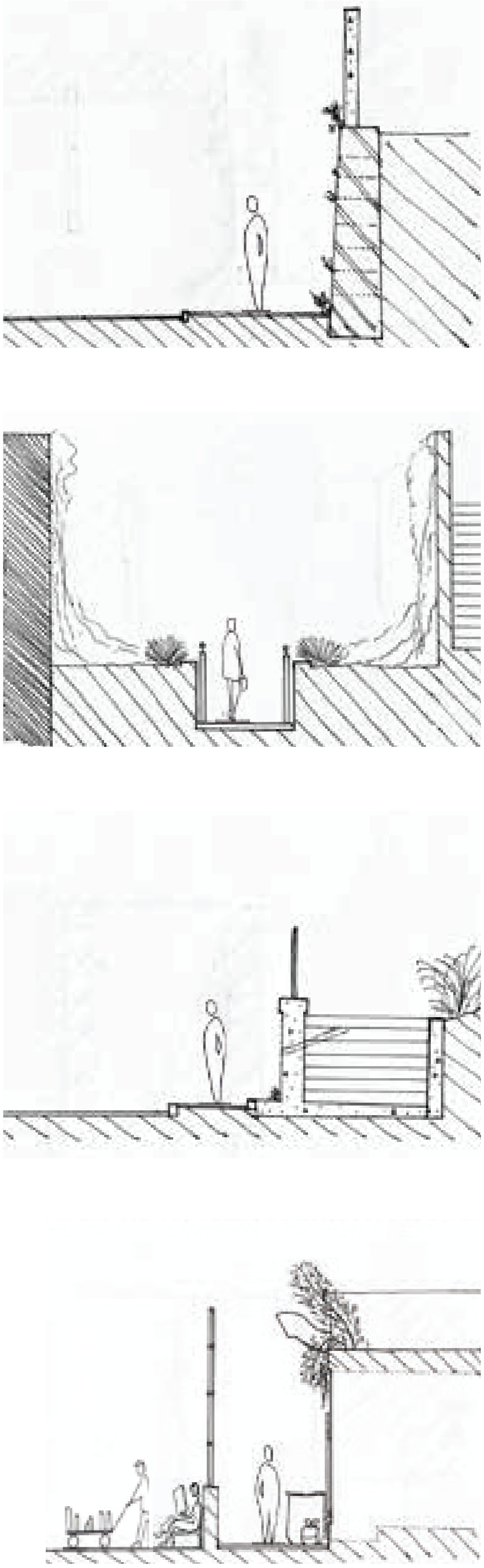


Fig. 07.05.03 Section sketches associated with photographic studies on the adjacent page.

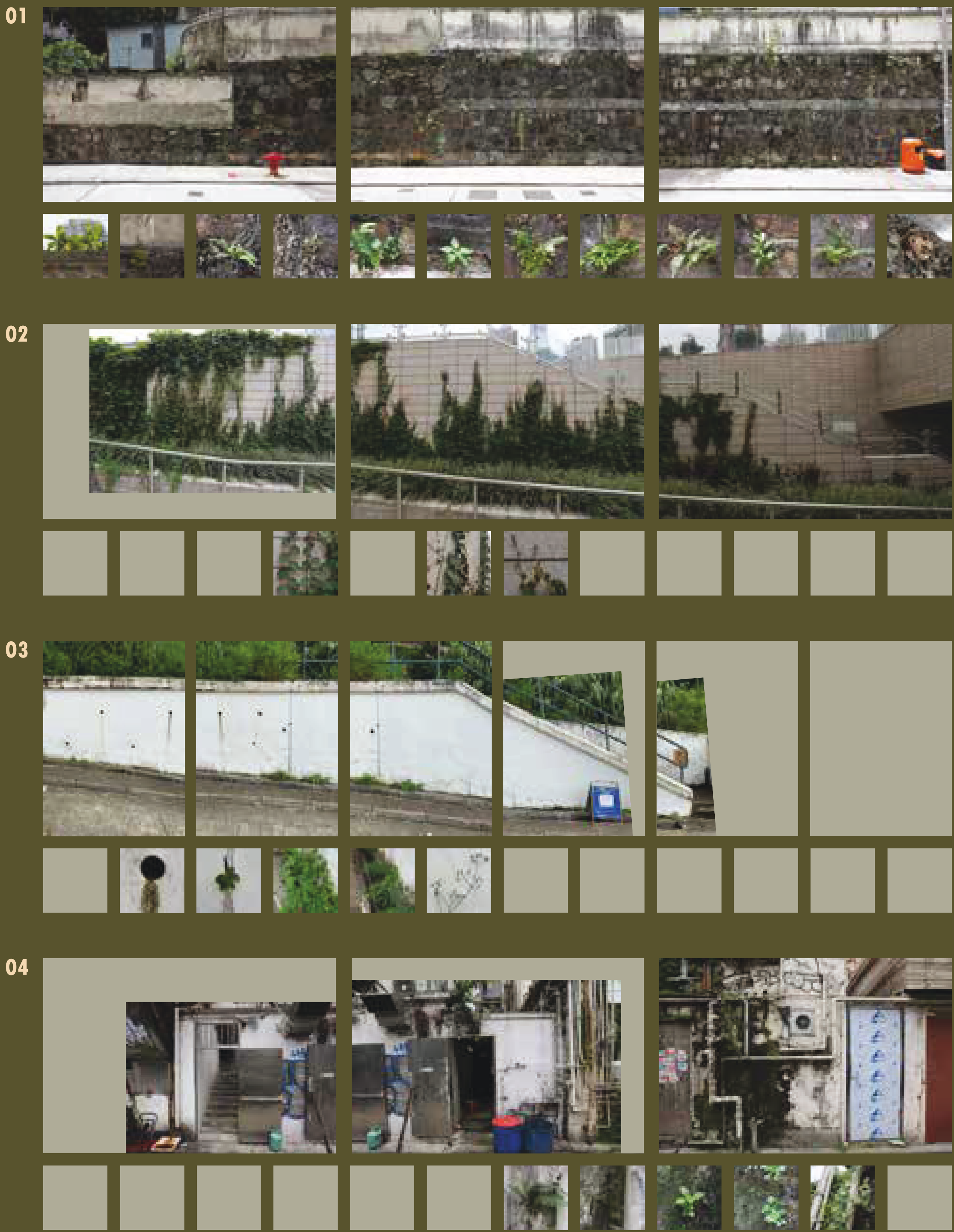
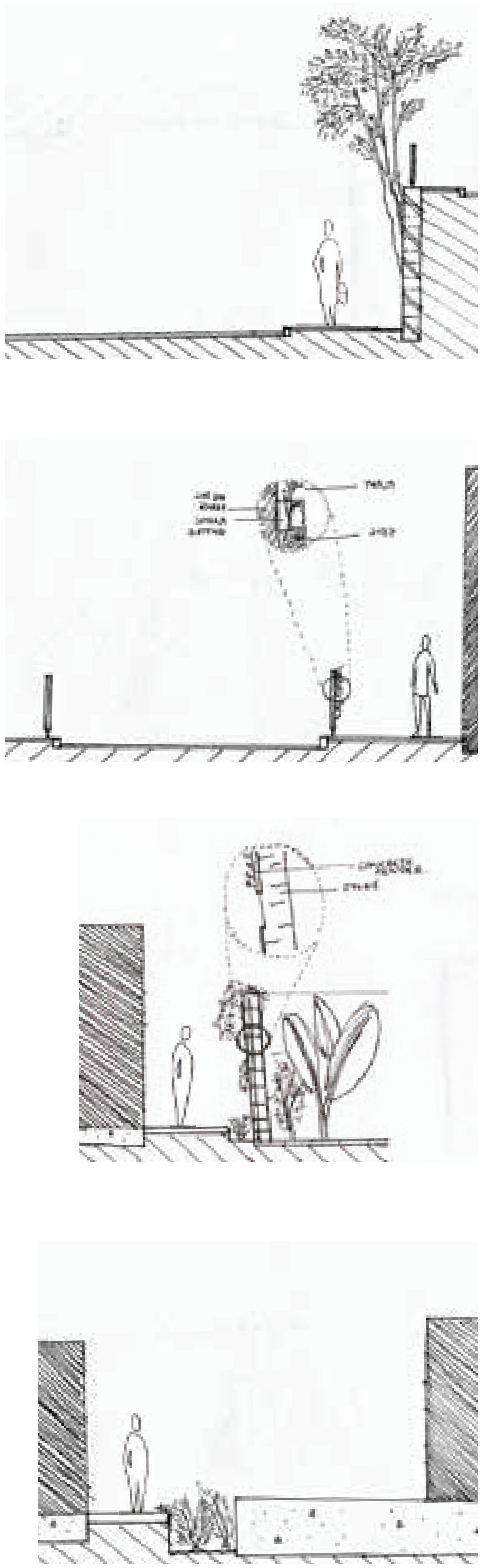


Fig. 07.05.04 Prior fieldwork investigating novel ecosystems within the dense urban environment of Hong Kong, including unplanned vegetation growth, and the specific conditions that enable it.

ECOLOGICAL INTERACTIONS

A further component of unplanned vegetation is the method of proliferation and seed transportation. As outlined previously, anemochory, hydrochory, and zoochory are the terms given for wind, water and animal seed dispersal, respectively. 'Endozoochory', a facet of zoochory specifying seed dispersal through ingestion in mammals such as birds, accounts for up to 34.4% of dispersal for trees and tall shrubs in forest environments in Hong Kong (Corlett, 2011). This method of dispersal is entirely reliant on fruit-bearing flora species, as these fruits are what lure animals to eat them, ingesting the seeds contained within the fruit, and spread through droppings.

Whilst this behaviour is specified to forest environments, there is potential for planning these interactions into our built environments through strategies such as the Green Mesh. This requires a further understanding of the unique conditions that promote or facilitate these interactions, the scope of further potential research and development. This has potential to not only encourage and accommodate fauna into our urban environments, particularly native birds and smaller insects, but to also introduce a method of autonomously vegetating certain areas through this natural mechanism.



05. Vines, climbers and aerial roots

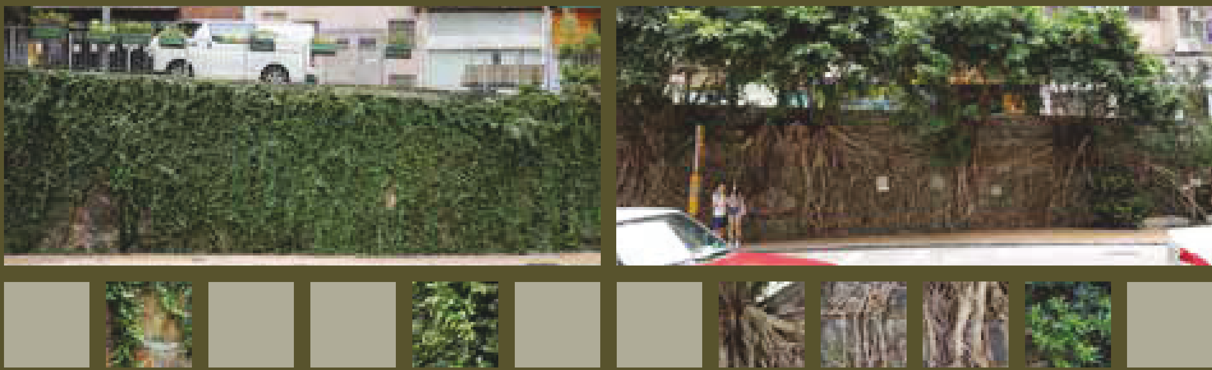
06. Small guerrilla ecologies established in urban areas by communities or individuals

07. Derelict, poorly maintained and deteriorating man-made surfaces.

08. Vegetation thriving in low-lying channels and divots, where water collects and pools

Fig. 07.05.05 Section sketches associated with photographic studies on the adjacent page.

05



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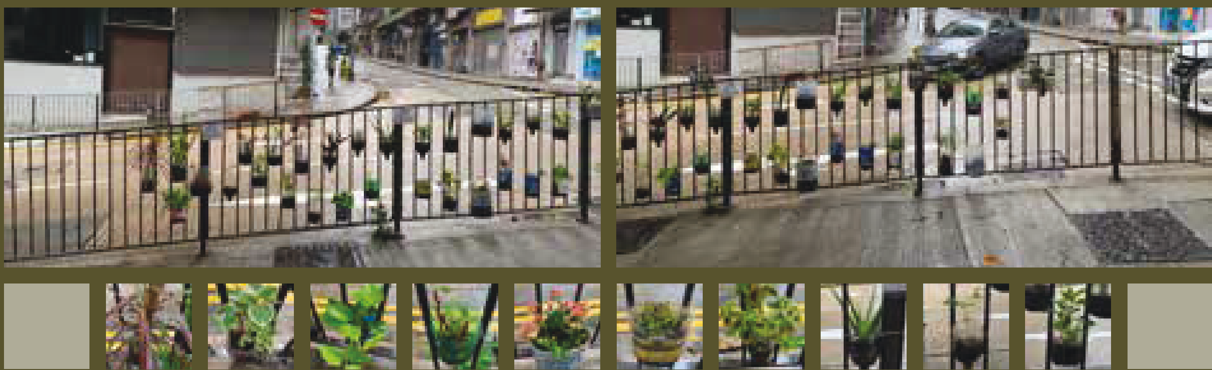

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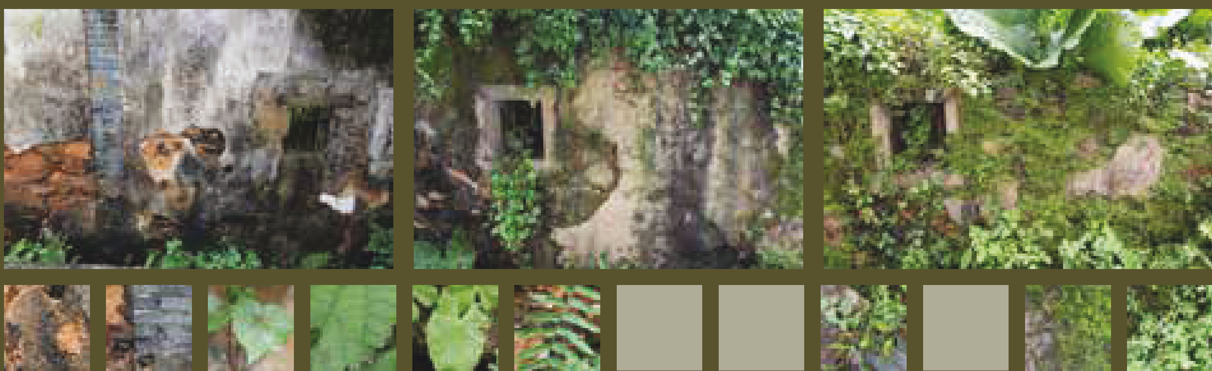

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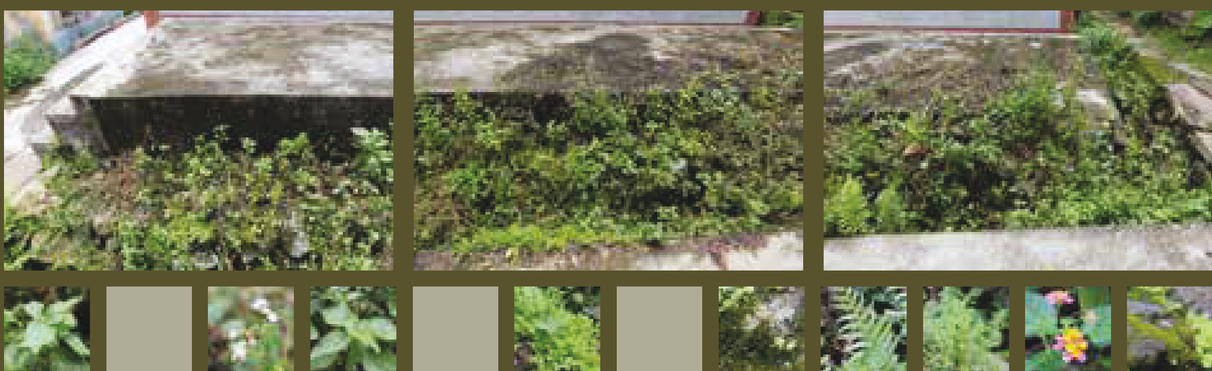


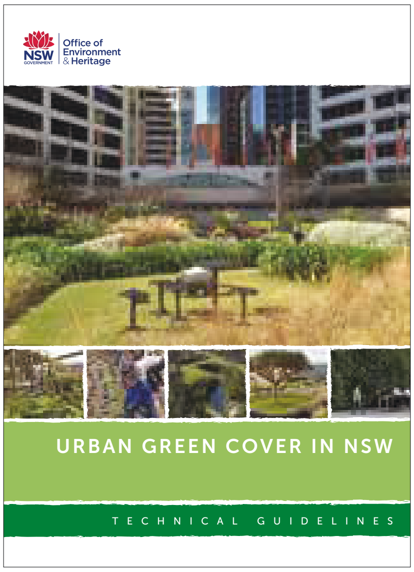
Fig. 07.05.06 Prior fieldwork investigating novel ecosystems within the dense urban environment of Hong Kong, including unplanned vegetation growth, and the specific conditions that enable it.

PLANNED URBAN VEGETATION: GREEN INFRASTRUCTURE TYPOLOGIES

URBAN GREEN COVER IN NSW - TECHNICAL GUIDELINES

Green infrastructure typologies, a type of planned urban vegetation, have introduced common ways of vegetating walls, rooftops, and ground surfaces, with numerous environmental benefits. These infrastructures are able to activate bare surfaces of buildings to urban greening, and have common forms of construction as detailed within 'Urban Green Cover in NSW - Technical Guidelines' (NSW Office of Environment and Heritage, 2015). This document was prepared by the Government Architect's Office in 2015, with contributions from the NSW Local Government Landscape Design Forum, the NSW Chapter of the Australian Institute of Landscape Architects (AILA), the Institute of Public Works Engineering Australasia and Fifth Creek Studio (Office of Environment and Heritage2, 2015).

The purpose of this document is to "offer built environment professionals working in state and local government and the private sector practical information and typical details to encourage best practice applications of green cover…" (Office of Environment and Heritage2, 2015). It covers green infrastructures from green/cool roofs, to green walls, green pavements, streets, and car parks. Whilst primarily focusing on the benefits of urban green cover in terms of Urban Heat reduction, the document advocates strongly for increased canopy cover throughout bushlands, habitat corridors, within streets, and across both green roofs and walls. It presents a range of typical construction drawings for each green infrastructure typology, outlining the benefits from both a human and ecological perspective, ranging from stormwater management, air quality improvement and urban heat reduction, to increased habitat, biodiversity and the treatment of pollination.



"Every 10% increase in tree cover can reduce land surface temperatures by more than 1°C… a 14% increase in tree cover would completely offset the thermal loading effect of urban structures in the Sydney basin."

- Office of Environment and Heritage[2] (2015)



Fig. 07.05.07 A range of green roof installations with different vegetation typologies. Source: [Left] Nest Architects (n/d), [Middle] De Boer (n/d), [Right] gardendesign.live (2021).

GREEN ROOFS

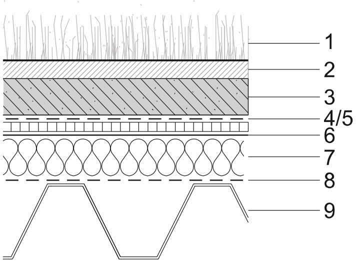
Green roofs are "roof surfaces that are partially or fully vegetated… [and] can be applied at a domestic or commercial scale" (Office of Environment and Heritage[2], 2015).

Rooftops throughout residential, commercial and industrial land zones alike, make up a significant proportion of hard, impervious surfaces within our built environments, and are therefore "one of the contributing factors to the Urban Heat Island (UHI) effect" (Office of Environment and Heritage[2], 2015). Similar to the installation of solar panels, green roofs can have a high initial cost, but "the insulative properties… will pay [themselves] off in savings from energy bills" (O'Donoghue, 2016), whilst improving visual amenity, reducing ambient and internal temperatures, supporting local ecologies and fauna, and supporting the environmental sustainability movement. Furthermore, with increasingly taller buildings in our urban areas, increasing the overshadowing effect on ground surfaces, rooftops have a high potential for sun exposure access and rainfall collection. A number of green roof variations exist that can be installed appropriately throughout residential, commercial and industrial building typologies.

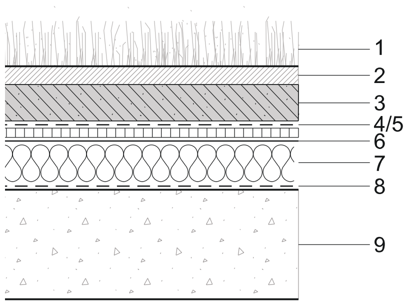
Green roofs can be classified into three variations [Fig. 07.05.08]; extensive, intensive, and elevated landscapes, with gradually deeper soil profiles and increasing abilities to support taller vegetation species. Deeper soil profiles, however, will have more significant structural requirements for the rooftops they are installed on. Supporting low-growing ground covers and the ability to be retrofit onto many existing buildings, extensive green roofs have a soil depth of less than 150mm and, as a result, have the greatest potential for widespread installation. Intensive green roofs, whilst limited to structurally stronger rooftops than that of extensive green roofs, will have higher ecological value due to a greater soil depth of between 150-600mm, and the ability to support vegetation from shrubs to trees. Green roofs within this classification, and with a depth of 300mm or more, "reduces roof surface temperature by 41% [or potentially more] in summer" (Hopkins and Goodwin, 2012). Finally, elevated landscapes have a soil profile of greater than 600mm, and therefore introduce the ability for a topographic variation, and come the closest to replicating the vegetation flexibility as the ground plane.

Green roofs can be installed across concrete roofs, plywood sheeting, or lightweight metal roof decks, with the latter restricted to extensive green roof typologies only, due to the lighter weight. Whilst typically flat, green roofs can be sloped as much as 35°.

1 LOW PLANTING
2 MULCH 50mm
3 SOIL TYPE 1
4 GEOFABRIC FILTER LAYER
5 DRAINAGE CELL
6 WATER PROOFING SHEET MEMBRANE
7 ADDITIONAL INSULATION (OPTIONAL)
8 VAPOR SEAL
9 EXISTING REINFORCED CONCRETE ROOF



1 LOW PLANTING
2 MULCH 50mm
3 SOIL TYPE 1
4 GEOFABRIC FILTER LAYER
5 DRAINAGE CELL
6 WATER PROOFING SHEET MEMBRANE
7 ADDITIONAL INSULATION (OPTIONAL)
8 VAPOR SEAL
9 EXISTING SHEET METAL ROOF



1 PLANTING
2 MULCH (50mm)
3 SOIL TYPE 1 (250 - 400mm)
4 SOIL TYPE 2 (300 - 600mm)
5 GEOFABRIC FILTER LAYER
6 20mm GRAVEL (NO FINES) LAYER
7 WATER PROOFING SHEET MEMBRANE
8 ADDITIONAL INSULATION (OPTIONAL)
9 VAPOR SEAL
10 EXISTING REINFORCED CONCRETE ROOF

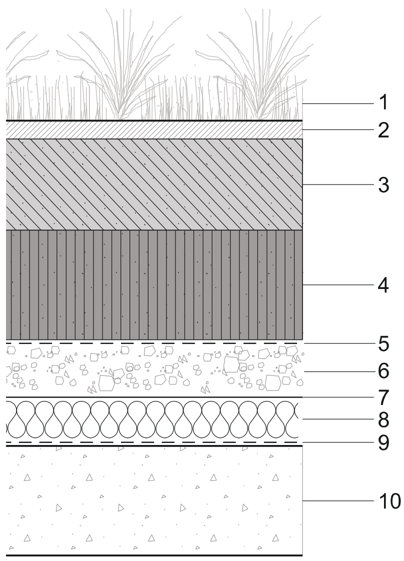


Fig. 07.05.08 A series of typical construction drawings for a variety of Green Roof implementations. Extensive green roofs [left, centre], and intensive green roof [right]. Source: Urban Green Cover NSW - Technical Guidelines', NSW Office of Environment & Heritage (2015).

MODULAR AND RETROFIT GREEN WALLS

Green walls, also called living walls, bio walls or vertical gardens, are "vegetated systems that are grown on the vertical facade of the building envelope… grouped into two main categories: green facade and green wall; each having several minor categories…. [and] rang[ing] from low technology to highly engineered" (Office of Environment and Heritage[2], 2015). As such, they range in scale from small, modular systems that can be fitted to residential walls and balconies, with planting 'pockets' or pots, to commercial-scale green walls that can extend vertically up high-rise buildings, and are architecturally integrated into the facade.

Green walls have a number of environmental and human benefits, improving liveability and mental health, whilst purifying the air we breathe, and introducing greater biodiversity into our urban areas. From a human and liveability point of view, the vegetation and greenery enabled on vertical, otherwise man-made concrete, brick or masonry walls, has a calming effect and a positive impact on stress-related illnesses (urbangreening.info, n/d). Furthermore, along with a greater aesthetic and property value, green walls actively "reduce adjacent pavement temperatures by 5°C through reduced building surface temperature and surrounding ambient air temperature" (Hopkins et al. 20122), whilst also "extract[ing] 2.3kg of CO2 per annum [per m2 of green wall]… produc[ing] 1.7kg of oxygen… [and] absorb[ing] harmful VOC's and convert[ing] them into a compound which plants use for food" (Tirelli, 2019). This helps, to a certain degree, to offset the carbon we produce day-to-day.

"Green walls can reduce adjacent pavement temperatures by 5°C through reduced building surface temperature and surrounding ambient air temperature"

- Hopkins et al.[2] (2012)

With increased potential surface area for planting enabled through green walls, this introduces a greater potential for water management practices, reducing or suppressing stormwater runoff and retaining more water on site through soils, roots and plant uptake, with more space for urban farming and the production of local fruits and vegetables. These two latter benefits can greatly reduce our reliance

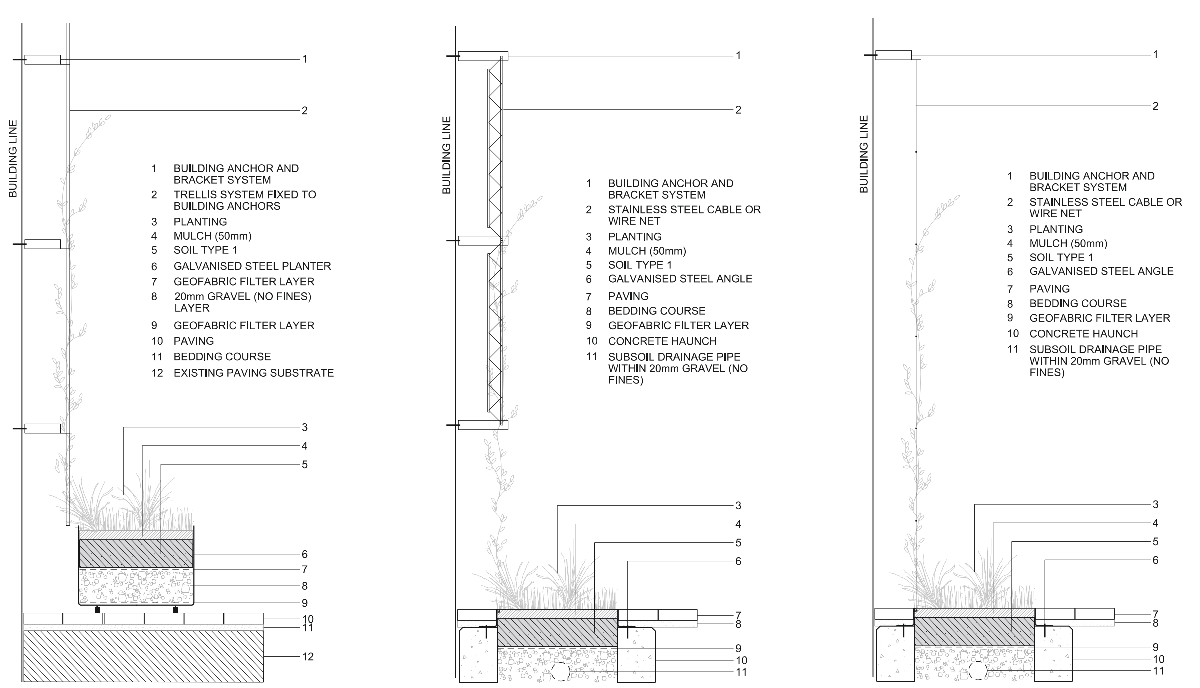


Fig. 07.05.09 Typical green wall construction, [Left] Trellis And Container System, [Middle] Modular Trellis Panels, and [Right] Cable And Wire Net System. Source: 'Urban Green Cover NSW - Technical Guidelines', NSW Office of Environment & Heritage (2015).

Fig. 07.05.11 Steel cable, trellis, and plant container green wall implementations. Source: [Left] Jakob Rope Systems (n/d), [Middle] Tournesol Siteworks (n/d), [Right] Jakob Rope Systems (2013).

on centralised water and food sources, increasing the resilience on these human systems. Finally, green walls bring significant ecological value, attracting a range of pollinator insects, and predators ranging from dragonflies, ladybugs, spiders and birds, promoting and facilitating natural food-chains and natural nutrient cycles.

"Approximately 25% of carbon emissions made by human activity are absorbed by plants, and living walls contribute to that absorption"

- Rinkesh (n/d)

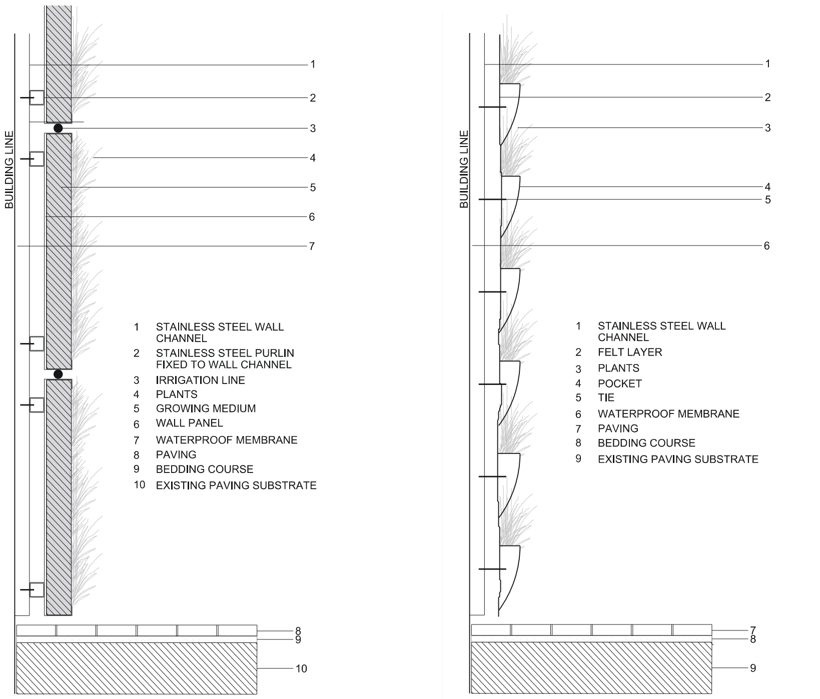


Fig. 07.05.10 Typical green wall construction, Modular Panel System [left] and Felt/Mat System [right]. Source: 'Urban Green Cover NSW - Technical Guidelines', NSW Office of Environment & Heritage (2015).

"Only one m² of living wall extracts 2.3 kg of CO2 per annum from the air and produces 1.7 kg of oxygen. There have been many studies which prove that plants and the microbes found in soil media absorb harmful VOC's and convert them into a compound which plants use for food."

- Tirelli (2019)

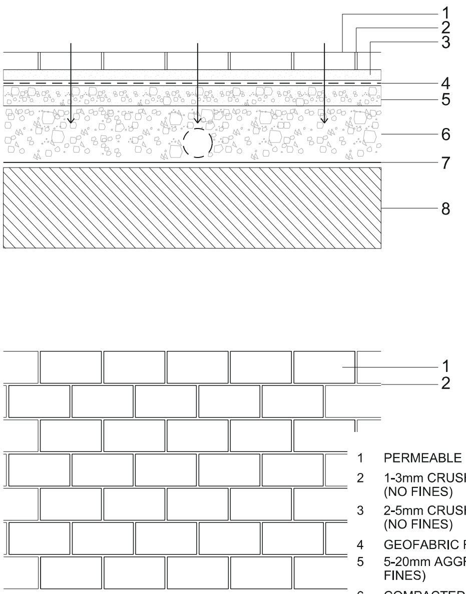
REFLECTIVE AND PERMEABLE PAVEMENTS

Green pavements are "reflective or light-coloured pavements and permeable pavements… designed with a number of objectives… [including] a cooling effect on surface and ambient air temperatures… flood control, pollution control and stormwater harvesting" (Office of Environment and Heritage[2], 2015). These systems replace traditional man-made, dark-coloured, hard pavements, that along with rooftops, contribute to a significant proportion of horizontal surface area within urban environments, together the major causes of the UHI effect that is exacerbated by car engines, air conditioners and reduced green cover (Office of Environment and Heritage[2], 2015).

"…reflective or light coloured pavements and permeable pavements have a cooling effect on surface and ambient air temperatures and over-night cooling of urban areas"

- Office of Environment and Heritage[2] (2015).

Green pavements can be classified into either reflective pavements, or permeable pavements, with each system significantly reducing the UHI effect through their specific functions. Reflective pavements include surfaces such as modified asphalts, white or coloured concretes, and resin bond aggregates, targeting solar reflectivity to reduce heat, by reducing the level of heat absorbed into the surface. Permeable pavements include materials such as porous asphalts and concretes, interlocking and unit paver systems, and resin bond aggregates, promoting surface infiltration and the cooling effect of evaporation.



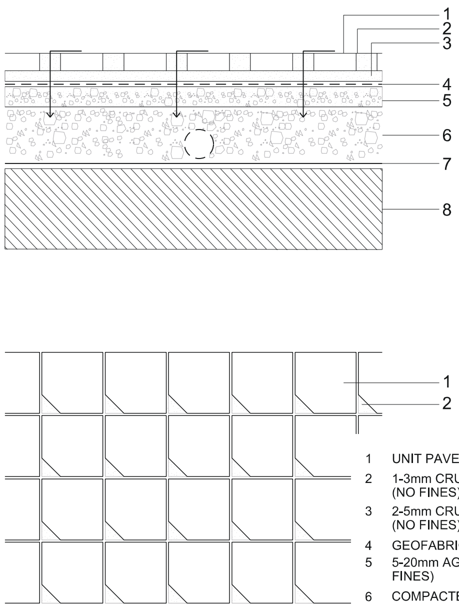


Fig. 07.05.12 Typical construction for permeable/porous pavers, [Left] Porous Pavers, and [Right] Interlocking System. Source: 'Urban Green Cover NSW - Technical Guidelines', NSW Office of Environment & Heritage (2015).

Fig. 07.05.13 Interlocking paver systems, and permeable asphalt. Source: [Left] Aveng Manufacturing Infraset (2014), [Second from the left] Andras Kis, NWRM (n/d), [Second from the right] Apartment Therapy Re-Nest (n/d), [Right] HydroCon (n/d).

SUMMARY & DESIGN PRINCIPLES

SUMMARY

A range of formal and informal urban vegetation typologies have been identified and detailed, informing a further six design principles for the implementation of the Green Mesh.

Studies into the physical characteristics of urban vegetation spontaneity in Hong Kong revealed a number of physical characteristics to accommodate the autonomous distribution of plant growth. By utilising more porous and imperfect vertical and horizontal surfaces, vegetation is able to establish in gaps, cracks, ledges and joins. Furthermore, natural ecosystem functions and animal-plant co-dependencies and environmental effects like wind and water movement are able to distribute seeds for autonomous and spontaneous growth. These functions can be replicated in a planned manner to encourage vegetation spontaneity across particular surfaces and walls, through the adoption of natural, porous materialities, and a selection of seed-bearing nearby vegetation to facilitate self-seeding.

Existing documentation from the NSW Office of Environment and Heritage (NSW OEH), prepared by the Government Architects Office in 2015 titled 'Urban Green Cover in NSW – Technical Guidelines', outlines a range of urban green infrastructure typologies and implementations that include green walls, roofs, and pavements, that can be adopted by the Green Mesh, and presented to individuals and communities in an understandable manner to encourage a far greater uptake in the adoption of these existing green infrastructure typologies throughout private gardens and lots. Furthermore, this will promote a draping of vegetation and greening over and around built form and along the ground surface, dynamically and gradually establishing the intended fine-granularity and wide-spread dispersal of ecological integration of the Green Mesh concept. Considerations into the solar irradiance potential of various surfaces within a particular lot, along with materiality and structure will be reflected in the strategy of implementation for these typologies, communicated to the public through the Green Mesh platform with simple instructions of where they can be implemented and to what extent, and whether it can be DIY or requires professional consultation and installation.

DESIGN PRINCIPLES

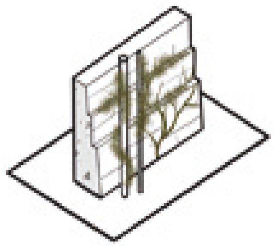
In contrast to previous sections of this chapter, this section sought to directly describe the physical characteristics which enable vegetation to grow and proliferate within urban environments - both in an informal manner through spontaneity, and formal green infrastructure typologies. As such, the final six design principles to complete the set of 24, are a direct reflection of the findings and research within this section. Principles 19-21 [Fig. 07.06.01] portray the findings of unplanned urban vegetation, with principles 22-24 including the outlined formal green infrastructure typologies.

The unplanned vegetation principles capture three distinct methods of spontaneous vegetation growth, involving the traits of the vegetation itself, guerrilla human interventions, and seed dispersal due to fauna or environmental factors like wind. These characteristics were revealed through primary research and observation.

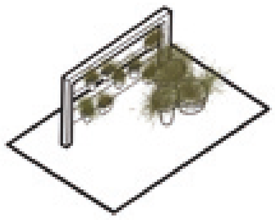
The formal green infrastructure principles feature three existing green infrastructure components informed through 'Urban Green Cover in NSW – Technical Guidelines' from NSW OEH, seeking to promote the further adoption of green infrastructures within our built environment. Permeability within pavements goes hand-in-hand with previous findings about materiality revealed in the micro-climate section. Not only does this allow for water infiltration into the soils for nearby plants and trees to make use of, but with the addition of reflective pavements our man-made hard surfaces will absorb less solar energy and therefore reduce ambient temperatures and UHIs. Green roofs and walls, traditionally installed in isolation and therefore providing limited interconnectivity between other ecological implementations, will instead become part of the broader green network when implemented within the Green Mesh strategy, as individual pieces of the mesh pattern. In tighter or space-restricted locations, along with locations with poor ground-plane sun exposure, green roofs and walls will make the most of available sunlight for a range of vegetation typologies, whilst acting to insulate buildings and reduce the need for artificial indoor cooling on warmer days.

07.05

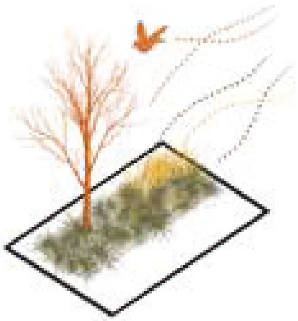
PLANNED & UNPLANNED URBAN VEGETATION - DESIGN PRINCIPLES



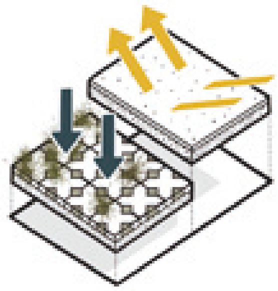
19. CREATE OPPORTUNITIES FOR SPONTANEOUS VEGETATION



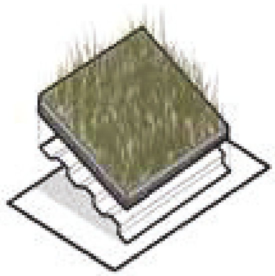
20. PUBLIC GUERRILLA ECOLOGIES



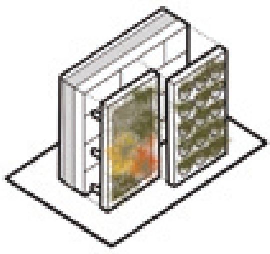
21. ANIMAL, INSECT AND ENVIRONMENTAL SEED DISPERSAL



22. PERMEABLE AND REFLECTIVE PAVEMENTS



23. FORMAL GREEN ROOF INFRASTRUCTURES



24. FORMAL GREEN/LIVING WALL TYPOLOGIES

19. Unplanned and naturally spread opportunist vegetation within cracks, on ledges, self-attaching, or attached to objects like pipes

20. Small guerrilla ecologies established in urban areas by communities or individuals, often recycling common materials for an alternate purpose

21. Natural seed dispersal through bird and insect movement as well as environmental factors such as wind and water, fire, and natural release

22. Utilise permeable and reflective materialities to replace traditional hard surfaces, promoting cooler urban areas and water retention

23. Formal green roof infrastructures requiring dedicated installation and structural considerations

24. Formal green/living wall infrastructures with a range of typologies and range of installation requirements from widely available easy to install methods, through to more complicated ones

DESIGN PRINCIPLES

Urban Micro-Climate Simulation

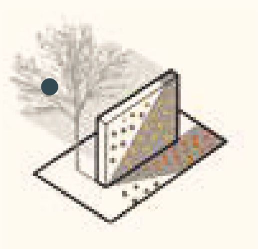
ENVIRONMENTAL BASELINE

07.02

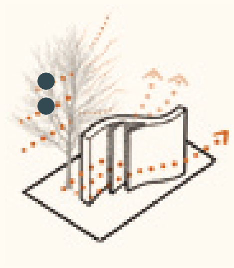
Socio-Spatial Observation and Place Narrative

THE SOCIAL DIMENSION

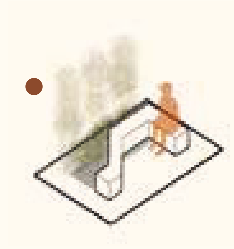
07.03



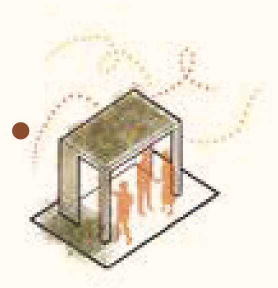
01. INCREASE URBAN SHADE & OPTIMISE PLANT SELECTION TO SUN EXPOSURE



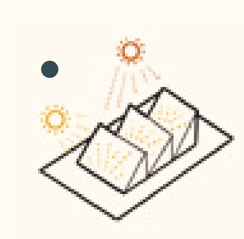
02. HARD & VEGETATED SURFACES FOR WIND BUFFERING OR VECTORING



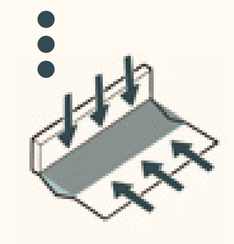
07. ECOLOGICAL SPACES FOR PEOPLE AND GATHERING



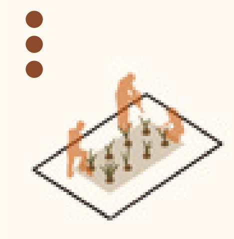
08. INTEGRATE ECOLOGICAL FUNCTION WITHIN COMMON PUBLIC ELEMENTS



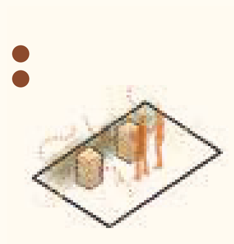
03. UTILISE SURFACES WITH OPTIMAL ASPECT & DIRECTION FOR SOLAR IRRADIANCE



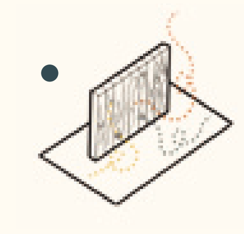
04. LOCATE WATER RETENTION WITHIN NATURAL AREAS OF SATURATION



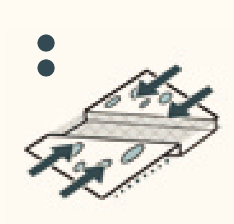
09. LOCAL NURSERIES TO PROMOTE A SENSE OF COMMUNITY AND SHARED RESPONSIBILITY



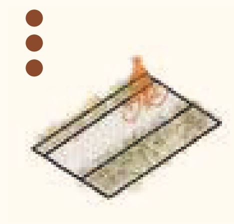
10. URBAN BEEKEEPING TO FACILITATE POLLINATION AND ATTRACT PREDATORS



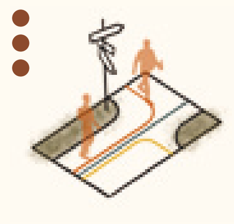
05. USE NATURAL MATERIALS THAT HAVE GREATER PERMEABILITY & ECOLOGICAL POTENTIAL



06. UTILISE SURFACE PERMEABILITY TO PROMOTE WATER INFILTRATION



11. ACTIVE TRANSPORTATION PATHS INTEGRATED ALONG LINEAR WILDFLOWER MEADOWS



12. WAY-FINDING AND SIGNAGE TO CONNECT PEOPLE WITH THE GREEN MESH

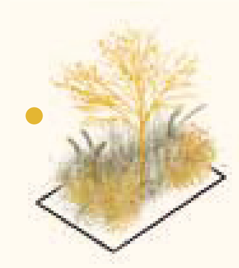
Fig. 07.06.01 Green Mesh Design Principles generated through fieldwork and first-hand investigation into micro-climate simulation, the social dimension, species specificity & backyard sustainability, and physical implementation.

Ecological Case-Studies and the Vegetation Matrix

SUSTAINABILITY AND THE NON-HUMAN BIOSPHERE
07.04

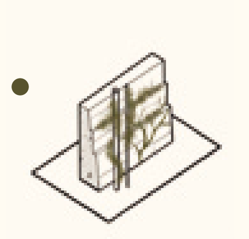
Planned and Unplanned Urban Vegetation

VEGETATION GROWTH AND PROLIFERATION
07.05

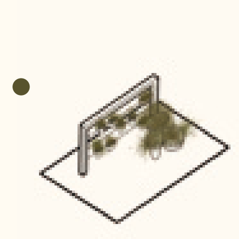


13. PLANTING IN CO-DEPENDENCY GROUPS

14. RESOURCE SUSTAINABILITY

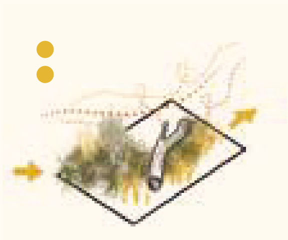


19. CREATE OPPORTUNITIES FOR SPONTANEOUS VEGETATION

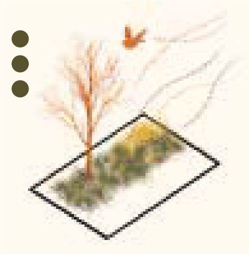


20. PUBLIC GUERRILLA ECOLOGIES

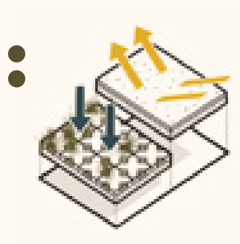
15. REDUCE WASTE, RECYCLE COMMON MATERIALS



16. FAUNA HABITAT AND VEGETATION CORRIDORS

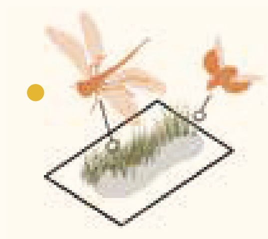


21. ANIMAL, INSECT AND ENVIRONMENTAL SEED DISPERSAL



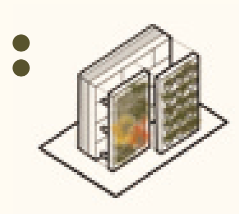
22. PERMEABLE AND REFLECTIVE PAVEMENTS

17. A DIVERSITY OF GARDEN-BED TYPOLOGIES



18. NATIVE INSECTS FOR PEST MANAGEMENT, ORGANIC WEED & DISEASE MANAGEMENT

23. FORMAL GREEN ROOF INFRASTRUCTURES



24. FORMAL GREEN/ LIVING WALL TYPOLOGIES

SCALE OF ECOLOGICAL OR SOCIAL INFLUENCE

Broad

Local

Micro

RESOLVING THE GREEN MESH: THE FINAL METHODOLOGICAL FRAMEWORK & INTERFACE

08

08. RESOLVING THE GREEN MESH: CONSOLIDATED METHODOLOGICAL FRAMEWORK & INTERFACE

08.01 Green Mesh Methodological Framework & Online Interface

METHODOLOGICAL FRAMEWORK

The Methodological Framework [Fig. 08.01.01] is the consolidated structure of all research findings, fieldwork outcomes, conceptual development processes, and testing undertaken throughout this dissertation. It presents a practical methodology for connecting individuals and community members to highly precise environmental data of their own property, within the united aims of the 'Green Mesh' metropolitan green network.

The methodology is framed around four distinct steps; Generate, Define, Receive, and Apply. These steps are directly related to fieldwork methodologies explored throughout chapter 07.

- **'Generate'** introduces the 3D spatial data into the methodology, using this data to simulate the micro-climate characteristics of the individual property or public space to inform all further steps of the methodology.
- **'Define'** is derived from the 'Social Narratives' section of the previous chapter, giving the user the ability to select the desired program or function of the Green Mesh implementation. This selection is tailored to individual surfaces of the property, influenced by whether the user selects a rooftop, ground surface for planting, or public verge area, and itself influencing the recommended vegetation typology of the next step.
- **'Receive'** incorporates the vegetation matrix and garden typologies into the process, using the micro-climate characteristics of the chosen surface, and the desired program, to suggest a range of particular species suitable for planting.
- **'Apply'** recommends the suitable physical implementation strategies for the user to action within their own property, in response to inputs and outputs of prior steps.

ONLINE INTERFACE

The theoretical Green Mesh Online Interface [Fig. 08.01.02] takes the steps outlined within the methodological framework, and translates it into a simplified interface for community members to interact with. This will allow users to receive property-specific micro-climate information, along with explicit instructions on how to construct their own ecological implementations for their desired function or purpose. Furthermore, the interface incorporates a 'social networking' capacity, displaying all nearby and adjacent Green Mesh implementations, with each user being able to explore these implementations within their neighbourhood. This allows users to not only gain inspiration from one another, in turn facilitating a sense of shared community responsibility, but also allow neighbours to reach out to one another and ask questions, whilst recommending implementation that might compliment ones in adjacent properties.

The following pages outline both the theoretical Methodological Framework, and this framework in-action within the theoretical Online Interface.

The online interface aims to provide a simplified platform for connecting communities to the information they require for implementation of the Green Mesh - matching suitable design principles and vegetation species to the micro-climate characteristics of their property, and the programmatic preferences of the user.

GREEN MESH
METHODOLOGICAL FRAMEWORK

THE FOUR STEPS

DESCRIPTION AND VARIABLES

01 GENERATE
Micro-Climate Data

Fine-grain, property specific data for plant suitability

DESCRIPTION

Property And Street Specific Micro-Climate Simulation Data (Simplified For A General Audience), Along With The Classification Of Other Place- Specific Vegetation Suitability Variables.

VARIABLES

Materiality & Permeability / Sunlight Access / Solar Radiation & Temp / Wind Conditions / Water Potential / Soil Landscape

02 DEFINE
Desired program & function

Programmatic possibilities on a Surface-by-surface basis for a given property

DESCRIPTION

Using micro-climate data to understand the possibilities for planting and vegetation for the different surfaces of a property. The desired surface and associated program are then selected.

VARIABLES

Private: Backyard / Front Yard / Rooftop / Vertical Surface / Driveway

Public: Roadway / Verge / Footpath / Park / Pavement

03 RECEIVE
Species Recommendation

Vegetation Matrix featuring a diversity of Garden Typologies

DESCRIPTION

The Chosen program will inform the Garden Typology and function of the garden. Species from one typology are then recommended based on suitability to the micro-climate conditions.

VARIABLES

Indigenous / Native Flowering / Green Wall Suitable / Productive / Wetland / Remediation

04 APPLY
Physical Implementation Strategies

Design Principles and Implementation Strategies

DESCRIPTION

Design Implementations, filtered by public/private, physical possibilities of the surface, and programmatic considerations, Present the physical implementations that can be constructed.

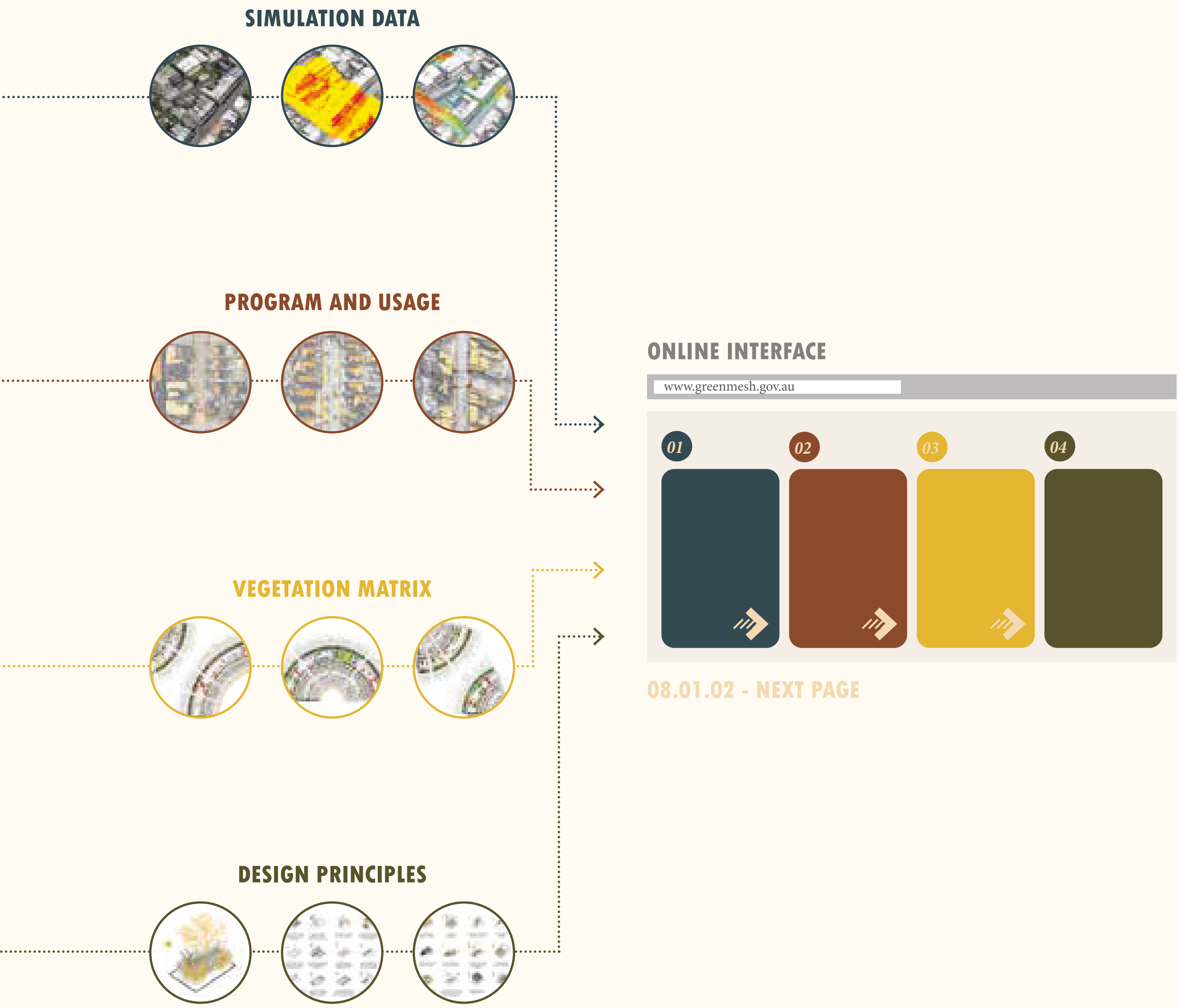
VARIABLES

Green Walls / Green Roofs / Raised Garden Beds / In-Situ Garden Beds / Sustainable Infrastructure / Urban Bee Hives / Bioswale Filtration / Urban Meadows / Street Trees / Accessibility & Transport

Fig. 08.01.01 Resulting theoretical Methodological Framework for the Green Mesh Online Interface, allowing individuals, community groups, and local councils the ability to implement green infrastructure and sustainability practices in a highly place-specific and responsive way.

DATA FILTERS

SYNTHESIS & SPECIFICITY

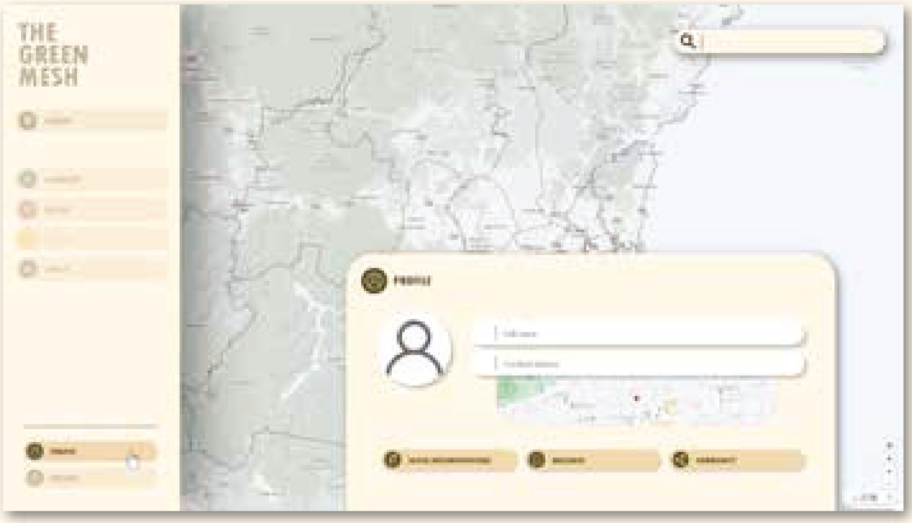


GREEN MESH ONLINE INTERFACE

CREATE

your profile and register your address

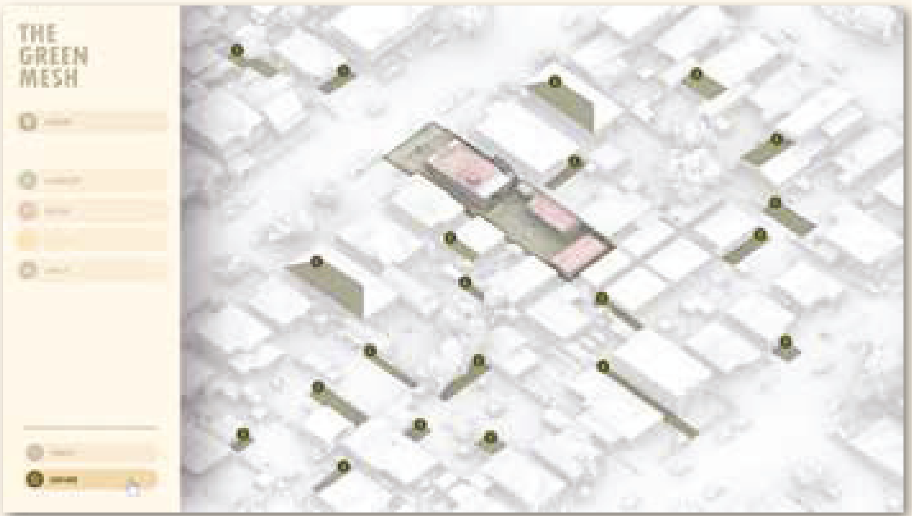
A profile will be created to enable access to the spatial data securely for their address. This profile will also be used to register and save the user's unique Green Mesh implementations and associated information, as well as connecting with other residents and community members.



EXPLORE

Green Mesh implementations within your neighbourhood

The user can view the network of existing Green Mesh implementations within their neighbourhood. They are able to view the type of implementation, and the species used, whilst also being able to send messages to neighbouring residents to ask any questions and share tips.



01 GENERATE

Micro-Climate Data

3D spatial data is used for micro-climate simulation, producing a property-specific analysis. The user can turn these 3D layers on and off, rotate the 3D model, and view the textural qualities of their property within a simplified context for the privacy of adjacent neighbours. In additional to private lots, there is potential for local councils and design professionals to use this data within public space projects, street greening, and parkland works.

Fig. 08.01.02 The theoretical Green Mesh Online Interface, following the steps of the Methodological Framework to connect individuals and communities to the information required for activation of the Green Mesh from the bottom-up.

02 DEFINE
Desired program & function

The user is then presented with the possible ecological implementations for their property, surface by surface. They are able to click between surfaces, each with a tailored selection of possible programs and garden typologies. Furthermore, they are able to view the details and extent of neighbouring Green Mesh implementations, providing inspiration and a sense of shared community responsibility.

03 RECEIVE
Species Recommendation

A vegetation matrix, particular to the ecological communities of the relevant LGA, will then provide a list of species suitable to the micro-climate conditions of the chosen surface. These species are also associated with the user-selected program or garden typology, where the user may prefer either a productive garden to produce fruit and vegetables, or a native garden to attract wildlife.

04 APPLY
Physical Implementation Strategies

Informed by the results and selections from all prior steps, the user is presented with a range of suitable physical implementation strategies. These implementations range from easy, DIY gardens, to more complicated projects that would require inputs from a range of professionals including landscape architects, architects or engineers. After making a selection, the user will be provided with, or referred to, the relevant details for construction.

08.02 Testing the Green Mesh Methodology: Exemplar Design Cases

METHODOLOGY

This final step in the research and development of the Green Mesh was to apply the Methodological Framework to real-world scenarios and neighborhoods. The methodology was applied to three distinct sites, two of the primary focus sites used previously within this dissertation, and a third from a different LGA to test replicability within other areas of Sydney. These tests led to the 'Exemplar Design Cases' [Fig. 08.02.01-03] on the following pages, in each case gathering all micro-climate simulation data, which was used to inform the suitable placement of ecological implementations selected from Design Principles.

The chosen locations, shown adjacent, represent industrial, commercial, and residential contexts, each with different built form typologies, urban challenges, and programmatic considerations As a result of these differences, the Exemplar Design Cases demonstrate the flexibility and dynamics established through the Green Mesh, responding to each situation with different connectivity patterns and unique combinations of design principles. Furthermore, through the urban meshing of these design principles, a range of interactions begin to form, where wildflower gardens provide food and habitat for native bee hives, water captured and filtered through green walls runs into adjacent retention ponds, and buffer planting provides a wind shield to urban agriculture plots.

The adjacent site descriptions correlate to Exemplar Design Case drawings on the following pages.

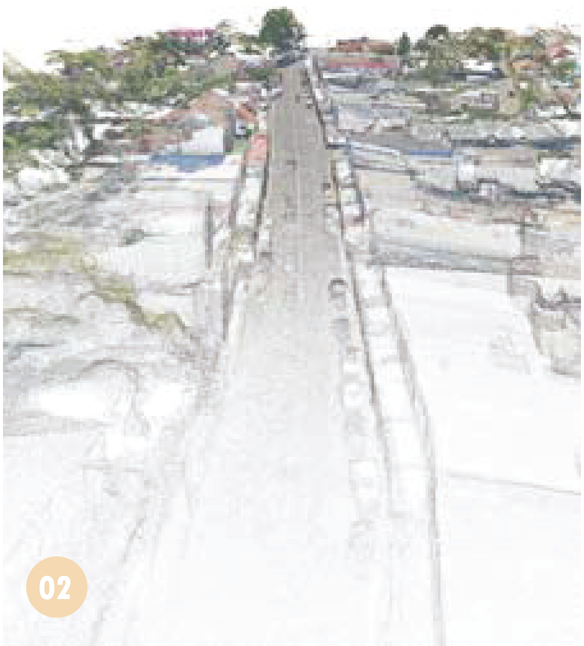


Fig. 08.02.01 Point cloud data, Willoughby Rd

01 EXEMPLAR DESIGN CASE: INDUSTRIAL & VACANT LOT

HIGH ST, CHATSWOOD

08.02.01 The first Exemplar Design Case is situated within a light industrial area of East Chatswood. It demonstrates the potential of the Green Mesh system within the context of large-lots, industrial building typologies, and the transformation of vacant lots into local community nurseries. To the north of the site, a Green Grid corridor follows a vegetated gully, whilst within the industrial zone, a distinct fragmentation of canopy can be seen.

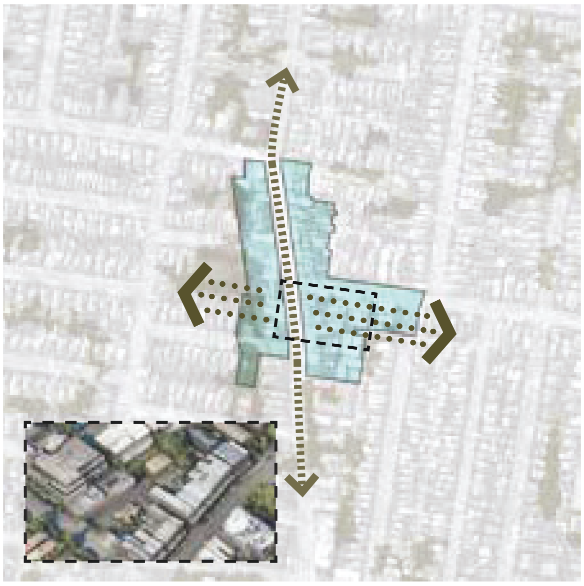
The Green Mesh linkage demonstrated through the exemplar design case in Fig. 08.02.01, establishes an ecological connection perpendicular to this Green Grid corridor, drawing it in and through the industrial zone. A matrix of ecological implementations, ranging from green roofs and walls, to vegetated wind buffers and bioswale retention pits, respond directly to the distinct micro-climate opportunities identified through the simulation process.

At the centre of the site, a community nursery provides space for vegetation to be grown, acclimatising to the local conditions, before transplantation into nearby backyards. This nursery is protected by wind-buffering trees to the south-west, creating a calm condition on the interior of the site for the growth of young plants and trees. There is further potential for the re-purposing of the adjacent industrial building into an indoor plant market.

Circulation throughout the site is enhanced through shade canopy, whilst to the north of the site, solar panels angled optimally towards the sun provide shade on terraced seating for the community to use.

02 EXEMPLAR DESIGN CASE: COMMERCIAL & HIGH DENSITY RESIDENTIAL

WILLOUGHBY RD, WILLOUGHBY



Local Centre (Commercial)

0 100m

08.02.02 Characterised by a mix of traditional terrace-style shopfronts and contemporary residential apartments, the local commercial centre of Willoughby Rd, classified by the Sydney Green Grid as an existing open space corridor, was the site of the second Exemplar Design Case.

Along the otherwise impermeable facade of shopfronts, a service alleyway provided the opportunity for infiltration to a carpark at the rear. Maintaining service access and function of this alleyway, a large, feature green wall and introduction of a permeable ground surface establish a more inviting environment for wildlife and human occupants alike. Full sun access of the green wall ensures the growth of suitable plant species, whilst the wall itself experiences less heat absorption, resulting in a cooler indoor temperature. The rear carpark itself features the addition of two pond habitats within naturally low-lying points. Water runoff from surrounding roads is guided into these ponds, providing filtration, and either absorption into the ground or evapo-transpiration into the atmosphere. A central bee-hive is located in a protected area of the carpark to pollinate all surrounding vegetation.

Finally, the rooftop of an adjacent apartment building is formalised into a diverse rooftop garden, once again utilising buffer-trees to protect from wind at this higher altitude. This garden has the potential to provide locally-grown herbs and vegetables to residents, a replicable model for many apartment blocks.

03 EXEMPLAR DESIGN CASE: LOW DENSITY SUBURBAN RESIDENTIAL

CHISHOLM RD, AUBURN

0 250m

Low Density Residential
Green Space
Remnant Canopy
Green Mesh Linkage
Green Grid or O/S Corridor

08.02.03 Along the major Duck River Green Grid Corridor, the third exemplar design case sought not only to test the Green Mesh against a residential context, but it's applicability within other LGAs of Sydney. As such, the Green Mesh here seeks to address the particularly poor canopy cover of this area in Auburn, which results in harsh summer temperatures exacerbated by the amount and density of exposed rooftops. Furthermore, with the high ecological potential of the Duck River corridor nearby, the design case aims to blur the intense division between river corridor and suburban living, integrating the former within the latter.

The small remnants of canopy that do exist are reconnected through new tree planting within backyards and along roadsides, introducing shade and cooler ambient temperatures, whilst establishing habitat for native fauna - particularly for many species of birds. A range of small-scale garden beds, implemented within backyards, are located based on sun or shade conditions particular to each property, whilst providing either food - through productive vegetation, or additional habitat - through native or flowering vegetation. Bee-hives provide pollination for nearby vegetation, whilst attracting larger predators in the form of native wildlife and other insects. Finally, solar panels and rainwater tanks promote resource sustainability and the densentralisation of energy and water supplies, with each example positioned for maximum solar irradiance, or shade, respectively.

01 EXEMPLAR DESIGN CASE: INDUSTRIAL & VACANT LOT

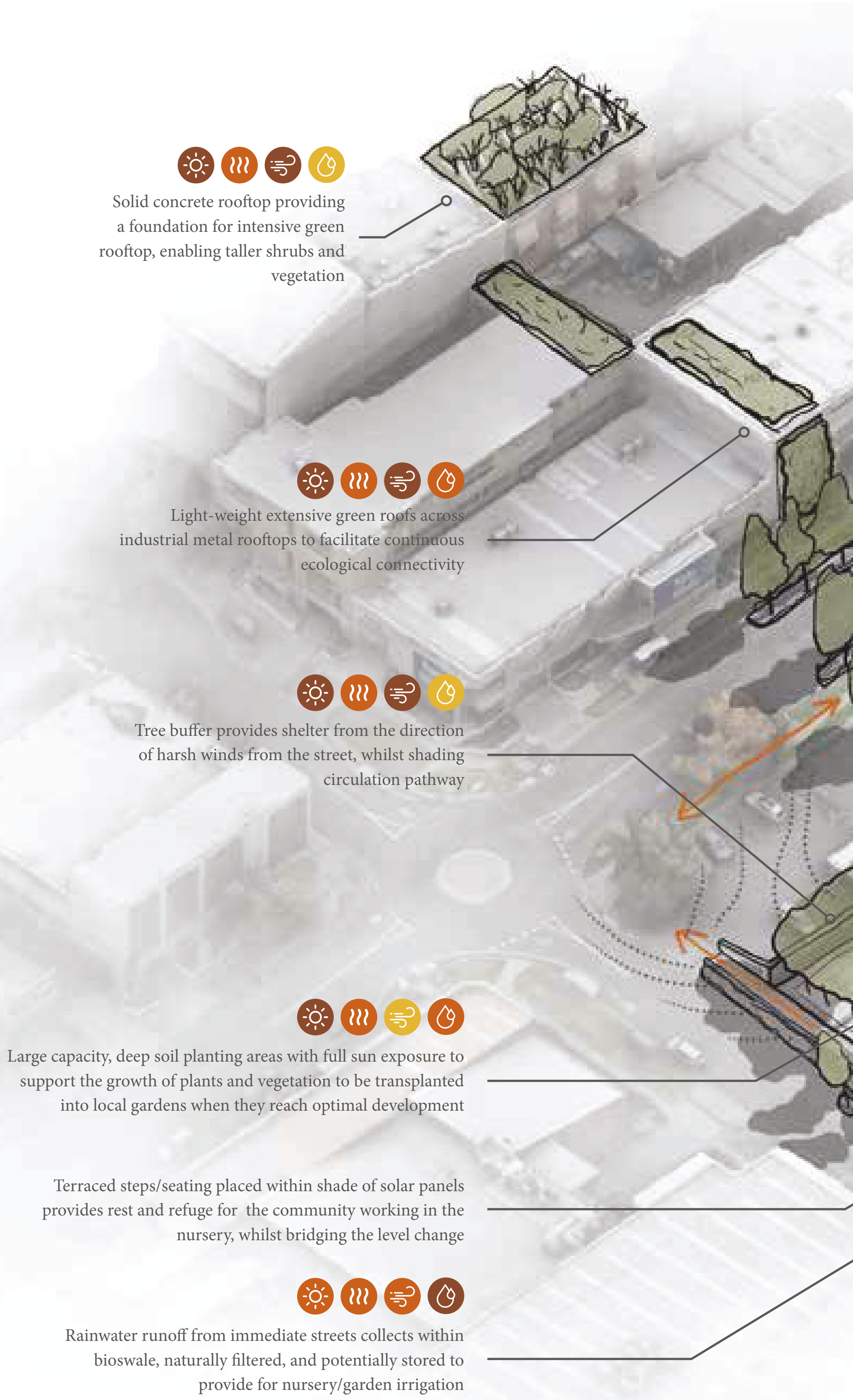
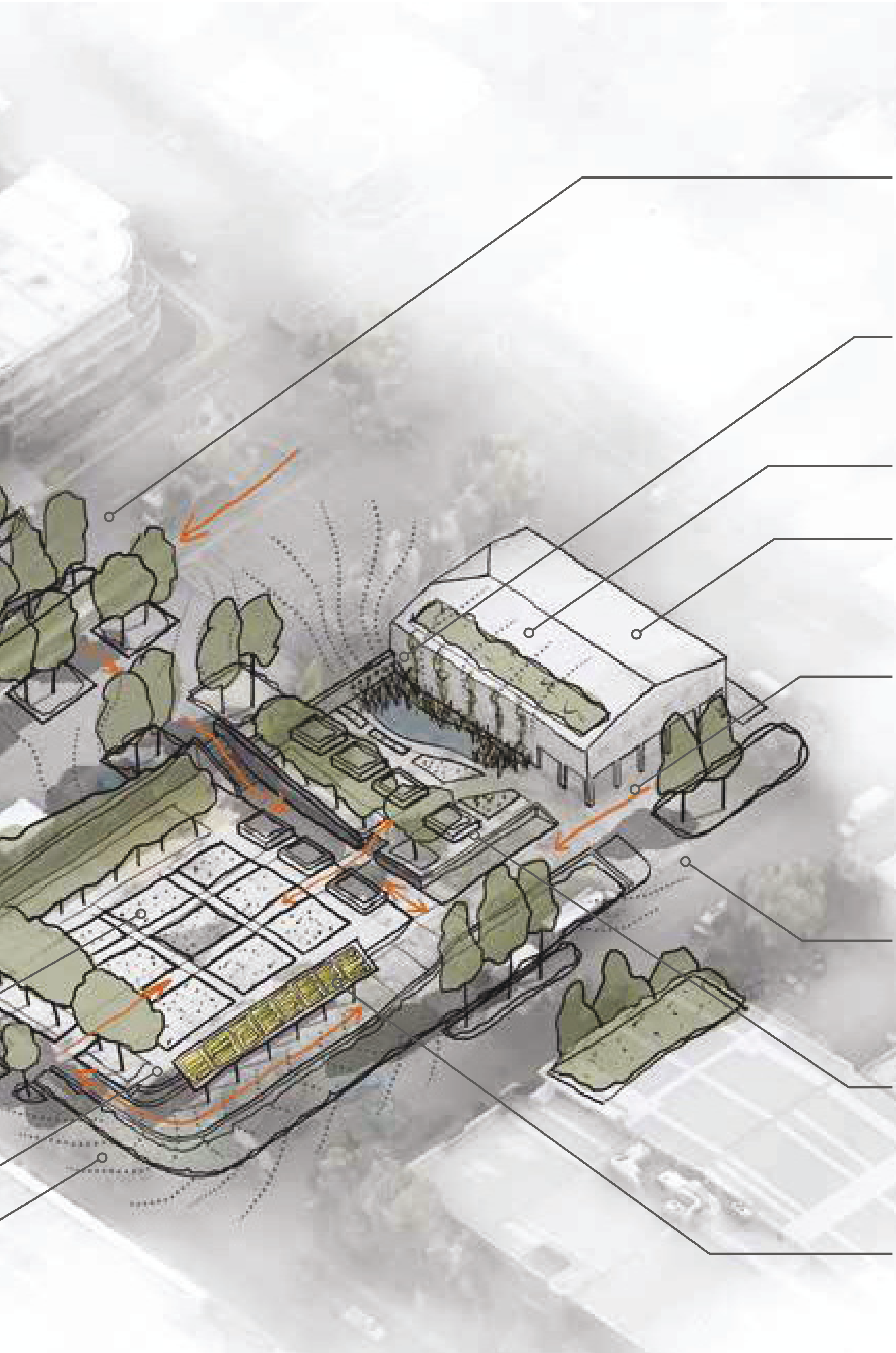


Fig. 08.02.02 Incorporating and synthesising a range of Green Mesh design principles to produce the first of the exemplar design cases, for industrial zoning and relevant built form typologies, producing a perpendicular green link to the roads, and introducing a productive community garden within a vacant lot.



Street and carpark tree planting creates a perpendicular ecological connection to the street, whilst shading road, pathways and parking spaces to reduce heat

Pond and water retention habitat collects water from adjacent carpark and rooftop

Rooftop water runoff filtered through green roof and collected in retention pool below

Potential re-purposing of industrial building into indoor plant-market space

Pedestrian circulation considered, maintained and enriched by vegetation and shade cover

Maintain vehicle access driveway for market setup. Exit through alternate driveway onto adjacent street.

Planter boxes in a range of sun conditions to suit a range of productive or smaller vegetation

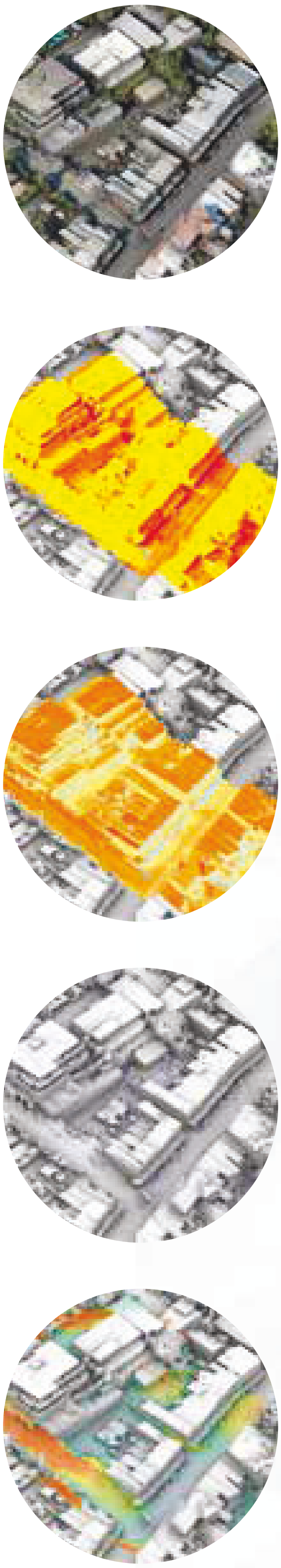
Solar panels positioned for optimal solar irradiance potential, providing energy for use within the gardens, for local street lighting, or to be fed back into the grid.

MICRO-CLIMATE CLASSIFICATION

Low
Moderate
High

Sun Exposure
Solar Irradiance
Water Saturation
Wind

0 10m



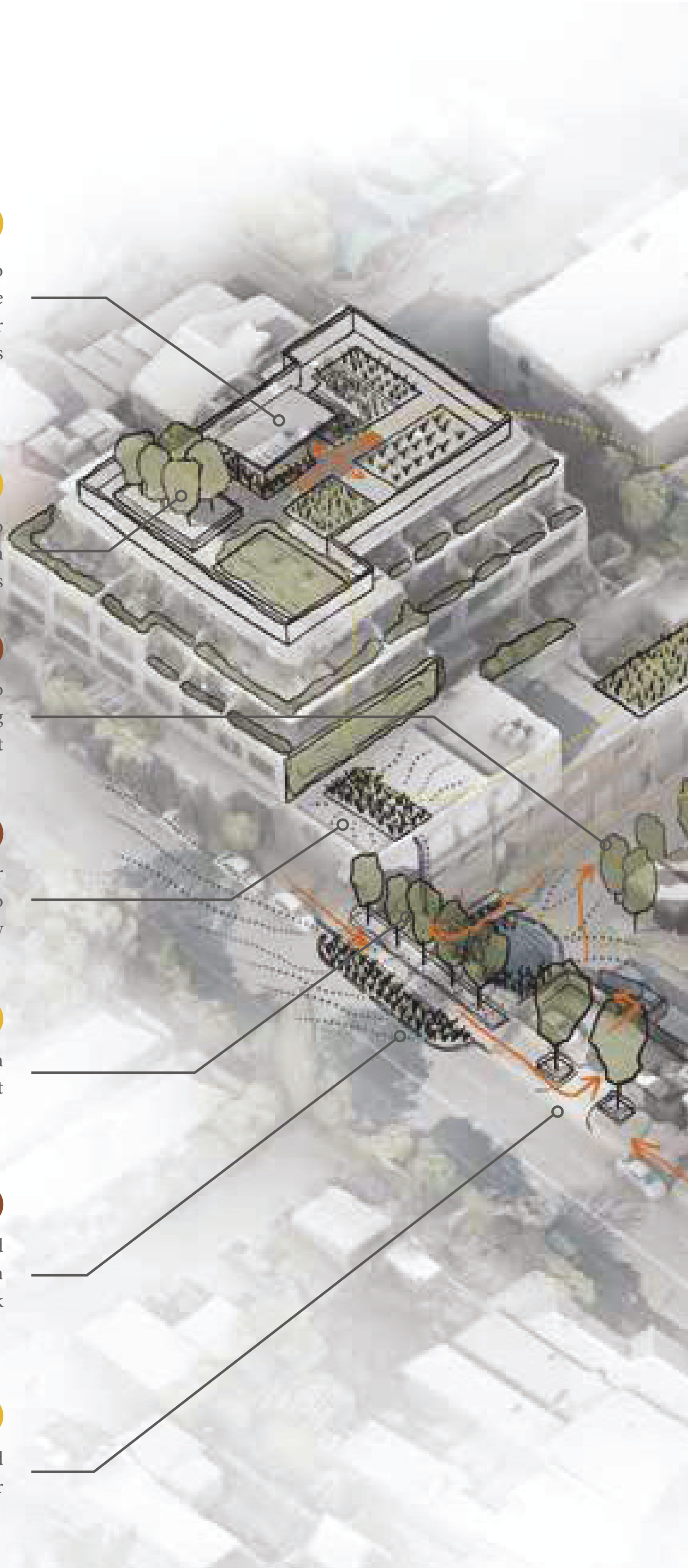


Fig. 08.02.03 Green Mesh design principles incorporated and synthesised within a local commercial centre and adjacent medium and high density residential, producing solar optimised green walls, reclaimed parking spaces for stormwater harvesting at water saturation spots, and a diverse productive rooftop garden with formalised rooftop access within an adjacent apartment building.

Connectivity to existing remnant vegetation to promote resilience and diversity within urban ecosystems

Urban beekeeping located in sheltered environment at the centre of numerous linear and ecologically diverse habitat and planting typologies

Reclaimed parking spaces within a naturally low-lying, sheltered location as a pond habitat for water filtration.

Light-weight extensive green roofs across commercial metal rooftops act to cool roof surfaces and facilitate ecological connectivity through meadow planting

Vertical garden maintaining access to commercial building whilst utilising full sun exposure for planting and ecological benefit, along with urban heat mitigation

Street trees provide an ecological refuge within the street, whilst helping increase shade over road surface to reduce heat.

Vegetated alleyway with permeable pavement allows for existing usage as a driveway and delivery-vehicle access, whilst facilitating water permeability and irrigation for green infrastructure

Solar panels positioned for optimal solar irradiance potential

MICRO-CLIMATE CLASSIFICATION

Low
Moderate
High

Sun Exposure
Solar Irradiance
Water Saturation
Wind

0 10m

03 EXEMPLAR DESIGN CASE: LOW DENSITY SUBURBAN RESIDENTIAL

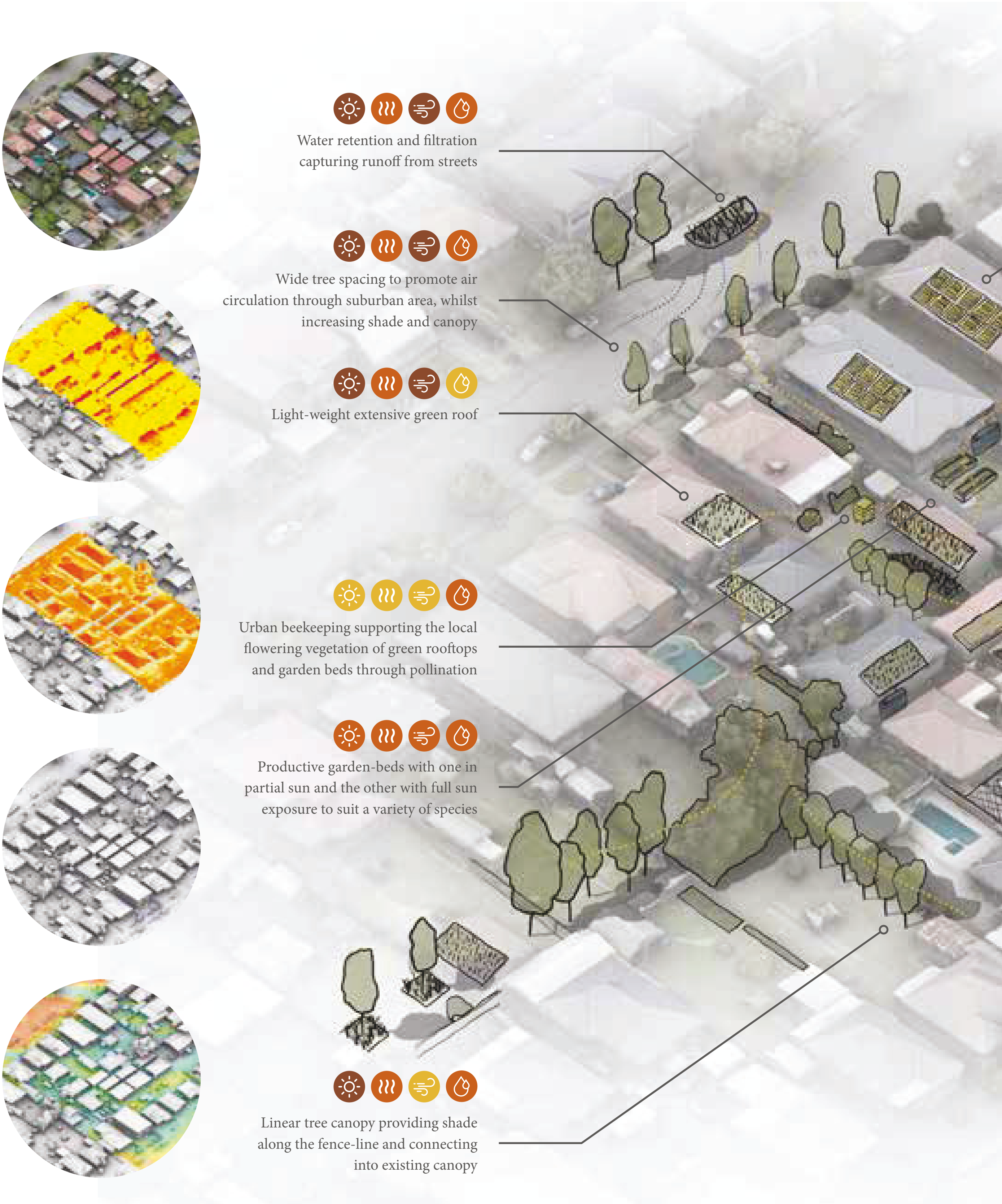


Fig. 08.02.04 Green Mesh design principles incorporated and synthesised within a low density residential area, establishing an increased canopy cover, solar panels with optimum solar irradiance potential, and a diversity of ground-level and rooftop gardens pollinated by local urban bee hives.

MICRO-CLIMATE CLASSIFICATION

Low
Moderate
High

Sun Exposure
Solar Irradiance
Water Saturation
Wind

0 10m

09

CONCLUSION: SUMMARY & DISCUSSION

09. CONCLUSION: SUMMARY & DISCUSSION

Q: How can new spatial technologies enable a finer-grain green network throughout Greater Sydney, and, how can this network be activated through community participation within private lands?

09.01 Summary

Driven by the global environmental issue of habitat fragmentation, the result of land-use change and urban development, the research presented within this dissertation aimed to develop the concept for a finer-grain green network, to re-establish ecological linkages between small, remnant vegetation communities. Informed through background research into global environmental aims, future city concepts, green infrastructure precedents, and Sydney's existing Green Grid strategy, the dissertation highlighted a need for a finer-grain green network to incorporate private lands, enabling a far greater degree of ecological integration. In achieving this level of granularity and site responsiveness, this research further revealed that traditional 2D GIS methodologies are a source of a spatial disconnection between high-level, broader mappings, and ground-level nuances.

These initial findings, whilst shaping the aspirations of the Green Mesh concept, influenced the trajectory of research in establishing spatial data as a key enabler and area of investigation. The subsequent aims and methodologies focused on how 3D point cloud and photogrammetry spatial technologies, still new and emerging within design practice, can enable the practical aims of the Green Mesh – the fine-grain analysis and understanding of site, scalability from individual lots up to the metropolitan scale, and a host of smart environmental simulation capabilities.

From a social perspective, community participation was identified as another key enabler, activating the private lands within the gaps of the Green Grid's coarse, corridor-based structure, which otherwise miss the potential of reconnecting the matrix of small, remnant vegetation communities within backyards. Community participation therefore introduced another unique characteristic of the Green Mesh concept, prompting the development of a theoretical platform to consolidate all methodologies and findings, into a simple, graphic interface accessible to the community. This interface, positioned as a framework for investment and further development by local governments and design professionals, would therefore connect communities to a diverse range of ecological implementations, informed based on the unique micro-climate conditions of their property, to promote the gradual 'meshing' of green infrastructures throughout private properties.

Consolidated into a number of theoretical outputs that aim to contribute knowledge and inform future design practice, the resulting methodologies and findings are categorised into three output themes; defining the 'spatiality of the Green Mesh', the 'role of the landscape architect' for future development, and facilitating 'accessibility for communities'.

09.02 Discussion

SPATIALITY OF THE GREEN MESH

The spatial benefits of the Green Mesh were tested and demonstrated at two scale extremes. Chapter 04 'Green Mesh Concept' introduced the high-level aspirations and aims of the Green Mesh, in response to background knowledge in global environmental goals, future city concepts, Sydney's prior and existing green strategies, and an understanding of green infrastructure typologies. This chapter established the broader aspirations and strategy of the Green Mesh, set out at an early stage to inform the aims of subsequent methodologies, testing and fieldwork. At opposite scale extreme, and following the development of the methodological framework, Chapter 08 'Resolving the Green Mesh' summarised the outputs from testing and development, detailing the finer-grain and site-specific spatial qualities of the Green Mesh applied within three real-world exemplar design cases.

At the high-level metropolitan scale, sited within Greater Sydney, the Green Mesh is positioned as a granular and dispersed ecological layer within the existing corridor-based structure of the Sydney Green Grid (SGG), seeking to address habitat fragmentation caused by poor urban development practices. In achieving this aim, the Green Mesh concept responds directly to key limitations identified within the existing SGG strategy, specifically in it's confinement to public lands, the coarseness of it's corridor structure, and the imprecision of mapping as a result of traditional 2D GIS methodologies used. These limitations result in a green network that misses a crucial opportunity to integrate the smaller, remnant vegetation fragments - many of which are located within private backyards. The Green Mesh addresses this through community participation, activating ecological connectivity within private lands, promoting an evenly dispersed 'mesh' pattern. This effectively stitches the 'gaps' within SGG corridors to reconnect all vegetation fragments within the broader, synthesised ecological network. This synthesis allows the Green Grid and Green Mesh to establish a cohesive, and multi-layered green network, learning from previous mistakes made with

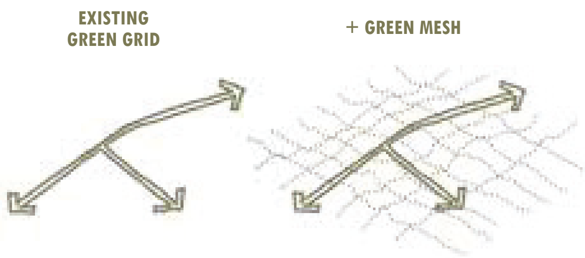


Fig. 09.02.01 High-level Green Mesh spatial concept

prior green strategies of Sydney's history such as the 'Green Belt' and 'Web', and the 'Sydney Region Outline Plan' – each undermining or replaced their preceding strategies. The Green Mesh therefore builds upon the existing framework of the SGG, utilising new spatial technologies to achieve a further level of detail and site-responsiveness, ensuring a distinct point of difference from the SGG in addition to the expansion of scope into private lands.

Further to the consideration of local and metropolitan green strategies within the context of Sydney, Green Mesh implementation would facilitate and support the practical delivery of the United Nations' '17 sustainable development goals' introduced in 2015. These goals aim to provide a 'shared blueprint' to inform human and infrastructural development within 193 member states, addressing a host of humanitarian and environmental issues. With the blueprint laid out, it is the responsibility of each member state to implement changes in support of these goals. The Green Mesh enables the delivery of the seven goals that are relevant to the built environment and ecological biodiversity. These goals include 'good health and well-being'- addressed through the proliferation of urban vegetation, connectedness to nature and biodiversity, 'affordable and clean energy' – addressed through the consideration of solar energy and decentralisation of the energy grid, 'innovation and infrastructure' – addressed through the use of new spatial technologies and incorporation of green infrastructure typologies, 'sustainable cities

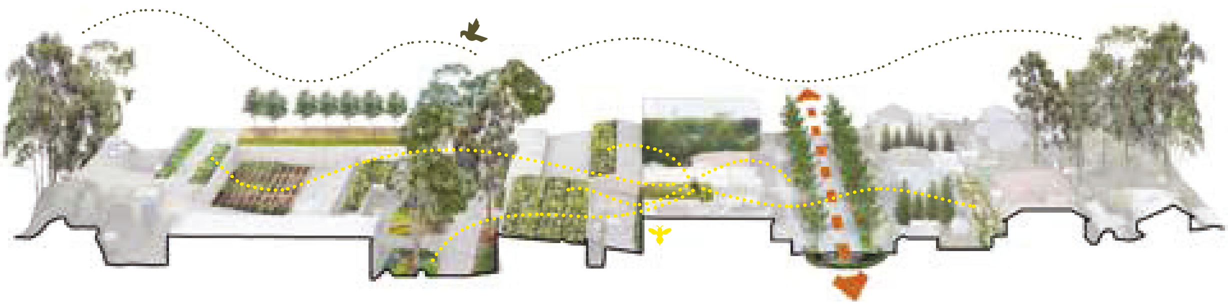


Fig. 09.02.02 The Green Mesh ecological concept, outlining the detailed spatial aspirations of the Green Mesh, and informing the subsequent aims of the methodological framework.

and communities' – addressed through resource sustainability such as water and energy, and the recycling of materials, 'climate action' – a broad goal addressed through all components including sustainability practices and urban greening, and finally, 'terrestrial biodiversity' – addressed through the implementation of ecologically valuable vegetation to support the habitats of local native fauna.

The Green Mesh is further informed by a number of future city concepts - including the Smart City, Woven City, and Biomorphic City, each with a unique take on technology, mobility, and urban ecological integration within our cities, respectively. The Green Mesh responds to particular critiques identified within these concepts. Smart Cities, conceived within the realm of IT, promotes a 'reactive' model that addresses urban challenges as they appear, as opposed to a 'proactive' model that would prevent the issue at a fundamental level. Furthermore, Smart Cities employ the use of sensors within the built environment to monitor and respond to human systems and interactions, with many examples of Smart Cities having a much smaller consideration of non-human systems and ecologies. Supporting the emerging 'post-anthropocentric' mentality, the Green Mesh presents the opportunity for the integration of these non-human systems within the Smart City framework, establishing

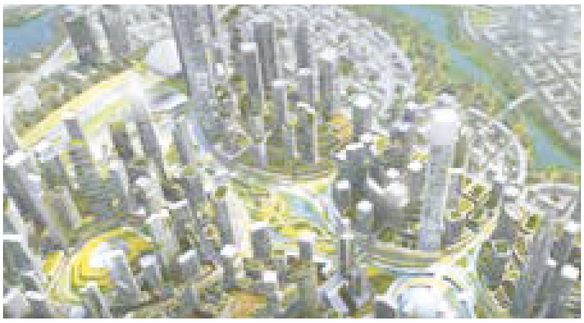


Fig. 09.02.03 SOM & National Geographic Biomorphic City concept. Source: National Geograophic Magazine, April 2019 Issue: Cities

a more holistic approach to future cities. The Woven City, with a distinct focus on sustainability through transport and materiality, and the Biomorphic City, where the city and urban growth actively promote the regeneration of native ecosystems, embed this post-anthropometric ideology more integrally than the Smart City, however, are each framed around development from the ground-up. The Green Mesh demonstrates a practical model for implementing similar principles within our existing built environments. The implementation of sustainable material choices and resource management practices, such as solar power and rainwater capture, and the promotion of native and ecologically valuable species within gardens and green infrastructures, demonstrate this.

THE ROLE OF THE LANDSCAPE ARCHITECT

Delivering the Green Mesh as a practical, implementable, theoretical framework, the methodologies explored throughout this dissertation demonstrated the possibilities of 3D point cloud and photogrammetry data in enabling a fine-grain, site-specific analysis, as a way of informing physical implementation. These technologies,

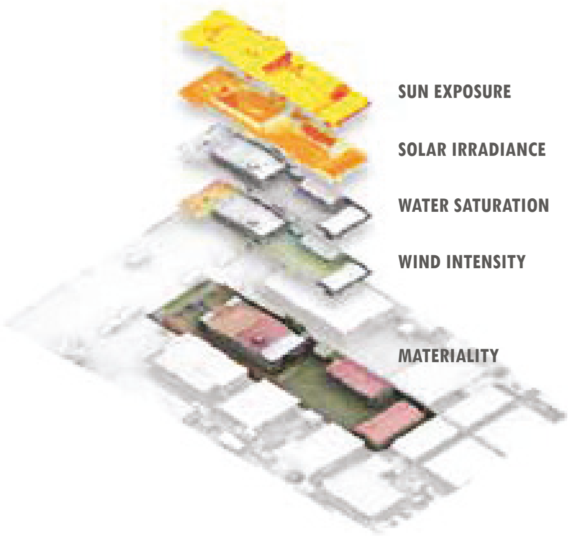


Fig. 09.02.04 Property-specific simulation of micro-climate characteristics

still emerging within current design practice, bridge the 'spatial gap' between traditional GIS data and the ground-level complexities of site, introducing a detailed 3D representation with a range of smart, simulation capabilities. Furthermore, this data is scalable from the LGA scale down to individual private properties. This process was informed by the works of Nicholas de Monchaux's 'Local Code' – specifically in his method of data capture and diagrammatic representation of water runoff and shading, and several projects from Christophe Girot, Future Cities Laboratory, and the university of ETH Zurich, including the 'Gotthard Landscape', 'Ciliwung River Project', and 'Singapore Rail Corridor' – demonstrating the potentials and capabilities of point cloud data for simulation, data extraction and consolidation.

Photogrammetry and point cloud data was captured for three urban areas within the broader study area of Willoughby LGA, representing the commercial, industrial, or residential built form contexts. Processing these models through a number of existing plugins for Grasshopper (Rhino3D), a platform for visual coding, several environmental outputs were synthesised to produce a holistic micro-climate understanding. This process was similar to flood simulations undertaken for the 'Ciliwung River Project' (FLC, 2014), though instead of a single environmental layer such as hydrology for flooding, micro-climate simulation required numerous outputs to be consolidated - including sun exposure, solar irradiance potential, water flow and saturation, and wind. Spatially mapping this data successfully revealed a rich and detailed representation of the invisible micro-climate characteristics within each of the three locations.

De Monchaux's 'Local Code' further inspired this process through the use of data and digital tools, where sunlight and water runoff where similarly mapped. The work within this dissertation takes de Monchaux's process a step further, integrating physical implementations within the overarching Green Mesh aim of reconnecting fragmented ecologies, where de Monchaux's implementations remain as isolated instances. Furthermore, the Green Mesh's synthesised micro-climate understanding leads to additional possibilities for suitably locating particular vegetation species and ecological implementations within the micro-climate conditions they most prefer. Therefore, the simulation process formed a crucial, data-driven analytical foundation for locating physical implementations within the Green Mesh strategy – a key bridge between high-level concept and ground-level responsiveness.

A range of field-studies then informed the development of a vegetation strategy and physical components of the Green Mesh, to be implemented by the community within private lands, and directly associable with the micro-climate spatial outputs. Socio-spatial analysis aimed to address the social dimension of the Green Mesh, considering human programmatic requirements and urban activities, along with potential urban greening opportunities. Results from these studies produced a qualitative narrative of the three sites, along with detailed spatial mappings of movement and interactions between people and the built environment. These narratives balanced out the intensity of quantitative data within the simulation process, whilst re-connecting the project back to human considerations. Ultimately, these studies informed the programmatic step of the methodological framework, allowing users to select a desired function from a list of suitable, case-specific recommendations. For example, vegetation typologies will be recommended based on the user's preference for either productive value, ornamental, or native biodiversity value.

Ecological field studies at various sites throughout Greater Sydney, informed the development a Vegetation Matrix, connected vegetation species and programmatic considerations, to micro-climate data. This matrix, detailing hundreds of species by their seasonality, colour, micro-climate preferences, and propagation method, classifies species into typologies including Indigenous/Keystone, Native Flowering, Green Wall Suitable, Remediating, Wetland/Aquatic, and Productive, defining their program or function. The species and typologies could be tailored specifically

Fig. 09.02.05 Productive vegetation component of the Vegetation Matrix

by LGA, supporting the unique ecological considerations of each by incorporating vulnerable and endangered species' into the matrix. The resulting diversity of planting species promotes the reinforcing of vital habitat for native fauna and pollinators, encouraging a growth in urban biodiversity.

Key observations throughout these field studies, and micro-climate considerations, were formed into 24 'design principles' for physical implementation. These principles therefore represent a holistic consideration of climatic, social, and ecological strategies

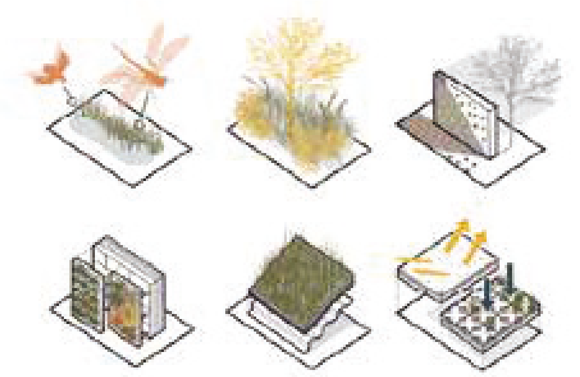


Fig. 09.02.06 6 of the total 24 design principles.

for achieving urban biodiversity and sustainability. Through the methodological framework process, these principles are filtered through to leave a refined selection of suitable principles for the site-specific micro-climate conditions, the desired program, and particular vegetation typology or sustainability practice. These principles embed an ongoing role and input from landscape architects within the Green Mesh.

ACCESSIBILITY FOR COMMUNITIES

The theoretical online interface aimed to connect communities and individuals to data and information required for physical implementation of the Green Mesh. The accessibility of this interface facilitates the participatory model of Green Mesh implementation, therefore representing a key link between data, methodology and physical outcome. A growing number of enthusiastic, environmentally concerned individuals within the community would be the first adopters, leading the gradual and dynamic proliferation of the Green Mesh throughout private lands. As a direct translation of the methodological framework, the online interface is designed to lead the user through the process, presenting them with the unique micro-climate characteristics of their property, the programmatic potentials suitable to particular vertical or horizontal surfaces, a recommendation of suitable vegetation species based on a chosen planting typology, and finally, the appropriate physical implementation strategies distilled through the 24 design principles.

Mirroring the high-level spatial strategy that informed the development of methodologies, the ‘exemplar design cases’ demonstrate the detailed, ground-level spatial outcomes of the Green Mesh, through the practical application of the framework and interface. Three exemplar design cases were developed, covering residential, commercial, and industrial contexts, each with different built-form typologies, urban challenges, and environmental opportunities to respond to. Due to these differing characteristics within each site, design cases produced naturally differing patterns in the green implementations that were proposed. The smaller lots within the residential area produced an evenly dispersed array of small-scale implementations. By contrast, the larger lots and built form typologies within an industrial context created an opportunity for more extensive green wall and rooftop implementations, with vacant lots providing a potential for community nurseries to grow vegetation naturally acclimatised to local environmental and soil conditions. The commercial example, a local centre which also included higher-density residential apartments, presented the opportunity for private communal rooftop gardens within concrete apartment rooftops, whilst the future shift towards shared mobility will present an increased opportunity for the reclamation of parking spaces to become planted habitat.

Overall, these exemplar design cases demonstrate how the methodological framework successfully achieves the finer-grain, site responsive, and ecologically integrated aspirations of the Green Mesh.

Fig. 09.02.07 Excerpts from the theoretical online interface [top, middle]. Exemplar Design Case within a residential context [bottom]

PROJECT SUMMARY

ISSUE & GAP IN PRESENT KNOWLEDGE

Habitat Fragmentation, Sydney Green Grid & Traditional GIS Methodologies

- ***Habitat fragmentation*** has become a major global ecological issue, with land-use change caused by urban development being a significant cause of this.
- Metropolitan Green Networks, such as the ***Sydney Green Grid*** (SGG), aim to re-establish ecological linkages throughout these cleared, urban landscapes, though face limitations in current policy, methodology, and implementation;
    1. ***Traditional 2D GIS methodologies***, as used to map the Sydney Green Grid, result in a high-level and imprecise understanding of urban extents, disconnected from ground-level nuances and complexities of site.
    2. LGAs/Councils are individually tasked with interpreting and ***resolving the SGG corridors down to a more precise level,*** creating an uneven uptake due to differing priorities between LGAs.
    3. The ***top-down implementation*** strategy restricts the Sydney Green Grid to public space only, missing the potential to reconnect a matrix of small, fragmented vegetation communities within private backyards.
- There is significant potential and support for the ***widespread implementation of green infrastructure typologies*** throughout existing urban and suburban extents of Greater Sydney.
- In order for a ***finer-grain meshing of ecologically-rich connections throughout private lands***, there is a need for a cohesive, community-activated green strategy to provide valuable interactions with native remnant vegetation.

ESTABLISHING A NOVEL METHODOLOGY

New 3D Spatial Technologies enabling a fine-grain vegetation & green infrastructure implementation strategy

- **05.03** Understanding the ***green infrastructure opportunities*** within existing built form of Willoughby LGA.
- **06.01-03** The positioning of new ***3D Spatial Technologies; point cloud and photogrammetry data***, in spanning the spatial gap between traditional GIS datasets and the ground-level, textural and micro-climate qualities.
- **07.02-03** Exploring the ***creation, representation, and advanced analytical methodologies*** enabled through point cloud and photogrammetry data.
- **07.02** Utilising a range of existing ***Grasshopper plugins*** for the generation of a holistic ***micro-climate simulation data*** particular to specific lots and built form, whilst ***demonstrating a practical application for 3D spatial data***.
- **07.03** A series of ***on-site socio-spatial studies*** revealing opportunities for urban ecological integration within the public realm, informing pro-active responses to current urban challenges within Willoughby LGA.
- **07.04** The development of a thorough and diverse ***Vegetation Matrix***, with planting species categorised by garden typology, and detailed by colour, seasonality, and micro-climate preferences - enabling direct association to micro-climate simulation data.

RESULTS & CONTRIBUTIONS

The theoretical Green Mesh platform & Methodological Framework

SPATIALITY OF THE GREEN MESH

04.01.01 The high-level ***Green Mesh concept***: a vision for a finer-grain, community activated green network throughout Greater Sydney.

08.02.03-04 ***Exemplar design cases***, testing and demonstrating the detailed spatial outcomes of the Green Mesh network, and the potential relationships between design principles within a practical context.

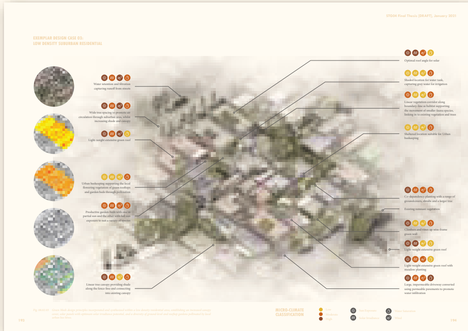
ROLE OF THE LANDSCAPE ARCHITECT

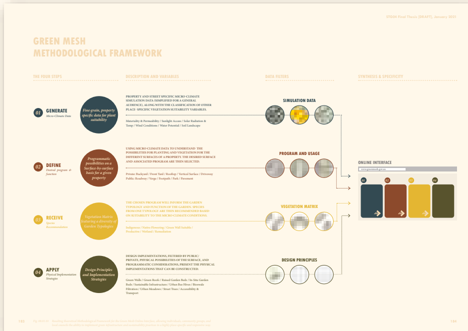
08.01.01 A cohesive ***Methodological Framework***, distilling all research findings into a theoretical structure with the potential for further investment and development, for the realisation of the Green Mesh concept.

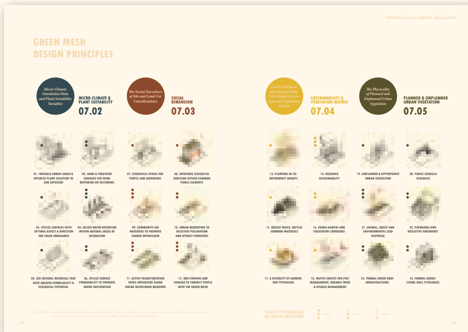
ACCESSIBILITY FOR COMMUNITIES

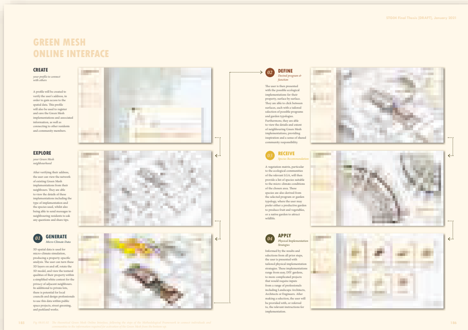
07.06.01 A set of ***design principles***, compiling a range of sustainability practices, social ecological integration opportunities, and planting strategies to inform the small-scale implementations of the Green Mesh.

08.01.02 A theoretical ***Online Interface***, adapting the methodological framework into a simple, graphic platform for individuals and community members to access all required information, for ecological implementation within their own property.









09.03 Conclusion

The following questions and answers conclude the research undertaken within this dissertation, whilst introducing the steps and actions required for the further development of the Green Mesh concept.

***

Q: What are current practices for Green Strategy planning and Green Infrastructure implementation within Sydney?

- Traditional 2D GIS methodologies, as utilised through the mapping of the Sydney Green Grid strategy.
- Initial adoption of new spatial technologies, with limited or basic application within current practice.

Q: How have 3D Point Cloud and Photogrammetry technologies been used up to now?

- Research projects such as the Girot's 'Gotthard Landscape', producing novel drawing typologies through the combination of several point cloud models.
- Niche applications for environmental simulation which are not widely used within current design practice.
- Feature extraction such as real canopy-cover and building footprints.
- Commercial mapping through Google Maps and Apple Maps to represent 3D built form.

Q: How can these technologies break the division between the pragmatic, scientific and quantitative side of data, and the dynamic, textural qualities of narrative and place?

- Bridging the scale-gap between traditional GIS mapping, and the human-scale qualities at a ground-level, point cloud and photogrammetry data are able to achieve a much higher level of detail that means they are accurate at this human-scale.
- As a result, these technologies are able to be combined and intertwined with socio-spatial considerations through other forms of analysis, as they act at the same scale.
- Design outputs based on this analytical methodology are therefore able to respond to a more holistic and finer-grain set of inputs in order to produce a highly responsive outcome.

Q: How can these technologies be used to define vegetation suitability within a particular site or property?

- Micro-climate analysis through the amalgamation of several small-scale environmental simulations using 3D spatial data, as demonstrated through this dissertation, demonstrated a methodology which enables vegetation suitability in combination with the vegetation matrix.
- This methodology, provided accurate point cloud data is captured, is positioned to enable a property-specific micro-climate analysis for any lot within the scale of metropolitan Sydney.
- Evidence of data validation has been included within Appendix 10.02, comparing simulation data against the equivalent real-world scenario, and the difference in plant growth between garden areas simulated to have full sun vs shady conditions.

Q: What is the feasibility of achieving detailed 3D spatial data coverage throughout the entirety of Greater Sydney, or any other major city?

- Online services already have a database of point cloud data for all of NSW, though at a far lesser degree of detail.
- Mapping services such as Google Maps and Apple Maps are able to generate detailed 3D photogrammetry models of major cities and landscapes of particular interest. This requires a combination of streetview and aerial images from planes, further to the general satellite imagery, which are then processed together to create a 3D photogrammetry model.

Q: Who are the relevant stakeholders for the further development of the Green Mesh platform?

- ***Landscape architects, urban planners, and architects*** would provide input into the refinement of design principles.
- ***LGAs together with ecologists and arborists*** would be involved in the tailoring of vegetation matrices particular to each LGA of Sydney.
- ***Engineers***, in addition to the aforementioned design professionals, would be involved further detailing and specifying green infrastructure possibilities and feasibilities.
- ***Coders and web designers*** would be required for the creation of a functional and working online interface.

Q: To what degree is the Green Mesh replicable between LGAs within Sydney, and to other cities both nationally and internationally?

- The Green Mesh is intended to be uniquely tailored to the ecological characteristics particular to LGAs throughout Sydney - through modification of the vegetation matrix. This makes the Green Mesh suitable to be replicated through all LGAs in Sydney.
- Furthermore, since habitat fragmentation is a global issue caused be urban development, the Green Mesh concept is relevant to many cities internationally.
- Provided the required point cloud spatial data is available or able to be created for a city, the methodological framework is replicable within these cities, with the ability to tailor the design principles (implementations), and vegetation species to suit the geographic location.

APPENDIX

10

10. APPENDIX

10.01 Grasshopper Simulation Definitions

Fig. 10.01.01 Solar Irradiance Analysis, Ladybug

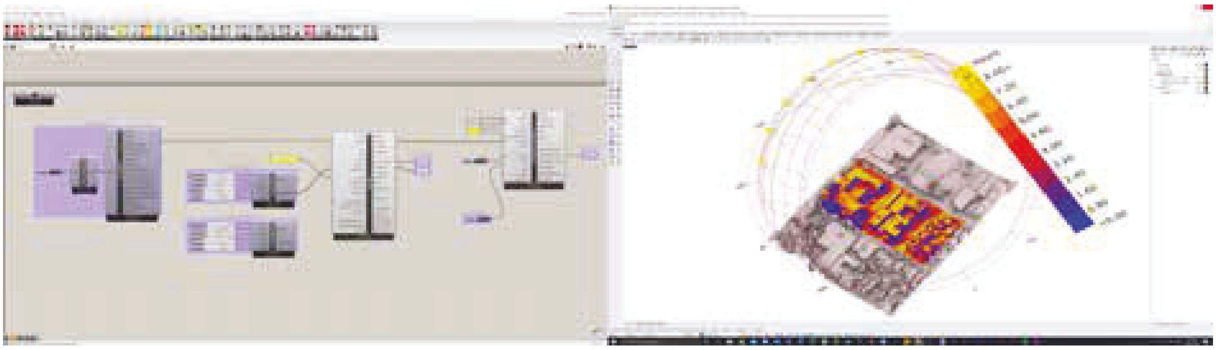


Fig. 10.01.03 Sunlight Analysis, Ladybug

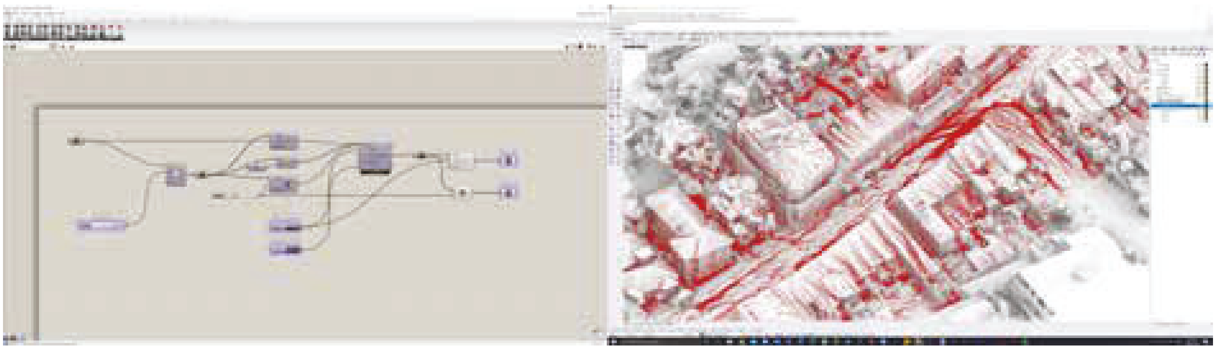


Fig. 10.01.02 Water Flow and Saturation, Kangaroo

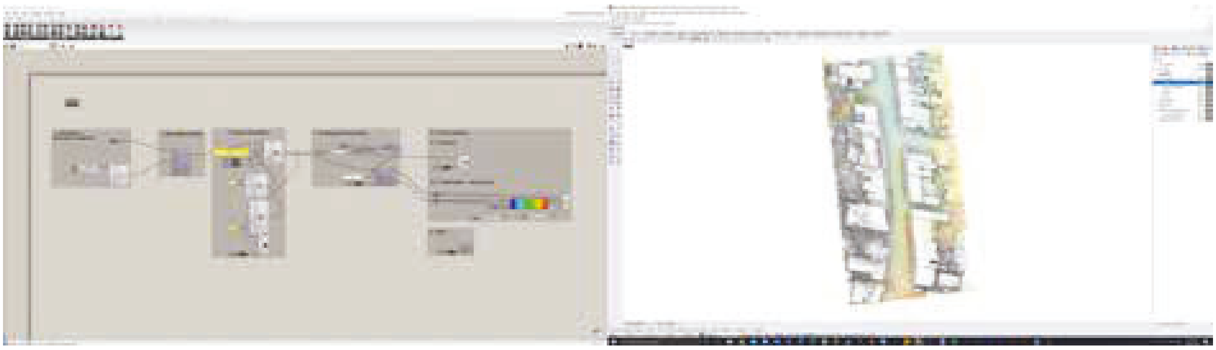


Fig. 10.01.04 Wind Analysis, Eddy3D

IMPACT OF SUN EXPOSURE ON PLANT GROWTH

A real-world test of plant growth of two identical species, planted in the same soils, though with differing sun exposure characteristics. Each plant was planted in June 2019, at the same stage of growth, and compared again 17 months later in October 2020.

With a tape measure placed next to each plant for scale, the plant within full sun exposure was measurably broader after this length of time, and featured a much higher density of flowers.

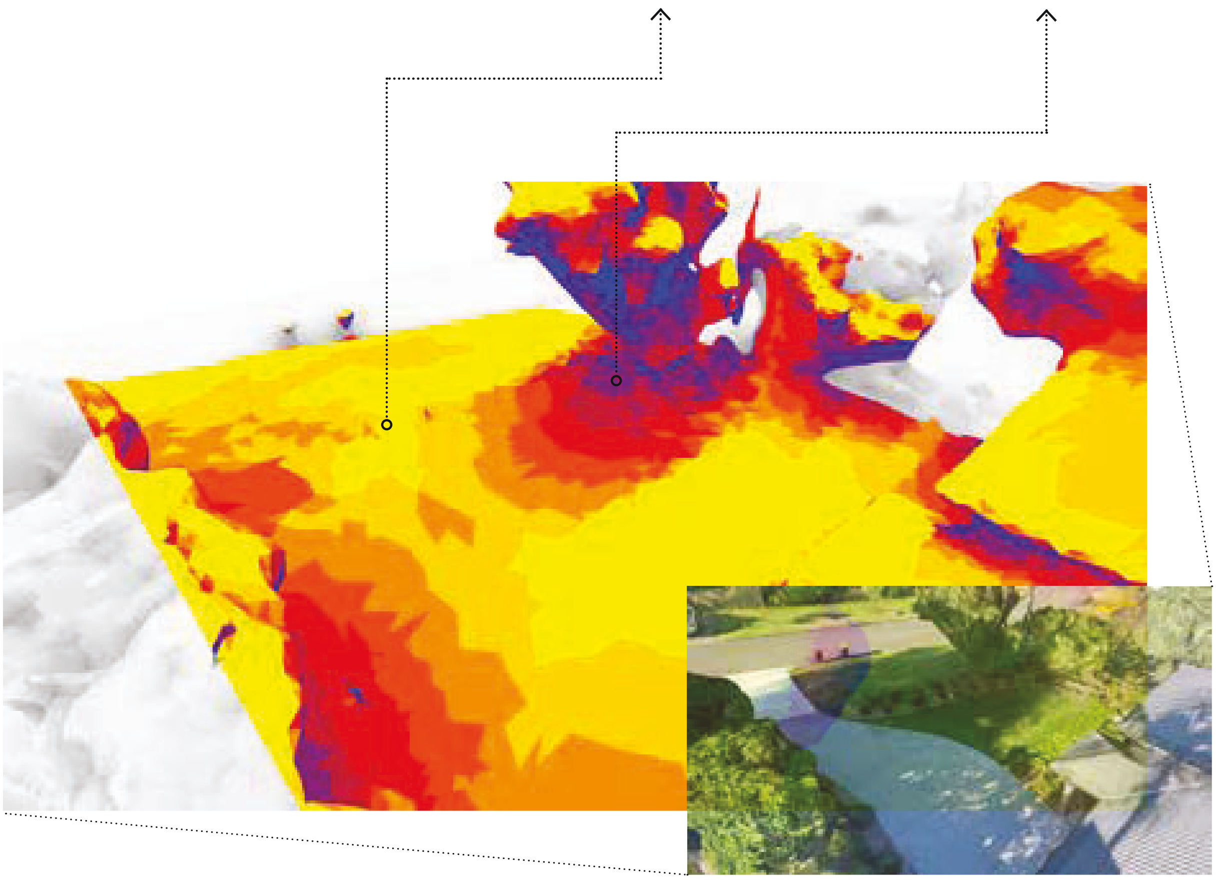


Fig. 10.01.05 *Plant growth comparison of the species Gazania Rigens, between an area of full-sun exposure (according to the simulation data) and an area of partial shade within the same garden bed, over a period of 17 months from initial planting in June 2019.*

ACCURACY OF SIMULATED SUN EXPOSURE

In order to validate the accuracy of the simulation methodology, data outputs were compared to the real-world hourly sun exposure of the same location and day of the year. In order to achieve this, a view within the 3D photogrammetry model was precisely aligned with a real-world camera angle, and areas of sun exposure for each hour were individually recorded. The resulting simulation frames and real-world images were overlaid, showing a high level of accuracy in the simulation methodology, as the two instances aligned remarkably well.

Fig. 10.02.01   Fig. 10.02.01   The 3D model [top] was aligned with a real-world camera angle [bottom] to compare real vs simulated shadow cast, for validation of the methodology.

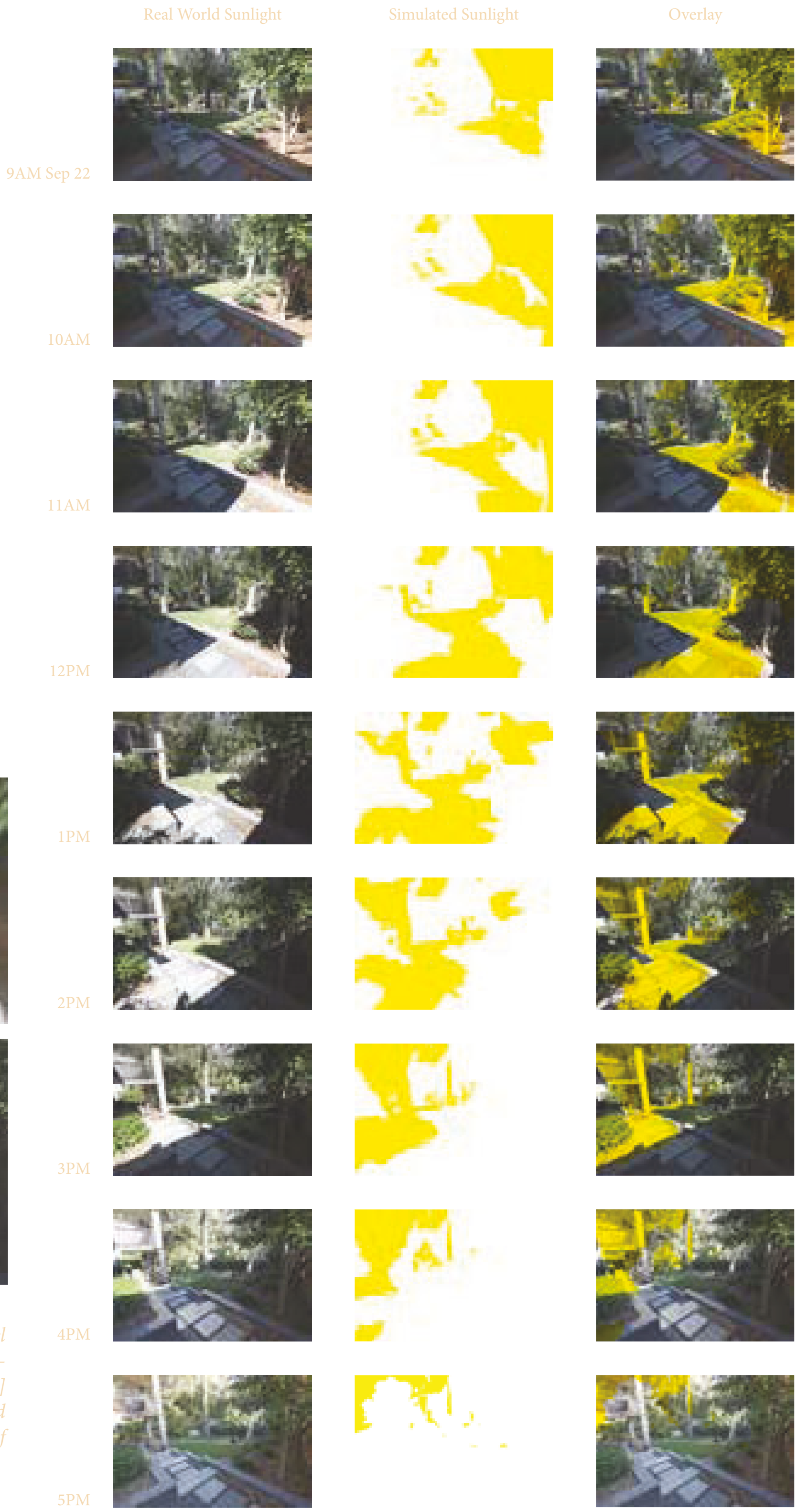


Fig. 10.02.02   Comparison of real-world and simulated sun exposure for the hours of 9am-5pm.

10.03 Socio-Spatial Site Analysis

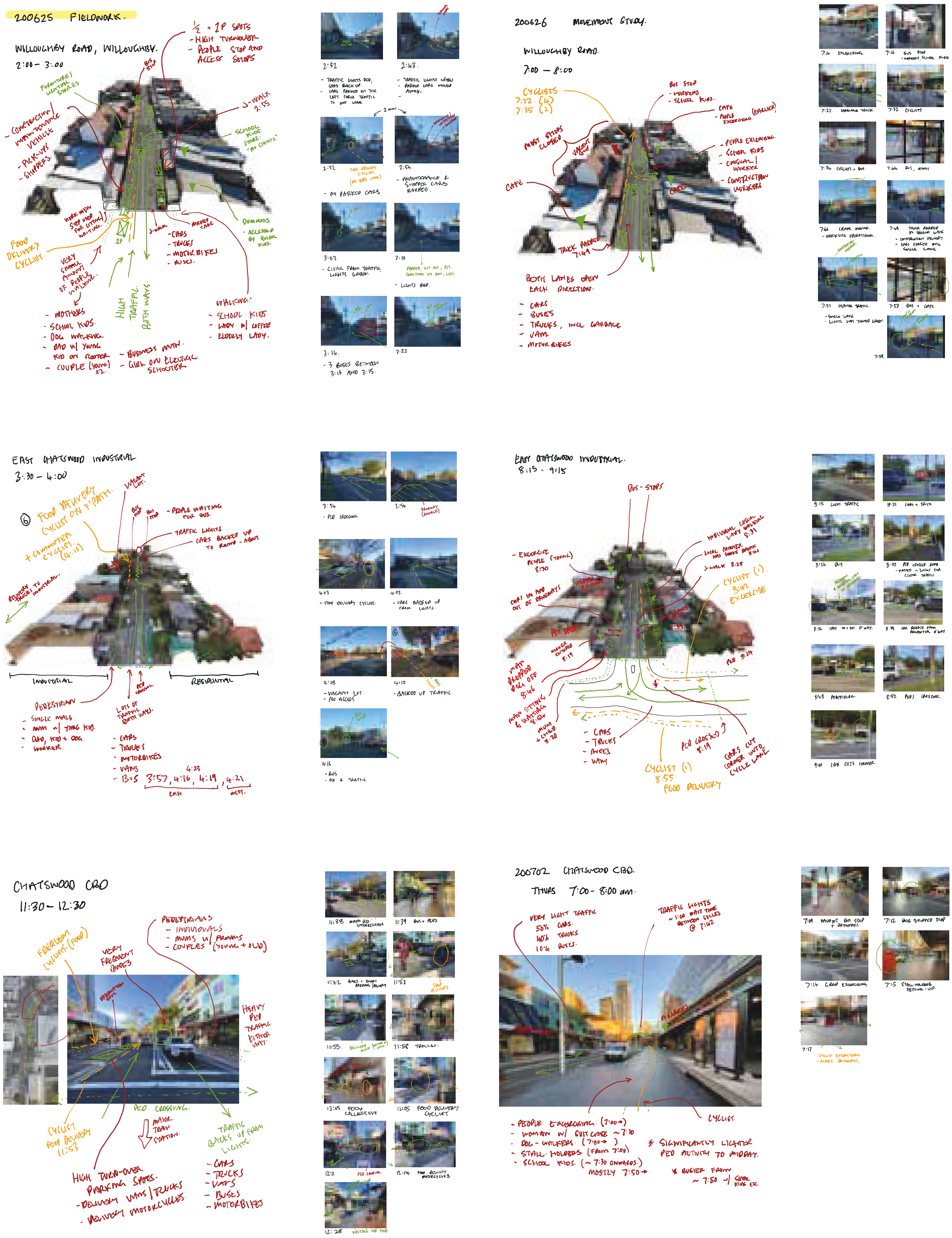
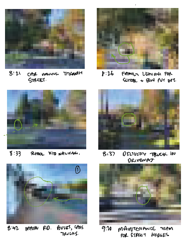


Fig. 10.03.01 Raw field-notes and imagery from socio-spatial analysis - used to inform social mapping, and taxonomy of actors and programs. Each of six sites were observed for two one-hour periods at different times of the day.



200704 Nicholson St, Chatswood.

10:00 - 11:00 am Sat.

- People running | jogging | stretching | exercising in adjacent parks
- Families w/ young kids in parks.
- Spectators & players at sport field → busy on and off - street parking.
- Cyclist along street.
- Mums w/ prams
- Dog walkers
- Man stopped on pathway on phone.

200704 Royal St, Chatswood

9:00 → 10:00 am Sat.
(Raining till ~ 9:20)

- Individuals walking w/ umbrella
- Parking on street and going into house
- People having coffee on front balcony.
- Multiple cars entering | exiting driveways.
- Delivery van moving along st
- Individual walking | exercising.
- Elderly man w/ walking frame
- Woman walking dogs.
- Other men | women walking dogs.
- Individuals casually walking along footpath
- Learner drivers practicing through st. (2 @ 9:56).

200605 Nicholson St, Chatswood

1:30 - 2:30 pm Sun.

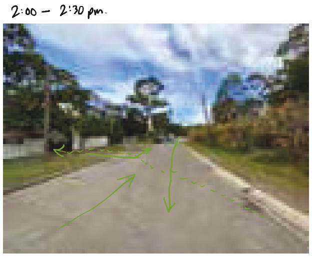
- Dog walkers
- Couples with prams
- Young groups of friends
- Families playing at the park.
- Kid on scooter
- Young individuals walking.

Wildlife 9

- Noisy miner
- Rainbow lorikeet
- Cockatoo
- Galah

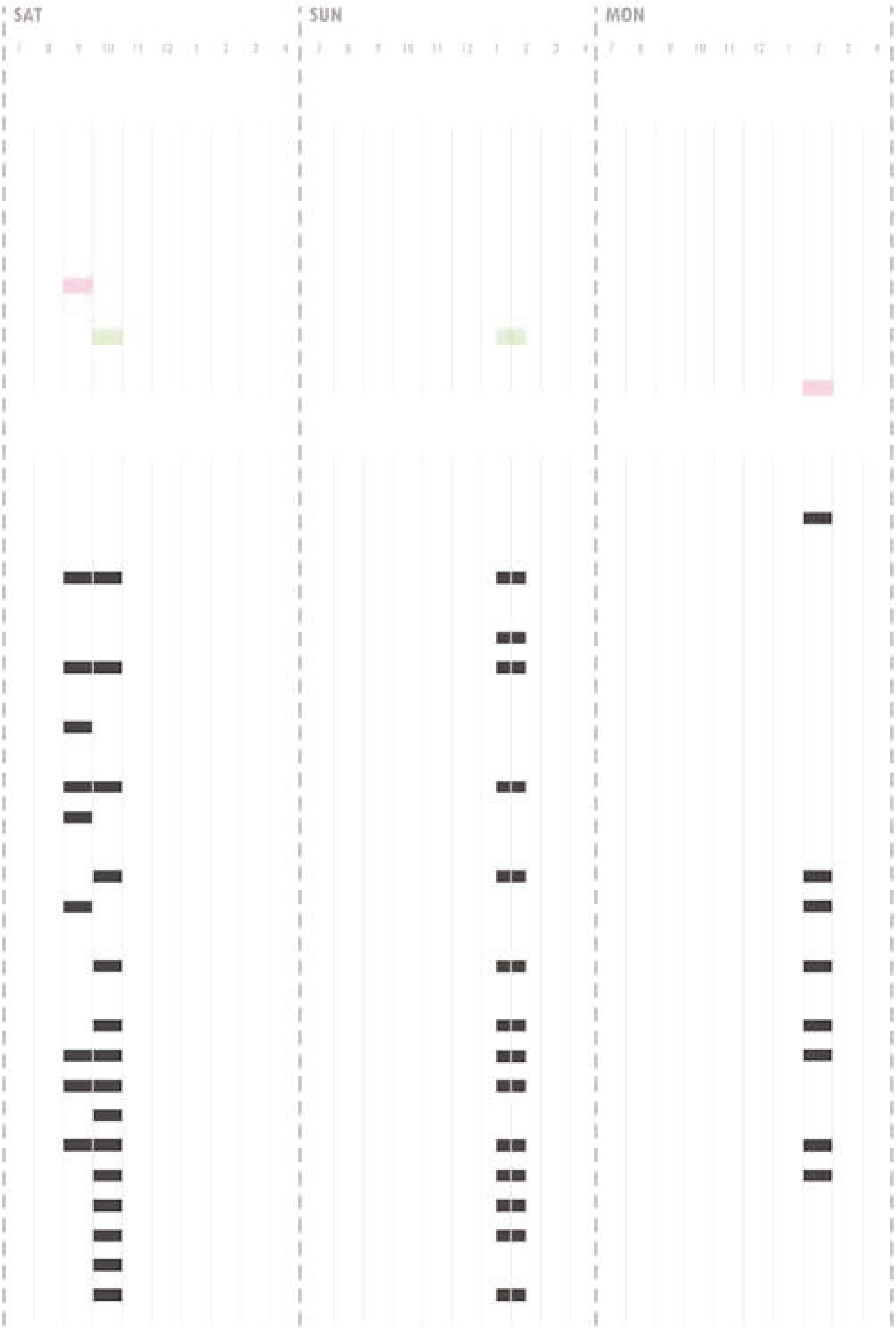
200629. Eden St, East Chatswood

2:00 – 2:30 pm.



- Worker truck → wheelbarrow + tools for public park maintenance
- Delivery trucks
- Family (elderly w/ kids) returning from walk through adjacent park.
- Individuals out for walk through park + streets
- Dog walker (s)
- Man w/ trolley.
- Individuals leaving home and accessing cars parked on street or in driveway.
- Rainbow lorikeets
- Kookaburras.

Fig. 10.03.02 Program and usage observations from a series of 1 hour movement studies at six different sites throughout Willoughby LGA.


SAT
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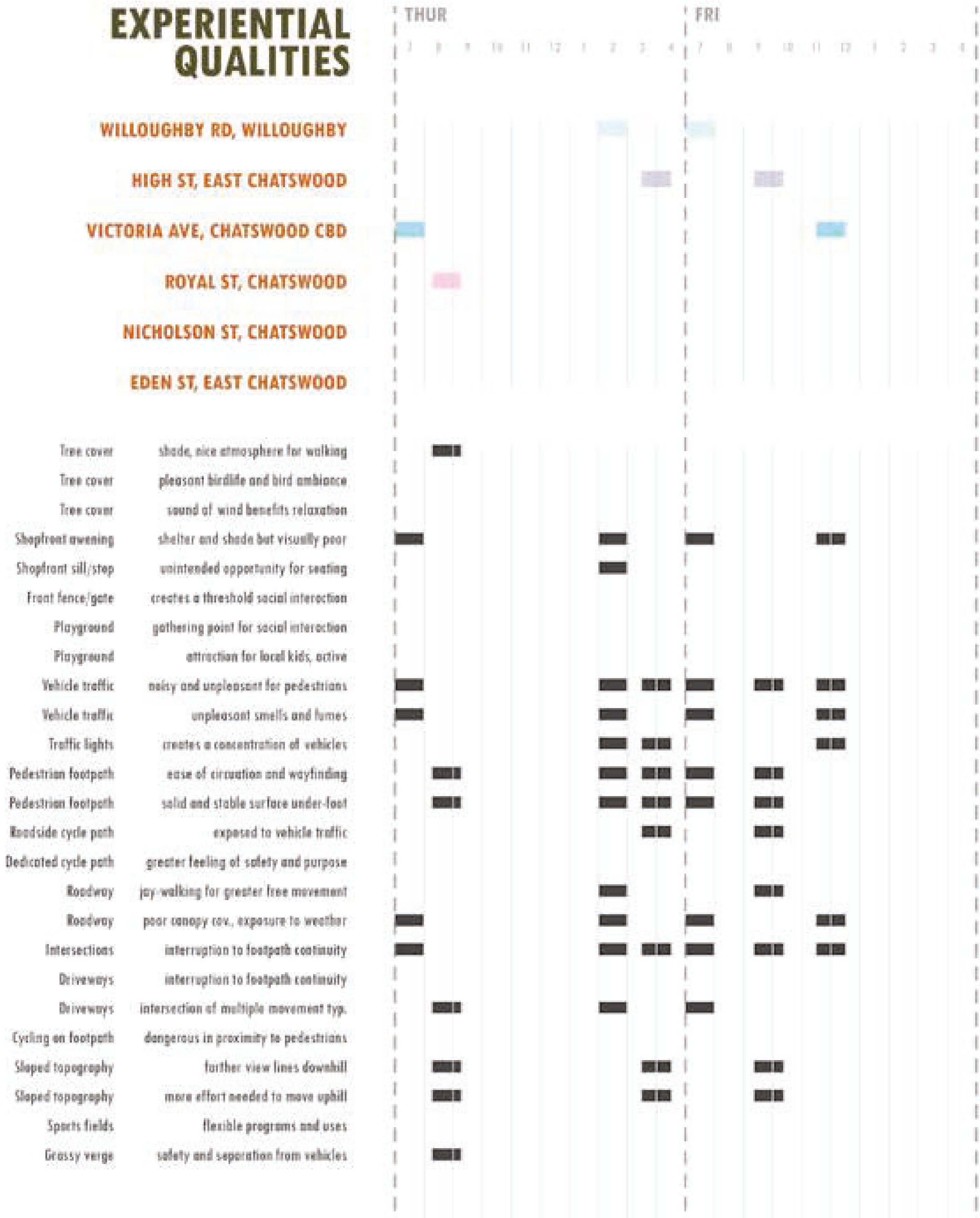
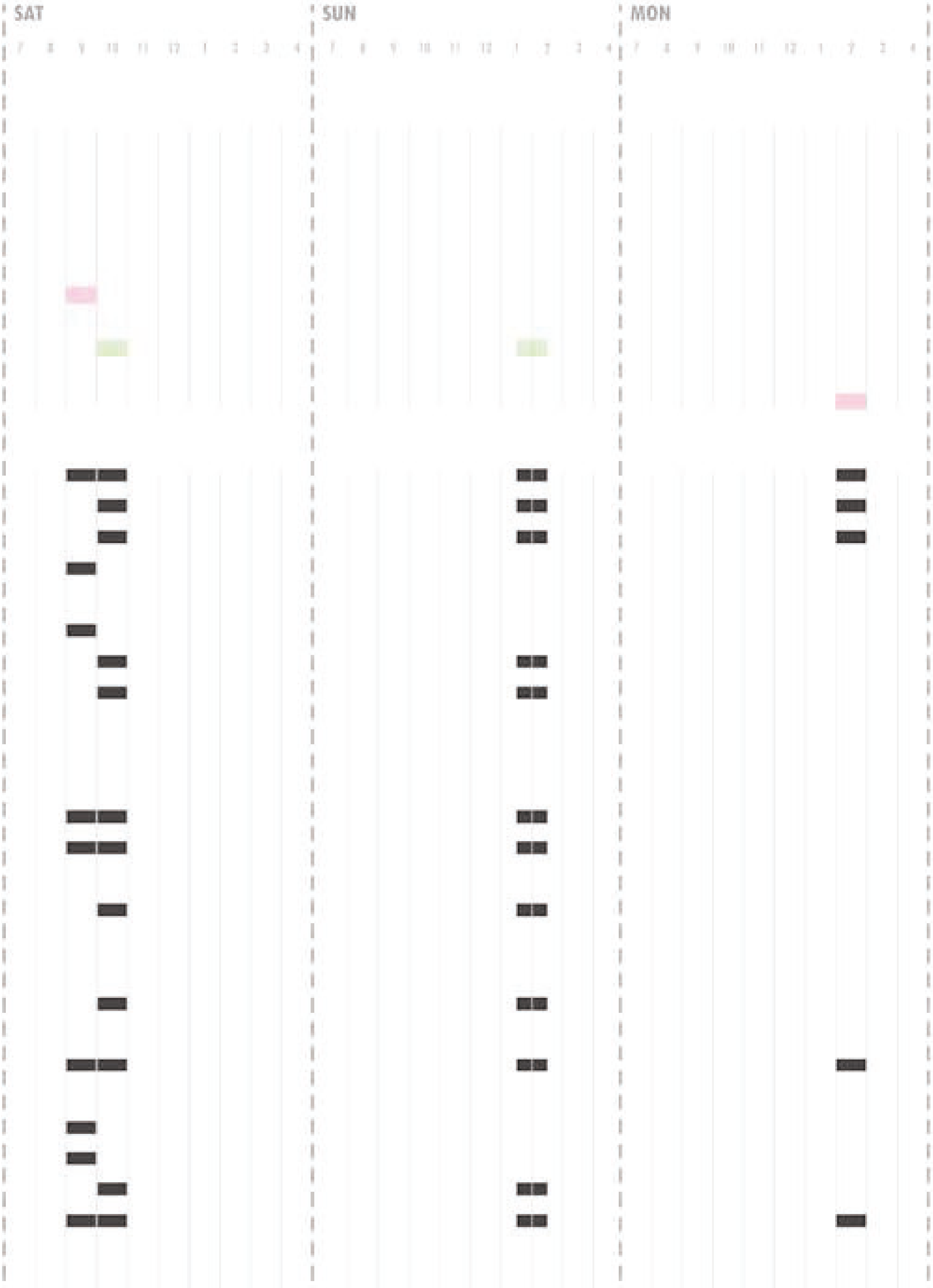


Fig. 10.03.03 Experiential qualities as observed through a series of 1-hour movement studies at six different sites throughout Willoughby LGA.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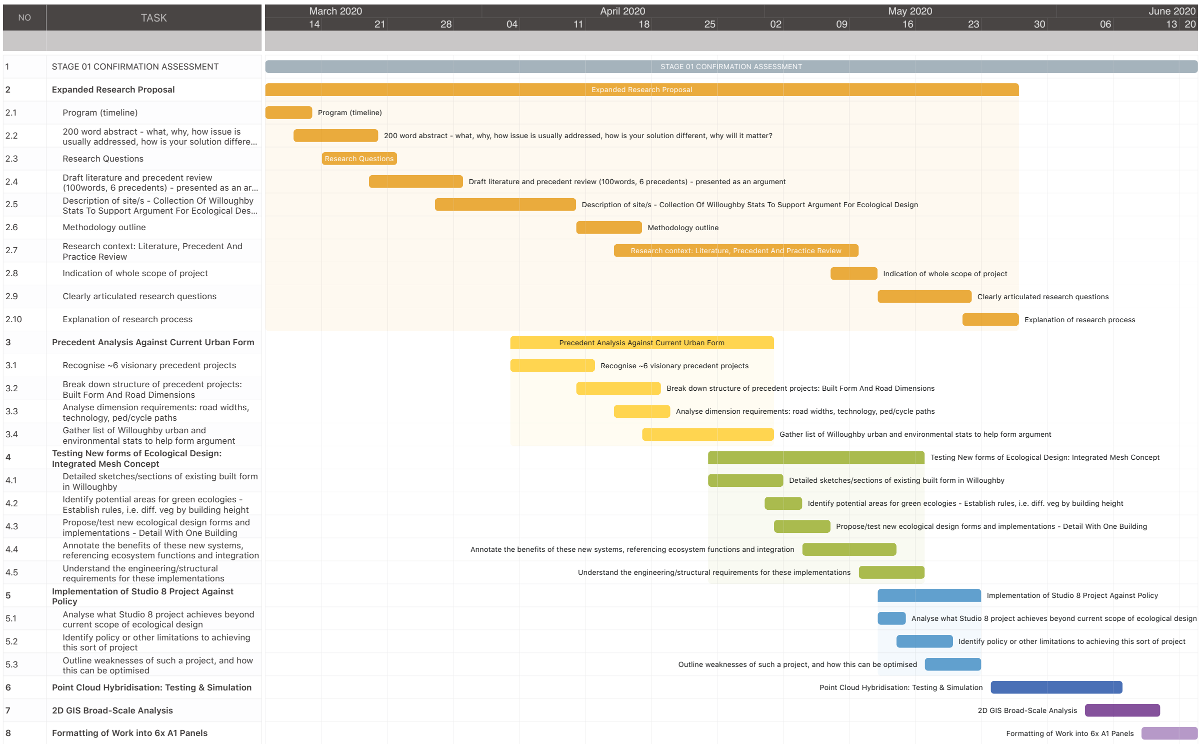
10.04 Project Management

GANTT CHARTS

STG01 CONFIRMATION

11/09/2020 created by QuickPlan Pro
Jeremy Chivas



STG02 INTERNAL AS

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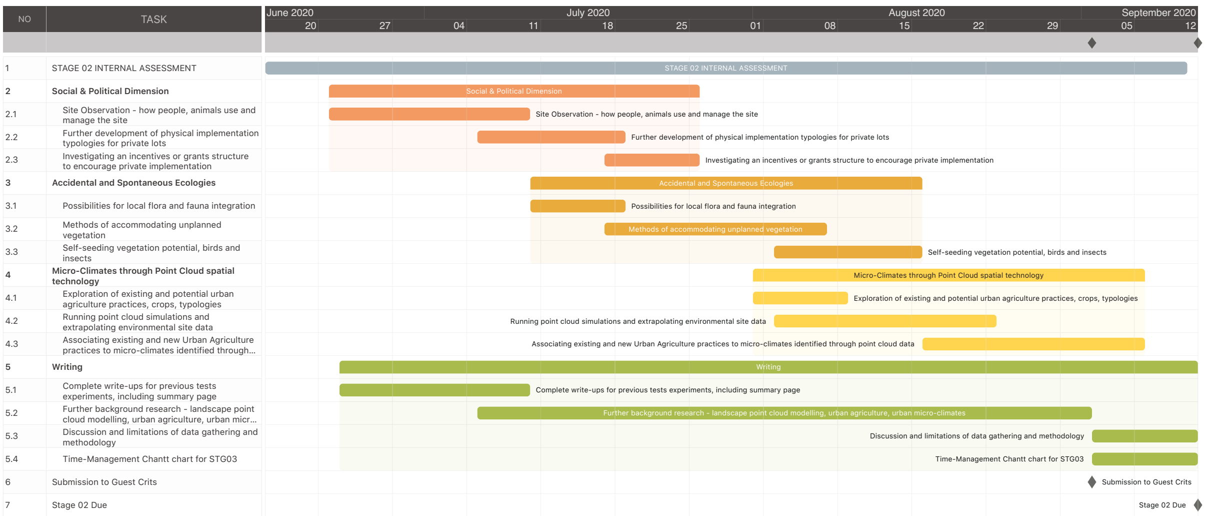
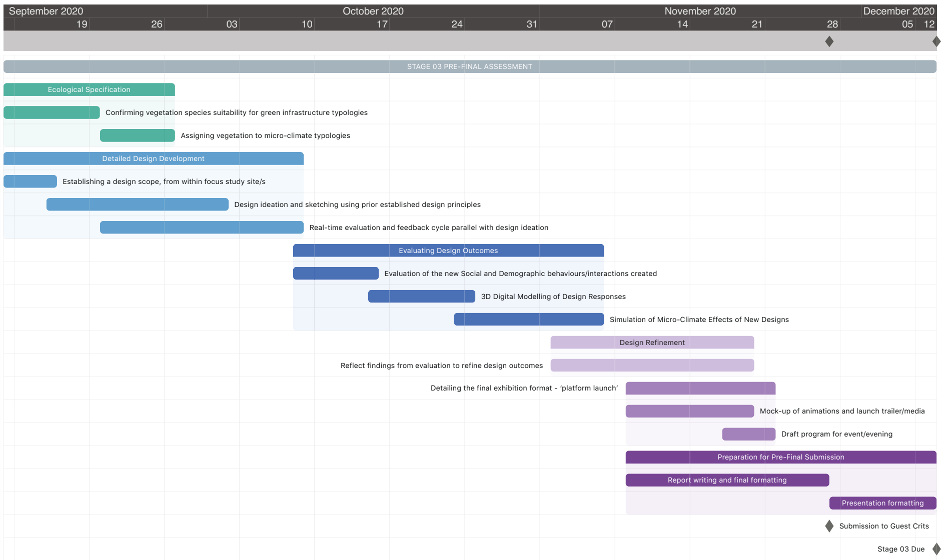
Jeremy Chivas



STG03 PRE-FINAL

11/09/2020 created by QuickPlan Pro
Jeremy Chivas

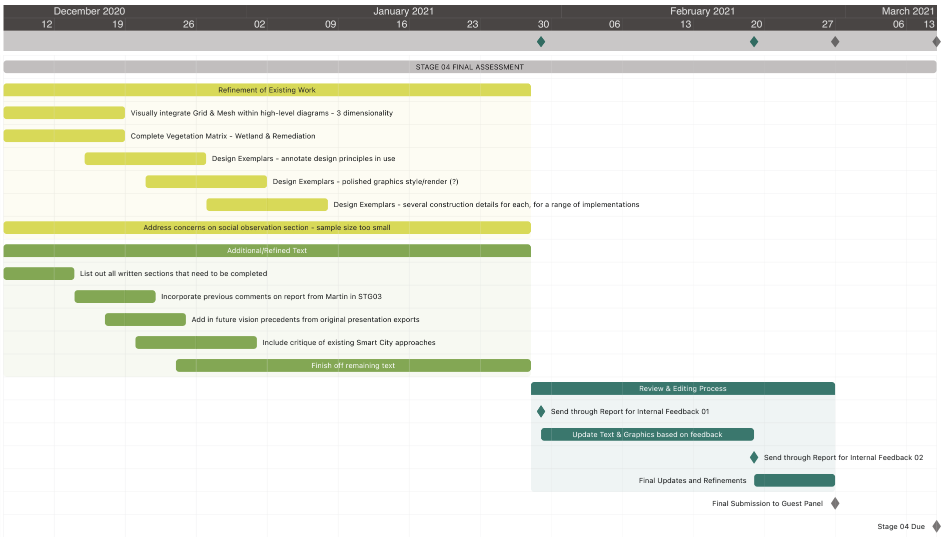
NO	TASK
1	STAGE 03 PRE-FINAL ASSESSMENT
2	**Ecological Specification**
2.1	Confirming vegetation species suitability for green infrastructure typologies
2.2	Assigning vegetation to micro-climate typologies
3	**Detailed Design Development**
3.1	Establishing a design scope, from within focus study site/s
3.2	Design ideation and sketching using prior established design principles
3.3	Real-time evaluation and feedback cycle parallel with design ideation
4	**Evaluating Design Outcomes**
4.1	Evaluation of the new Social and Demographic behaviours/interactions created
4.2	3D Digital Modelling of Design Responses
4.3	Simulation of Micro-Climate Effects of New Designs
5	**Design Refinement**
5.1	Reflect findings from evaluation to refine design outcomes
6	**Detailing the final exhibition format - 'platform launch'**
6.1	Mock-up of animations and launch trailer/media
6.2	Draft program for event/evening
7	**Preparation for Pre-Final Submission**
7.1	Report writing and final formatting
7.2	Presentation formatting
8	Submission to Guest Crits
9	Stage 03 Due



STG04 FINAL SUBMISSION

11/12/2020 created by QuickPlan Pro
Jeremy Chivas

NO	TASK
1	STAGE 04 FINAL ASSESSMENT
2	**Refinement of Existing Work**
2.1	Visually integrate Grid & Mesh within high-level diagrams - 3 dimensionality
2.2	Complete Vegetation Matrix - Wetland & Remediation
2.3	Design Exemplars - annotate design principles in use
2.4	Design Exemplars - polished graphics style/ render (?)
2.5	Design Exemplars - several construction details for each, for a range of implementations
2.6	Address concerns on social observation section - sample size too small
3	**Additional/Refined Text**
3.1	List out all written sections that need to be completed
3.2	Incorporate previous comments on report from Martin in STG03
3.3	Add in future vision precedents from original presentation exports
3.4	Include critique of existing Smart City approaches
3.5	Finish off remaining text
4	**Review & Editing Process**
4.1	Send through Report for Internal Feedback 01
4.2	Update Text & Graphics based on feedback
4.3	Send through Report for Internal Feedback 02
4.4	Final Updates and Refinements
5	Final Submission to Guest Panel
6	Stage 04 Due



11

11. BIBLIOGRAPHY & DEFINITIONS

11.01 Definitions

ANTHROPOCENTRISM

A philosophical viewpoint arguing that human beings are the central or most significant entities in the world. Anthropocentrism regards humans as separate from and superior to nature and holds that human life has intrinsic value while other entities (including animals, plants, mineral resources, and so on) are resources that may justifiably be exploited for the benefit of humankind. Source: Britannica

BIODIVERSITY

The variety of living animal and plant life from all sources, including diversity within and between species and diversity of ecosystems.

BUILT ENVIRONMENT

Comprises the extent of our human-made environment, as distinguished from the natural environment. It includes all aspects of our surroundings made by people that provide the place for human activity. The built environment can be understood to include cities and towns, neighbourhoods, parks, roads, buildings and even utilities like water and electricity. Source: NSW Government Architect, 2016

COMMUNITY

Local residents or a unified group of individuals living in the same area.

COMMUNITY-ACTIVATED

Physical realisation of a concept or strategy through the participation of local residents and individuals.

DECENTRALISATION

The dispersal of resource delivery or production from a single, private or government controlled facility, to many smaller independent facilities within a more localised area.

ECOSYSTEM

A geographic area where plants, animals, and other organisms, as well as weather and landscape, work together to form a bubble of life. Ecosystems contain biotic or living, parts, as well as abiotic factors, or nonliving parts. Biotic factors include plants, animals, and other organisms. Abiotic factors include rocks, temperature, and humidity. Source: National Geographic (n/d).

ENVIRONMENTAL SIMULATION

The process of theoretically replicating of environmental considerations within CAD, GIS and other spatial programs.

FINE-GRAIN

Dealing spatially at a larger scale to achieve a higher level of detail, and subsequently a more responsive outcome.

GIS (GEOGRAPHICAL INFORMATION SYSTEMS)

A framework for gathering, managing, and analysing [spatial] data, and organising layers of information into visualisations using maps and 3D scenes. Source: ESRI (n/d).

GRASSHOPPER

A visual programming language and environment within the 'Rhinocerous 3D' CAD program, facilitating the generation of complex and custom algorithms to achieve a range of advanced outputs from parametric modelling, to performance analysis and simulations.

GREEN CORRIDOR

A linear ecological and active transportation connection through an urban or suburban environment, linking between significant vegetation remnants and environmental areas.

GREEN GRID

Strategic planning document for the greater Sydney region, and a precursor to the Greener Places design framework comprising a cohesive map of green assets across metropolitan Sydney. Source: NSW Government Architect, 2017.

GREEN INFRASTRUCTURE

The network of green spaces and water systems that deliver multiple environmental, economic and social values and benefits to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, squares and plazas, roof gardens and living walls, sports fields and cemeteries. Green infrastructure is the web of interrelated natural systems that underpin and are integrated into our urban fabric. Source: NSW Government Architect, 2016.

GREEN SPACE

An area of grass, trees, and other vegetation set apart for recreational or aesthetic purposes in an urban environment. Source: NSW Government Architect, 2017.

GREEN STRATEGY/NETWORK

A broad term which usually refers to a set of connected areas of green space and habitats such as parks, paths and woodlands within an urban or suburban region which provide a range of social, ecological and economic benefits such as increasing the quality of life within an area, and creating sustainable communities Source: SGIF, n/d.

HABITAT FRAGMENTATION

The process during which a large expanse of habitat is transformed into a number of smaller patches of smaller total area isolated from each other by a matrix of habitats unlike the original Source: Fahrig, 2003.

INTEGRATED

A built environment that links communities and functions and activities within a cohesive place. Source: NSW Government Architect, 2016.

LAND USE CHANGE

All components of change in the quality and quantity of land cover types as habitat for organisms and productive land for humans Source: Didham, 2010.

LIDAR (LIGHT DETECTION AND RANGING)

A remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth, generating precise, three-dimensional point cloud information about the shape of the Earth, its surface characteristics, and detailed features of the natural and built environment. Source: National Ocean Service, 2021.

LIVEABILITY

A built environment which supports and responds to people's patterns of living, and is suitable and appropriate for habitation, promoting enjoyment, wellbeing, safety, and prosperity.

METROPOLITAN

The area of a city comprising of the dense urban centre/s or CBD, as well as the less dense surrounding areas and suburbs.

MICRO-CLIMATE

Any climatic condition in a relatively small area, within a few metres or less above and below the Earth's surface and within canopies of vegetation. Source: Britannica.

OPEN SPACE

Land that has no buildings or other built structures, which is accessible to the public, including green space.

ORTHOMOSAIC

A geometrically correct aerial image that is composed of many individual still images that are stitched together.

PHOTOGRAMMETRY

A remote sensing technique used for mapmaking and surveying, using photographs from at least two different vantage points to obtain depth and perspective information through parallax. Photogrammetry can produce accurate orthomosaic aerial imagery, along with complex digital 3D textured models. Source: Britannica & GISGeography, n/d.

PLACE

A social and a physical concept – a physical setting, point or area in space conceived and designated by people and communities. In this sense, place can describe different scales of the built environment – for example, a town is a place, and a building can be a place. Source: NSW Government Architect, 2017.

POINT CLOUD

A set of 3D spatial data points which represent a shape or object, produced through LiDAR or Photogrammetry scanning methods.

POST-ANTHROPOCENTRISM

An ideology proceeding the notion of anthropocentrism, annulling humanity's need to conquer nature, instead promoting the thought that all living things are equal and should therefore be of equal consideration within human development, activities, and our built environment.

PRIVATE LAND

Parcels of land classified through the NSW LEP as any of the residential land zones.

PUBLIC DOMAIN

The public domain is the collective, communal part of cities and towns, with shared access for all.

RENEWABLE ENERGY

Energy from resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat.

RESPONSIVE

Buildings and spaces that are react positively to place and local character and context. Source: NSW Government Architect, 2016.

SOCIO-SPATIAL

A method of urban analysis in order to understand the interactions between humans and the built environment.

SOIL LANDSCAPE

Areas of land that have recognisable and specifiable topographies and soils that are capable of presentation on maps and can be described by concise statements. Source: Northcote, 1978.

SPATIAL DATA

2D or 3D relative geographic information about the earth and it's features, including both natural landscapes and human built environments, across a broad range of scales.

SPATIAL TECHNOLOGIES

The scanning and surveying systems used in the capture of spatial data, as well as the data typologies used to represent their outputs. Scanning systems include LiDAR and Photogrammetry, with their respective data outputs in the form of Point Clouds and textured meshes.

SPONTANEOUS VEGETATION

Early-succession vegetation which establishes autonomously within abandoned, unmaintained, or otherwise disturbed, man-made urban environments, spread through natural processes or unconscious human impacts.

SUSTAINABILITY

Relates to the endurance of systems, buildings, spaces and processes – their ability to be maintained at a certain rate or level, which contributes positively to environmental, economic and social outcomes. Source: NSW Government Architect, 2016.

TYPOLOGY

The comparative study of physical or other characteristics of the built environment and their classification into distinct types. Source: NSW Government Architect, 2016.

URBAN AGRICULTURE

The production of food within urban or suburban contexts, regional centres, cities, and towns, which may include the production of vegetables or fruits, livestock raising, beekeeping, aquaculture, hydroponics, and the making of preserves – all undertaken within private gardens, publicly-owned land, or within land managed by private institutions. Source: Urban Agriculture Forum, n/d.

URBAN DEVELOPMENT / URBANISATION

A process of land-use change, where the expansion of our built environment leads to the conversion from natural ecosystems into urban or suburban areas – in order to provide additional housing for growing populations, or provide industrial, commercial, or recreational services through built form.

URBAN ECOLOGICAL DESIGN

A design practice that aims to integrate green infrastructures and otherwise ecologically-beneficial planting typologies within buildings and the built environment, providing numerous human and non-human benefits which may include lower ambient temperatures, improved water management, urban habitat creation, visual amenity, and benefits to mental health.

URBAN FOREST

The layer of trees and tree populations that exist in urban settings Source: NSW Government Architect, 2017.

URBAN HEAT ISLAND EFFECT (UHI)

A built or metropolitan area which experiences significantly warmer temperatures that the rural areas surrounding it, caused primarily by excessive man-made hard surfaces, poor shade-cover and harsh sun exposure, and heat energy emitted from vehicles.

USER INTERFACE

The method of interaction and accessibility between a digital service and the user.

WATER SENSITIVE URBAN DESIGN (WSUD)

A design approach which integrates the urban water cycle into urban design to reduce environmental degradation and improve aesthetic appeal.

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