Mainstreaming Green Infrastructure Elements into the Design of Public Road Reserves:

Challenges for Road Authorities

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***Abstract*-Global warming poses particular challenges for urban areas due to the greater intensity of rainfall and issues of stormwater runoff, and the heat island effect generated by the reflection of the sun off hard surfaces, such as buildings and road pavements; for example, in Australian cities (i.e., Sydney), roads account for approximately 25% of all urban land use. The challenge for road authorities is to implement green infrastructure in road planning, design and implementation as the term "green infrastructure" has appeared increasingly throughout the world in land management and planning. Despite these environmental challenges, traditional highway engineering practices use arguments regarding the economic inefficiencies of urban traffic congestion to justify the business case for road-widening schemes and new road construction projects with associated de-forestation and vegetation loss. An international literature review and site visits of green infrastructure best practice in Australia, Singapore, the U.K. and the USA is reported. A typical road authority project is described in Sydney, Australia, where the initial design concept to accommodate growth in all modes of transport was road widening and land acquisition, but the authors persuaded the local and state government authorities to consider other options to "green" the infrastructure, particularly opportunities to add trees and vegetation near the roadway, which provide the additional bonus of managing surface water runoff. From this general problem, the case for, and value to, road authorities to develop green infrastructure guidelines for project planning and implementation, are presented. The conclusions include ongoing research to formulate draft guidelines for governments based on a holistic approach to the planning and design of high-density urban development around transport nodes that includes green infrastructure principles.**

Keywords-Green Infrastructure; Road Planning and Implementation; Best Practice Guidelines

I. INTRODUCTION

The idea of green infrastructure is not new: Jacobs [1] has examined green streets and boulevards known as "great streets", stating that street trees can make a significant contribution to make a place for walking, increase physical comfort, provide a sense of human scale and add visual complexity to the streetscape. Green infrastructure is rooted in the past: it stems from the idea of parkways and greenways, the British garden city movement, greenbelts, ecological corridors and smart growth [2, 3]. Ten years ago, the term green infrastructure was relatively new [4]; however, as discussed by MacFarlane [5], it is really "new wine in old bottles". In 1969, *Design with Nature* [6] introduced the idea of "physiographic determinism" combined with the importance of natural features in design, and encouraged planners and decision-makers to consider an environmentally-conscious approach to land design. However, few of these concepts were incorporated into highway engineering practice.

The primary imperative for road authorities to act has been climate change and its effect on the environment, where the term "green infrastructure" has appeared increasingly in land management and planning. For example, in England, the National Planning Policy of 2012 [7] designed a new framework for climate change adaptation and mitigation through the planning of green infrastructure into the city [8]. Global warming poses additional design challenges for urban areas due to the heat island effect generated by the reflection of the sun off hard surfaces, such as road pavements and buildings, and more intense rainfall and water quality and quantity runoff from hard surfaces. The greening around main roads and streets in the public domain with various landscape treatments is one way to address these two key problems of climate change in the quest to produce "smarter cities" [9]. It must be acknowledged that there are many other design elements that can contribute to a "smarter", more sustainable city; for example, the Asian Development Bank [10] summarises these other "green" elements of urban infrastructure services as water and sanitation services, waste management, and energy sources. However, the scope of this research is confined to the role of road authorities in addressing climate change. Traditional highway engineering practice is based on the premise that the economic inefficiencies of urban traffic congestion justify road-widening schemes (and new road construction projects) with associated de-forestation and vegetation loss. The mindset of road designers is to focus on the engineering specifications and to treat landscaping as a peripheral design element.

The argument underpinning the research reported in this paper is that guidelines for practitioners form an important tool to assist in urban planning and design, and that any practical guidelines for road authorities must undertake a holistic approach to road design that in turn can help address problems of heat island and water runoff and produce better places for people, all leading to beneficial environmental outcomes. The research methodology is a desktop literature review complemented by site

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visits made by the authors to iconic "green" infrastructures in Australia, Pilsen (Chicago), Emeryville (California), San Francisco and Singapore. (For a European perspective, see [11] on Merseyside, UK; [12] on Barcelona, Lyon and Rotterdam; and [13] on the Netherlands.) The primary contents of best-practice sustainable road infrastructure guidelines are summarised for Australia, Singapore, the United Kingdom and the USA. This paper introduces a typical, general problem of the "de-greening" of road infrastructure with a case study of the Norwest Park Boulevard in an outer suburb of Sydney (undertaken by the second and third authors) before extracting the main elements to be included in any holistic guidelines, so as to mainstream "green infrastructure" in the practice of road authorities.

The organisation of this paper is as follows. The first section describes the research problem of the urban heat island effect and rainfall and runoff, with particular reference to Australia, where the summers can be hot and dry and rainfall can be intense in other seasons. The second section introduces some of the cutting-edge approaches adopted in the USA and Australia, where urban densities are low; in the UK, from which many landscape architectural principles are copied; and in a city where the urban densities are high, but where the Singapore government has mainstreamed the greening of the city. The third section expands upon the general climatic problem, with reference to the more specific road sector problem, in which the dilemma facing local and state government authorities responsible for roads is illustrated with a real road project in northwest Sydney, and some design are solutions proposed to minimise vegetation loss. The final section identifies elements that must be incorporated by road authorities into best practice for green road infrastructure.

II. THE PROBLEM

A. *Urban Heat Island Effect*

The link between urban design and its affect on micro-climate is scientifically well understood, and can be clearly illustrated with temperature gradients across metropolitan Melbourne [14]. When asphalt and concrete replace soil and plants, the natural heat and moisture balances of the region are affected. Heat is stored in pavement and concrete, and trapped between close-packed buildings. The urban heat island effect creates localized warming as a result of the large amounts of paved and dark-coloured surfaces such as bitumen roads, roofs and car parks. Approximately 25% of the surface area of metropolitan Sydney is paved. Philipp, Wannous, and Pakzad have estimated land temperature in various land covers and thermal impact of the land use change in CBD and dense area after the reconstruction of the Cheonggyecheon (Seoul) from an expressway into a water stream. It shows the restoration of river and vegetation area how it reduces the land temperature in Seoul CBD [15].

However, the loss of trees and vegetation from urban development is an additional factor which influences the urban heat island effect. This is a global issue, as urbanization of the planet increases. Heat from the sun is absorbed but not reflected, and this causes surface and ambient temperatures to rise. Heat produced by car engines and exhaust also contributes to the urban heat island effect. Hotter air increases both the frequency and intensity of ground-level ozone (the primary ingredient in smog) that can aggravate respiratory problems. On hot summer days, cities can be several degrees hotter than their rural surroundings. Western Sydney is particularly impacted as, unlike the coastal suburbs, it does not receive the moderating influence of a cooling sea breeze. Furthermore, the January mean maximum temperatures for Western Sydney (Prospect Reservoir) have increased at more than twice the rate experienced by the coastal suburbs (Observatory Hill), and global warming trends indicate that temperatures in the west will continue to increase at more than twice the temperatures in the coastal suburbs [16].

B. *Stormwater Runoff*

Green infrastructure is usually understood as a natural and semi-natural network that is planned and maintained in order to provide multiple benefits to humans [17]. The Living Melbourne Living Victoria Road Map focuses on the role of water management in urban liveability [18]. Among all direct and indirect benefits of urban greenery, runoff mitigation is the most frequently mentioned benefit in research papers and guidelines, and a potential solution to confront climate change. According to Wong, Allen, Beringer, Brown, Deletić, Fletcher, et al [19]:

> "The way we manage urban water, particularly urban storm water, influences almost every aspect of our urban environment and quality of life. Water is an essential element of place making, both in maintaining/enhancing the environmental values of surrounding waterways and in the amenity and cultural connection of the place".

A study on the health benefits of green infrastructure concluded: "Every small patch of nature in cities and built areas can be 'hyper-functional' and provide co-benefits. While performing the primary purpose of stormwater management, green infrastructure also can be designed to augment park systems and provide places of respite, recreation, and delight" [20].

Urbanisation, and consequently land consumption, have created significant changes in the natural water cycle that has been replaced with an urban water cycle: increased volumes of stormwater runoff from impervious urban surfaces, and a decline in the quality of runoff from pollutants generated by human activities [21]. Water sensitive urban design (WSUD) emerged in the 1990s as a practical solution for sustainable management of the water cycle in an urban landscape. Trees and other vegetation can act as green infrastructure, providing alternatives to conventional engineering infrastructure in the process of integrated water cycle management and water sensitive urban design. There are at least eight hydrological and water cycle functions that

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are performed by green infrastructure: 1) canopy interception: the leaves of trees can capture (reduce) approximately 10% of the total annual rainwater and other precipitation; 2) streamflow: trees and shrubs capture and delay in peak flows; 3) leaf litter absorption: approximately 2-4% of annual precipitation is absorbed by dead leaves that transmit water and protect soil from erosion; 4) soil infiltration; 5) evapotranspiration; 6) hydraulic lift/redistribution; 7) groundwater recharge; and 8) conveyance of large storms [22].

In Australia, a number of state Governments and local authorities have adopted WSUD strategies or guideline documents [23]. These usually comprise a set of guiding principles and a set of Best Management Practices (BMP's) which may address the three "streams" of urban water cycle management: potable mains water, stormwater and wastewater. Greening the streets and networks has become a growing practice, in which streets are designed to accommodate stormwater runoff management and treatment, along with other sustainable design solutions such as traffic calming, pedestrian and cycle use, and the creation of attractive streetscapes. Thompson and Sorvig [24] have described green streets as "constructed ecological networks". In the United States, two cities leading the way in green street design are Portland, Oregon, and Seattle, Washington [25]. The SW 12th Ave Green Street project in 2005 involved retrofitting a series of stormwater planters into an inner urban street in Portland. Seattle Public Utilities has adopted a Natural Drainage System (NDS) strategy. This is based on Street Edge Alternative (SEA) neighbourhood streets, incorporating a variety of low impact development techniques to store, infiltrate and filter stormwater [26]. New York City has developed a set of High Performance Infrastructure Guidelines, which provides a roadmap for incorporating sustainable practices into the city's infrastructure capital program [27]. Additionally, the Chicago Department of Transportation developed a Green Infrastructure program between 2006 and 2008 that includes recycled construction materials, permeable pavements, recycled rubber sidewalks and other efforts [28].

III. LITERATURE REVIEW :GREEN INFRASTRUCTURE GUIDELINES

Although the previous section and the introduction to this paper have made reference to previous research and other reports, this section specifically focuses on guideline materials available to road design practitioners. The literature review is based on practices in four countries: Australia, Singapore, the U.K. and the USA. Cities in Australia are closer in density and urban form to cities in the USA, whereas much of the landscaping practice in Australia is derivative of research and guidelines produced in the U.K. Singapore is a country that is recognised as a leader in global best practice regarding green cities.

A. The USA

In April 2011, the U.S. Environmental Protection Agency [29] released the Strategic Agenda to Protect Waters and Build More Liveable Communities through Green Infrastructure. Green infrastructure uses vegetation, soil, and natural processes to manage water. At the neighbourhood scale, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. American cities have a high proportion of urban land use allocated to roads and surface car parks as paved surfaces compared to many cities of the world. The generic problem is that U.S. cities have a high percentage of all land surface devoted to pavements that exacerbate runoff. For example, San Francisco's streets and public right-of-way comprise 25% of the city's land area, which is more space than all the public parks combined.

The three issues associated with pavement surfaces are (a) contribution to the heat island effect, (b) problems with runoff from heavy rain and (c) aesthetics (i.e., bleak, hard-edged appearance, particularly when empty of cars). For example, the City of Emeryville, California explains that a "Green Dense Redevelopment" is a project that creates vibrant neighbourhoods and helps deliver ecological benefits:

> "…the thinking behind 'green dense redevelopment' is that urban infill projects can benefit water resources by directing growth away from the undeveloped portions of a watershed…by reducing the amount of paved surface that exacerbates runoff and by providing on site storm water treatment facilities"[30].

Many U.S. streets are excessively wide and contain large under-utilised areas, particularly at intersections. The San Francisco "Pavement to Parks" program seeks to test the possibilities of these underused areas of land by quickly and inexpensively converting them into new landscape treatments and pedestrian spaces. Each Pavement to Parks project in San Francisco is intended to be a public laboratory for the city government to work with local communities to temporarily test new ideas in the public realm. Materials and design interventions are meant to be temporary and easily reversible, should the trial run demonstrate the need for design changes. After testing their performance, some spaces might be reclaimed permanently as public open spaces. Seating, landscaping, and paving treatments are common features of all projects.

As the city of Chicago [28] has received national recognition for its forward-thinking commitment to urban environmental sustainability, it is an important case study for benchmarking. Federal, state, and municipal decision-makers look to Chicago's leadership on such issues as green roofs, green-building permits, green alleys, sustainable streets, bicycle and public transport planning, park and open space development, and urban wildlife habitat preservation. The city government of Chicago is also rethinking the planning, design, building, and maintenance of its public right-of-ways, which represents 23% of its land area and more than 70% of its public open space. Comprising more than 4,000 miles (6,500 km) of streets and 2,100 miles (3,400 km) of alleys, these mostly-paved surfaces contribute significantly to environmental challenges, such as (a) stormwater

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management; (b) water use; (c) urban heat island effect; (d) energy use; and (e) and waste management.

The mission statement by the Chicago Department of Transportation is supported by three purposes and statements, which express the high-level outcomes and goals of the principles, objectives, requirements and processes outlined in The Sustainable Urban Infrastructure Guidelines and Policies:

> "To create a safe, liveable, and sustainable city with great streets and healthy places.
>
> To provide simple, pointed design, construction, and maintenance guidance for the creation of a sustainable urban infrastructure for all Chicagoans.
>
> To prepare the city's infrastructure to respond to the challenges of climate change and enact policies to reduce its negative impacts" [28].

Chicago is playing an active role in project-specific mitigation efforts, including the award winning Green Alley and Sustainable Streets programs that have transformed the success of pilot projects into an effective program [28]. Projects within these programs are redefining infrastructure in an urban environment by integrating complete streets and sustainable design best practices to achieve increased environmental performance from investments in transportation infrastructure. The sustainability criteria and specific objectives are summarised by category.

B. Singapore

Amongst high-density Asian cities, Singapore, despite having a population density of over 7000 persons per square kilometre, has been ranked as one of the most highly liveable cities in many international surveys, including Siemens's Asian Green City Index [31], Mercer's Quality of Living Survey [32] and the Global Liveability Ranking by the Economist Intelligences Unit (EIU) [33]. This indicates the importance of well-planned dense cities that can deliver a more liveable and sustainable urban environment. One solution to the limited land in the city is the vertical zoning that Singapore, "a city within a garden", has applied in its city planning according to Newman [34].

A study undertaken in 2013 by the Urban Land Institute using Singapore as a model aimed to determine principles of well-designed highly dense districts that resulted in liveable spaces and a high quality of life [35]. Ten principles were developed that provide an insight into Singapore's integrated model of planning and development, which combines the physical, economic, social, and environmental aspects of urban living:

1. Plan for long-term growth and renewal.
2. Embrace diversity, foster inclusiveness.
3. Draw nature closer to people.
4. Develop affordable, mixed-use neighborhoods.
5. Make public spaces work harder.
6. Priorities green transport and building options.
7. Relieve density with variety and add green boundaries.
8. Activate spaces for greater safety.
9. Promote innovative and non-conventional solutions.
10. Forge 3P (people, public, private) partnerships.

Principle 3 (draw nature closer to people) relates specifically to urban greening and the concept of green infrastructure. According to the report prepared by the Urban Land Institute:

> "Blending nature into the city helps soften the hard edges of a highly built-up cityscape and provides the residents with pockets of respite from the bustle of urban life. What started as an aim to build Singapore into "a garden city" has now evolved into Singapore being "a city in a garden". In addition to the many parks scattered across neighbourhoods, water bodies course through the city and form an important part of the landscape. Nearly half of Singapore is now under green cover, which is not only aesthetically pleasing, but also is good for the air quality and mitigates the harsh heat of the tropical sun. Another aim of having Singapore residents experience nature as an integral part of their lives is to encourage them to value and, as a result, take better care of the environment and the city's limited natural resources." [35].

City planning in Singapore is based on a flexible strategic planning concept for long-term growth (40-50 years), and for medium and short terms in combination with a strategic land-use and transport plan; the master concept goes into more details to guide development and implementation in the medium term of 10-15 years. Strategies such as greening the transport and

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building systems that use land and resources more efficiently increases the liveability of highly dense areas in several ways: they improve the city's social and economic vitality; there is an integrated network of pedestrian links; residential and commercial entities at transit centres help people move about more comfortably, encourage social interaction, and promote the use of public transport.

Singapore has a Streetscape Greenery Master Plan that has adopted the concept of "pervasive greenery" in city planning, according to which developers insert greenery wherever they can: pavements, parking lots, road medians, building façades and on rooftops. The concept is known as "cloak spaces with green wherever the eye could see". Tree-lined roads provide shade and a pleasant microclimate, and friendly spaces for pedestrians and cyclists, while providing an aesthetically softer feeling as compared to hard concrete structures and edges. More recently, environmental sustainability has been added as another layer to street and network design.

The National Parks Board of Singapore has actively promoted various methods to bring visible greenery from the ground level up to building tops, cityscapes and vertical greenery and has also published extensive guides on Skyrise Greenery. Following this, a number of recently built high-rise buildings in Singapore have created rooftop gardens, and some commercial complexes have also included swimming pools, food and beverage outlets, and viewing decks atop the buildings. The key green infrastructure documents in Singapore on which the above summary is based is the Streetscape Greenery Master Plan-SGMP [36] that provides planning and design guidelines to achieve variation in the character of Singapore roads and streets [34, 37]. The National Parks Board (NParks) is responsible for providing and enhancing greenery of the garden city vision (National Park (NPark) https://www.nparks.gov.sg/). Other relevant documentation includes Singapore's National Biodiversity Strategy and Action Plan [38], the Singapore Green Plan 2012: Beyond Clean and Green towards Environmental Sustainability, produced by the Ministry of the Environment and Water Resources [39], and the Greenery Provision for Roadsides [40] by NPark.

IV. UNITED KINGDOM

One of the issues with the practice of green infrastructure is the economic justification of projects. The United Kingdom has made a valuable contribution to the international literature on this topic. "Green Infrastructure-valuation" [41] is the only comprehensive economic appraisal toolkit that has been developed, and covers trees, green roofs and urban green space. The Green Infrastructure Valuation Toolkit was released in 2010 (Table 1); it is a set of individual spreadsheet-based tools that assess the value of green assets across a wide range of criteria in 11 categories, derived from various workshops in the U.K., and including: (1) climate change adaptation and mitigation; (2) labour productivity; (3) water and flood management; (4) tourism, (5) place and communities; (6) recreation and leisure; (7) health and wellbeing; (8) biodiversity; (9) land and property values; (10) land management, and (11) investment.

TABLE 1CHARACTERISTICS OF GREEN INFRASTRUCTURE VALUATION TOOLKIT

Name, sponsor date of origin	Applicability	Characteristics
Green Infrastructure-Valuation Toolkit (GIVT) [41] Commission for Architecture and the Built Environment	Tree cover, woodland, green roofs and urban green spaces, green corridor elements (pedestrian and cycle routes) and water courses, ponds and wetlands	• Excel spreadsheet tool. • Comprehensive cost and benefits of green infrastructure assessment toolkit only applicable in U.K. However, this tool needs to reassess the input by economic experts and occasionally default values need to be updated to current related values. • The benefit estimation tools are grouped into 11 categories which are designed through a series of workshops in the U.K. This is a mixed list of ecosystem services and contribution of green infrastructure in local economic growth. • Estimates the total benefits and full costs to society and, where feasible, all are expressed in monetary terms to arrive at a net benefit or cost. The strength of this tool is its transparency; users can understand the process of evaluation. • Estimates pedestrian and cycle route benefits by estimating the number of people to utilize it for exercise; this will result in reduction of mortality rate • Weaknesses: significant risk of double counting and overlapping if different benefits such as health, recreation, tourism and labour are aggregated. The tool is a mix of benefits and multiple values. Unit values used in this tool are not proved with evidence and it is not clear how to sum and/or distinguish between different values in various scales and units.

All results are given in financial terms. This tool covers a range of mixed indicators of ecosystem services (climate change adaptation, water and flood management, etc.) and the associated economic benefits of green infrastructure (land and property value, investment and land management). In the second portion, the economic value and local economic impacts are aggregated; however, the unit values are not always substantiated based on the literature, which may potentially expose a significant risk of double counting. However, the economic impact is only about the traded economy property values, employment, tourism spending, etc. The economic value takes into account economic welfare, which goes beyond the traded economy [42]. Therefore, there is no evidence or proven guidance on the establishment of these different unit values. The tool is transparent and users are aware of the valuation process. It can be applicable to other countries if the default data assessed by

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economists is adjusted based on local and national regulations. In the United Kingdom, this tool is not recommended for economic valuation without reassessment and input from expert economists, and the default values must be correctly updated [43]. Another limitation of this tool is in lifespan benefits evaluation of the green infrastructure asset. This toolkit selected various timeframes for each indicator; this timescale is typically associated with economic benefits that affect the added gross value. It assesses the cost-benefits of green infrastructure over the periods of 10, 20-25 and 30-50 years. However, for example, this is dependent on the condition of each tree, and a tree's lifespan can vary substantially.

V. AUSTRALIA

With approximately 89% of residents living in cities or towns, Australia is one of the most urbanised societies in the world [43]. These land transformations have raised the surface temperature of Australian cities by as much as 10-20ºC compared to surrounding air temperatures [44]. Therefore, green infrastructure solutions have become increasingly valued in a wide variety of settings: a system for water management [45]; climate mitigation and adaptation strategies; ecological services and land conservation; or as an attitude for a strategic planning approach [46].

The Australian Institute of Landscape Architects [47] defines green infrastructure as:

> "a network of natural landscape assets which underpin the economic, socio-cultural and environmental functionality of our cities and towns – i.e. the green spaces and water systems which intersperse, connect, and provide vital life support for humans and other species within our urban environments."

In the last decade, most green infrastructure research studies have taken place in the United States and Europe. However, a number of significant studies have also been undertaken in Australia [48-58]. The Nursery and Garden Industry Australia [59] has studied the benefits of urban trees and green spaces [60]. Scholars such as Moore [61], McPhearson [62] and Thom, Cane, Cox, Farrell, Hayes, Kay, et al [63] have explored green infrastructure concepts in various disciplines, such as climate change mitigation and adaptation. Urban heat island effect mitigation have been studied by Coutts, Beringer and Tapper [64] and others [65-67], sustainable water management system and blue/green infrastructure [19], carbon storage and sequestration [68], human health and wellbeing of urban nature and green infrastructure, including recent Australia-based research [15, 25, 68-71]. Selection and approval of urban tree quality should use the NATSPEC "Specifying Trees a Guide to Assessment of Tree Quality" authored by Clark [72].

In Australia, the main approaches for green infrastructure can be identified from the literature: the ecosystem services approach by Austin [3], and Lafortezza, Davies, Sanesi, and Konijnendijk [8] that is a general framework for green infrastructure. Pakzad and Osmond [73] propose a conceptual framework which links green infrastructure performance into ecosystem health and human health and wellbeing. This framework examines in Australia context by interview with stakeholders. This study concludes with a list of performance indicators to best reflect the comprehensive and integrated functions of green infrastructure.

Historically, the integrated concept of human health, ecosystem services and ecosystem health is linked to the concept of sustainable development and urban ecology developed by Pitman and Ely [25], Spirn [74] and Hough [75]. The connectivity approach by Benedict and McMahon [76] improves functions of a system in various settings such as biodiversity protection and habitat enhancement, ecology performance, social connectivity and opportunity for recreation and tourism, resulting in overall economic benefits. Green engineering is considered a specialised form of green infrastructure by retrofitting and/or substituting conventional infrastructure with living elements.

Technical Guidelines for Urban Green Cover in NSW (2015) have been prepared by the government architect's office for the Office of Environment and Heritage [77] to provide practical advice on best practice and assist NSW environment building professionals. The purpose of these guidelines is to increase the resilience of NSW settlements and communities to climate change, specifically to increasing temperatures in urban settings. It provides practical advice regarding the adaptation of the urban environment through urban green cover projects. Urban green cover includes a range of strategies such as vegetated and reflected roofs and green walls, street plantings, permeable and reflective road surfaces, and cool open spaces and parks. The Green Cover Demonstration Project, conducted by the Office of Environment and Heritage (OEH) in collaboration with the NSW Government Architect's Office, showcases leading landscape design principles for urban green cover. It uses examples in Liverpool and Penrith to model the principles, which can be applied to all local government areas.

VI. CASE-STUDY: ROAD DE-FORESTATION

With such a wealth of resource material identified above, it might be anticipated that road authorities are well-positioned to implement green infrastructure; in practice, this is often not the case. Throughout the urbanised world, travel demand is increasing and there is a substitution of private transport, primarily motor cars and motor bikes. For journeys previously made on foot, by bicycle or by using public transport. Highway authorities plan, design and build roads to cater to this projected increase in road-based traffic and the land allocated to infrastructure inevitably leads to tree and vegetation loss. This general and widespread environmental problem that faces local and regional governments is an attempt to balance the imperatives of

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economic growth against maintaining the integrity of ecosystems. This can be illustrated with a case study drawn from the western suburbs of Sydney, in which the researchers were involved.

The example is that of a development project for a highway, currently well-landscaped, where all future options indicate vegetation loss in an existing road right-of-way. The initial option proposed by the road authority was to widen the road to accommodate all modes of future traffic projected to use the road corridor, and hence to remove trees and vegetation. Most road design solutions involved the utilisation of the median strip for additional lanes, with the consequential loss of vegetation. The action-based research topic addressed by researchers was how elements of "green infrastructure" and material in the guidelines identified in the literature review could be mainstreamed into the core business of road authorities when designing road improvements in the road reservation. The outcomes are described below in sufficient engineering design detail for the reader to understand the project solutions.

VII. PROBLEM CONTEXT

Norwest Boulevard is located in the Local Government Area (LGA) of The Hills, approximately 40 km northwest of the Sydney CBD. Currently, it is a well-landscaped road that is subject to a road-widening project, a business case justified by increased population and economic growth and increased travel demands. The aim of the project is to accommodate additional vehicular travel demand with "minimal impact on urban design and the green environment". The Norwest Boulevard study area itself is approximately 2.7 km long and is classified as a state road with two lanes of mixed traffic in each direction. The corridor is the primary access road to the Norwest Business Park as well as a principal access connection between the M7 Motorway at its western end, and the general Castle Hill residential and commercial district at its eastern end.

VIII. EXISTING ROAD GEOMETRY

Essential features of the Norwest Boulevard are shown in cross-section in Fig. 1. The key geometric elements are as follows:

- Overall road reserve is 30 m-34 m, typically 33.2 m.
- Lane widths are typically 3.3 m wide, with two lanes in each direction.
- Footpaths are of variable width, either 1.2 m or 1.9 m, and brick-paved.
- The footpath environment, including verge, footpath and the heavily-landscaped buffer, is typically 5.0 m in width.
- Traffic lanes are divided by a wide central median approximately 9.0 m in width, planted with rows of gum trees next to the traffic lane, interspersed with ground-level planting. An underground stormwater drainage structure runs down the centre of the median.
- The corridor is bookended by major signal intersections on other state roads: at Old Windsor Road and Windsor Road.
- At intermediate locations, a series of two-lane roundabouts control turning movements into and out of side streets.

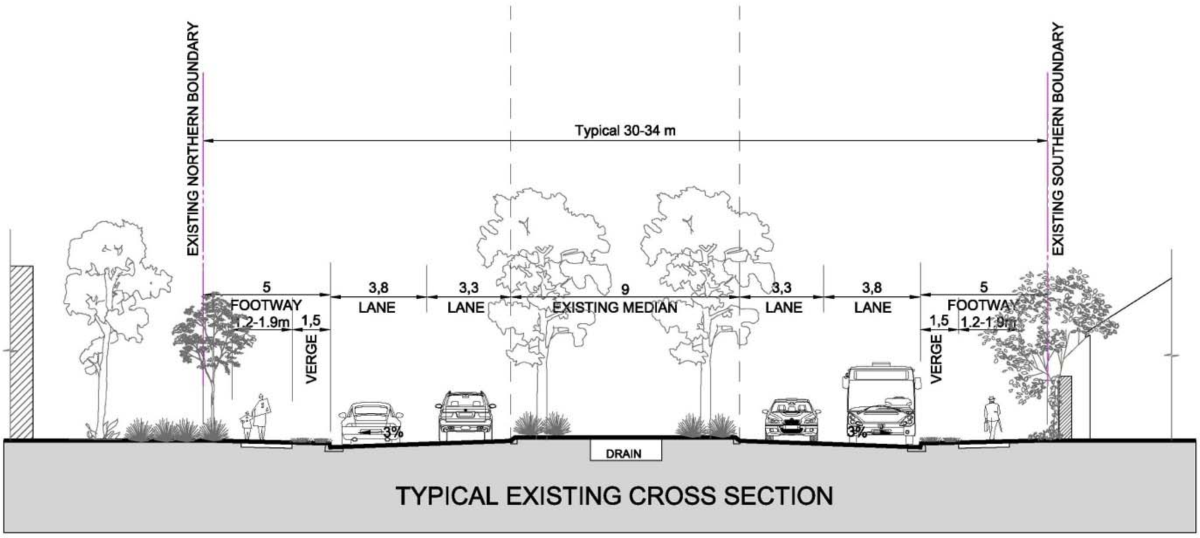

Fig. 1 Typical cross-section of Norwest Boulevard, Sydney, Australia

IX. LAND USES ADJACENT TO THE ROAD

The predominant type of land use adjacent to this road corridor is commercial, with the Norwest Business Park serving as the largest employment centre in the region. The employment population within the Norwest Business Park was approximately

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25,000 employees in 2011 (The Hills Shire Council Media Release, 7 March 2011). However, there are pockets of medium-density residential housing, local parks, and community uses (such as the Castle Hill Country Club and the Catholic Convent to the southeast of the corridor, Hillsong Church and a shopping precinct in the centre of the corridor). The forecasted land-use changes for the study area includes a rise in employment by an additional 14,000 jobs, and a future additional population of approximately 100,000 by 2031.

Norwest Boulevard provides a high level of access for cars and trucks, but a very limited service for pedestrians and bicycles. Currently, regional buses provide services along the route; however, the introduction of the Norwest Rail with a station along the boulevard is imminent in the very near future. The New South Wales State Transport agency envisages the introduction of a rapid bus corridor along its length, which is an additional justification for widening the boulevard. Due to the inherent design limitations along the road, there are only limited locations that pedestrians can cross the road with confidence and safety. The car-oriented design means that it is often easier to use private transport from a place of employment along the boulevard to visit a restaurant or shops, although they are within a convenient walking distance of approximately 400 m.

X. LANDSCAPING

The corridor is heavily landscaped and has a particular visual appeal. The central median has semi-mature gum trees planted at regular intervals in two rows within a planted zone of 9.0 m in width. The bare tree trunks, tree canopies that are regularly-spaced, and ground-level cover (Fig. 2) are dominant features that are worthy of preservation or replication.

Fig. 2 Photographs of Norwest Boulevard, Sydney, Australia (July, 2015)

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The landscaping strategy used for the Norwest Boulevard also includes gateway-landscaping treatments at each end of the corridor at Windsor and Old Windsor Roads, incorporating multi-layered hedges into the centre median and adjacent to the buildings flanking the road. The footpath reserves on each side of the road are approximately 5.0 m wide. The landscaping elements of these are less-regularly established than those in the median: they range from dense shrubs in front of noise walls that screen residential areas from the road corridor, to small street trees in planting rows, to blended planting in front of landscaped commercial building frontages. The wide footpath reserve also allows the provision of indented bus bays.

XI. FUTURE ROAD OPTIONS

Any proposal to upgrade the current four traffic lanes of the corridor will potentially impact the landscaping that has been described and illustrated, as well as the overall landscape character of Norwest Boulevard, and the visual amenity of local communities. All options for road upgrades require careful visual analysis with the goal of minimising adverse impacts and optimising the landscape character of the corridor. Where it may not be possible to avoid landscape clearance, replacement landscaping must be considered to retain landscape quality and overall character.

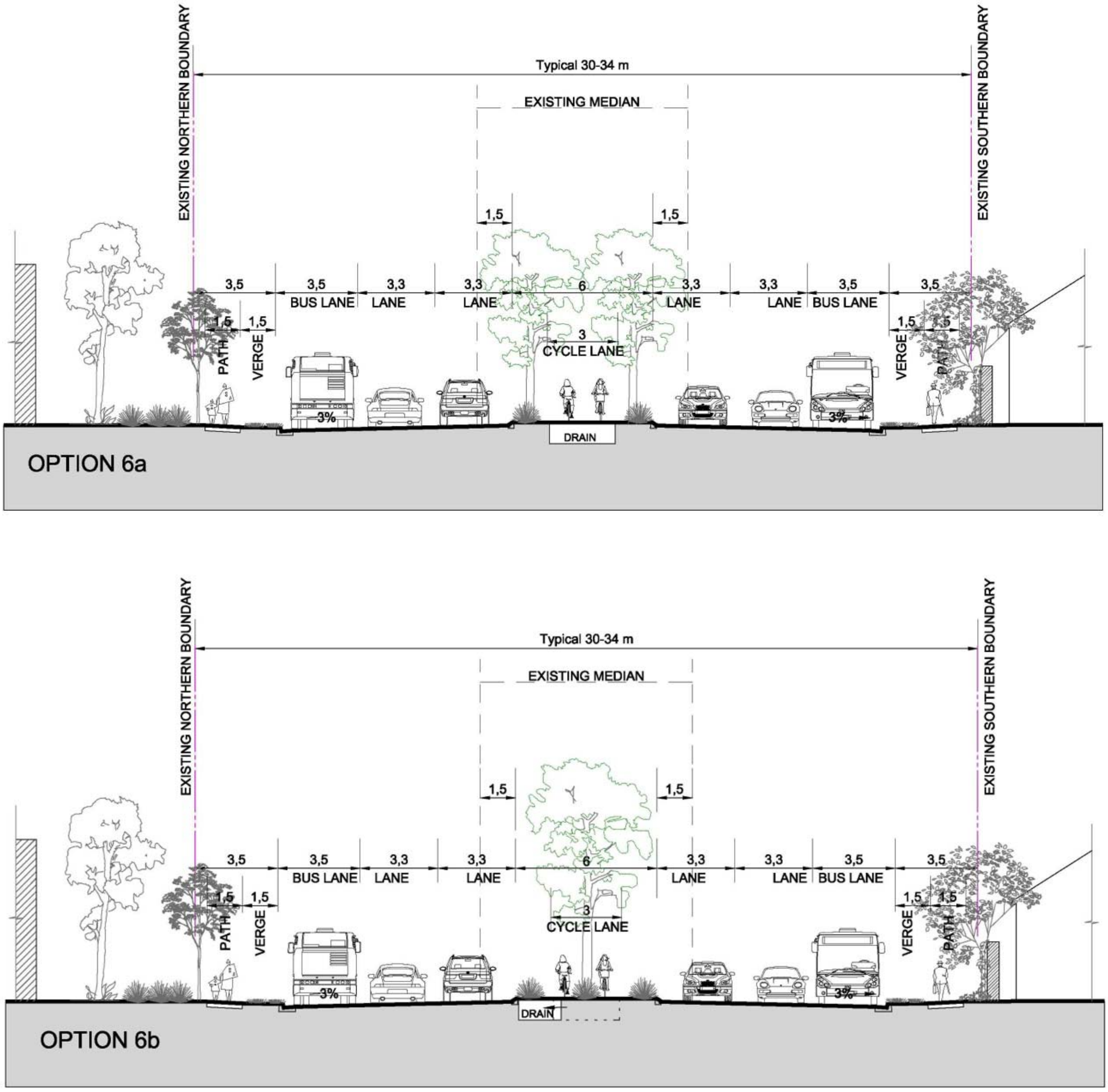

Fig. 3 Norwest Boulevard road corridor design options, in cross-section

As part of the design process, a number of options were considered and evaluated according to the strategic directions summarised in Appendix A. This led to two preferred design options (Fig. 3). Option 6a is to upgrade the road to 6 lanes, to retain the current reservation (33.2 m), but to narrow the road median. This will allow two lanes for general traffic and one bus lane in each direction. The current width of central median is to be narrowed to able up to two, opposing right-turn lanes at

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intersections. The current footway is retained on both northern and southern sides. As an interim approach, a shared footway/ cycleway on one side only (northern side preferred) could be considered. Pedestrian crossings at side roads are to be managed, and eventually a two-way bicycle lane in the narrowed central median will be implemented that is contingent on the signalisation of all intersections. Option 6b is a variation of Option 6a except that a separated one-way bicycle lane in the narrowed central median is provided (this is still contingent on the signalisation of all intersections being achieved).

The preferred concept design, particularly Option 6a, has the characteristics of:

- Minimising the impact on the green environment and disruption to existing urban design features that are familiar to existing users;
- Accommodating additional lanes for bus movements while accommodating the future demands for vehicular traffic;
- Providing pedestrian crossing points at proposed signal intersections and at mid-blocks; and
- Establishing a safe and efficient bicycle path.

Thus, there is potential within the road reserve, either current or planned, for the efficient movement of vehicular traffic and landscaping that delivers green infrastructure. In order to advance the development of practitioner guidelines to assist road authorities, the next section suggests the value of producing specific guidelines for road authorities, and the content of such guidelines.

XII. GREEN INFRASTRUCTURE GUIDELINES FOR ROAD AUTHORITIES

From the above case study, it is clear that there are pressures to achieve holistic solutions for the built environment and street systems. It has become evident that road authorities should not issue guidelines, procedures and technical directions that are structured in a one-dimensional manner. To illustrate this point, a common practice in road safety is to remove or relocate trees and plants associated with kerb lines or medians in order to minimise any possibility of vehicular crashes into fixed objects. Similarly, the introduction of trees and planter boxes as part of the street furniture has been one of the primary features of urban design in the development of street schemes. Most guidelines are developed in isolation and it is often during the implementation phase in which one criterion overrules another, which is subject to the preference of practitioners/officers of the involved agencies. Accordingly, this calls for a review and update of road authority guidelines in general, to reflect and include various related areas of urban and streetscape design.

The current Australian guidelines for traffic management schemes are generally well prepared to cater to the amenity and safety of various road users. These guidelines all prescribe a range of measures in terms of accessibility and road safety with an aim to minimise conflicts between pedestrians and vehicular traffic. It should be noted that most road-related guidelines consider environmental design aspects, but such treatments are generally cosmetic and ornamental with little effect on any real environmental benefits. This could also be said about some of the streetscape measures that are purely justified by urban design, with little acknowledgment of their practicality and impact on road safety. For example, the installation of trees at or near the desired pedestrian lanes (including people with prams and strollers) is common practice, particularly in Australian country towns and suburbs. Furthermore, the area of green infrastructure and its vital impact on an ecosystem and associated benefits have hardly been quantified and acknowledged, despite the general recognition of green infrastructure within the industry, as noted in the international literature review.

The way forward for road authorities to achieve unified guidelines could be a difficult and time-consuming affair. The development and use of any innovative guidelines comes at a cost, but that expenditure can be justified. For instance, the philosophy of the Chicago document [28] is that while there are cost implications to some of its new requirements, such as increased staff time in review and documentation, modest design fee increases while consultants adjust to new standards, and potential modest construction fee increases as the entire industry adopts and adapts to a revised practice, the value of the increased investment reflected in these costs justifies the expenditure. Furthermore, many of the requirements lead to cost savings such as the use of recycled materials, recycling of construction waste, use of energy-efficient lighting, and reduction of "grey" or "pipe" stormwater solutions. For example, the successful construction bid for the Pilsen Sustainable Street Project was 21% less per block than the average per block cost of the 10 other similar projects bid on that year. Street flooding can be eliminated, or greatly reduced, with stormwater best management practices. This reduces homeowner and business insurance claims, protects road infrastructure, maintains walkable and cycleable footpaths and streets, and reduces interruptions to economic activity [28].

However, the first steps towards mainstreaming green infrastructure in road authorities could be taken with capacity building and professional development of the involved professionals. The benefits arising from such initiatives would be surprisingly high, resulting in improvements to the built environment and urban living conditions, enhancement of visual amenity, accessibility to natural flora and achievement of comprehensive solutions. Such efforts must also aim to address the challenges demonstrated in the case study described above, in which there is a persistent demand to meet the needs of growth and expansion of the road system as the result of excess vehicular trip generation.

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Accordingly, the elements of green infrastructure as part of a street system environment require a detailed evaluation for their amalgamation into road and traffic guidelines. Green infrastructure planning approaches address four primary principles, which can provide a scope for the development of guideline documents regarding urban greenery for road authorities: 1) integration with other infrastructure; 2) multi-functionality, in which green infrastructure planning seeks to combine ecological, social, and economic and cultural functions; 3) connectivity, or a multi-scale approach (from individuals to community, regional and state); and 4) a multi-object approach (green infrastructure includes all kind of green, blue space, natural and semi-natural areas).

Based on these principles, existing guidelines should be modified in terms of their scope and approach. For example, the aspects of green infrastructure connectivity that have been highlighted in documents relate to biodiversity, habitat connectivity, wildlife corridor, recreation and ventilation in a high level of detail. The majority of guidelines that have been released are related to the multi-functionality of green infrastructure or regulating functions that are broad in thematic scope [73], e.g., carbon sequestration and storage [68], runoff reduction, and urban heat island effect mitigation [15]. In these guidelines, rarely has the term green infrastructure been used: urban forestry, street trees, urban greenery and green cover are the most commonly-used keywords. Cultural functions, such as recreation, are usually documented with the regulative functions of ecosystems.

VI. CONCLUSIONS

The problems which green infrastructure proposals aim to address include reducing the urban heat island effect, better management of stormwater from hard surfaces, and creation of an improved environment in which to walk and cycle. This paper has presented a comprehensive review of existing documents from four countries (Australia, Singapore, the United Kingdom and the USA), representing different planning systems and approaches that integrate green infrastructure concepts into the planning phase. Among these planning systems, Australia demonstrates a gap between theory and practice, because the theories mostly originate from the USA but implementation and action plans are derived from approaches utilized in the U.K. Based on ongoing research conducted by the third author from a summary of interviews conducted with 21 multi-disciplinary experts across Australia, it can be established that the concept and principles of green infrastructure are not fully understood. Even between three groups of participants (practitioners, academics and government officials), the definitions and conceptual approaches of green infrastructure vary. Most participants defined “green infrastructure” as green roofs and walls rather than an interconnected network of green assets on a broader scale; therefore, it is of little surprise that Australian road authorities are a long way from integrating green infrastructure principles into guidelines and practice. The documents cited in Appendix A should assist in the writing of such guidelines.

This paper has outlined the principles that can provide a scope for the development of guideline documents regarding urban greenery for road authorities: integration with other infrastructure; multi-functionality, in which green infrastructure planning seeks to combine ecological, social, and economic and cultural functions; connectivity and a multi-scale approach (from individuals to community, regional and state); and a multi-object approach (green infrastructure including all kind of green, blue space, natural and semi-natural areas). The case study of Norwest Boulevard demonstrates the current limitations to practice by road authorities, although the authors where able to inject more “greenery” into the options under consideration. However, our future research aims to be more ambitious in developing guidelines for road corridors.

The future direction for this research is to formulate draft guidelines for the government based on a holistic approach to the planning and design of high-density urban development around transport nodes that includes green infrastructure principles. Further efforts should also be made to include “smart city” design principles:“The point is not to forget the urban green infrastructure while developing a Smart City” as recommended by Reinwald, Damyanovic, Brandenburg, Allex, Gantner, Czachset al [9].Considering that the concept of green infrastructure is one of the key elements of a “smart city”, attention to such components should also be made for inclusion in the guidelines for road authorities. For example, in the USA, the implementation of transit oriented development (TOD) that follows green building standards and integrates sustainable measures exponentially increases the value of neighbourhoods as sustainable places. In addition to reducing vehicle kilometres of travel, these areas have the potential to offer low impact development through the application of green building standards and sustainable site development practices. They can also provide trees, green space, and landscaping; places to grow healthy food; permeable surfaces and green stormwater infrastructure; and other eco-friendly elements as detailed by the Puget Sound Regional Council and Growing Transit Communities Partnership [78].

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APPENDIX A: Australian Guidelines of Green Infrastructure.

Sustainable Sydney 2030 Community Strategic Plan (2014) City of Sydney.
Environmental Management Plan (2014) Department of the Environment Australian Government.
Green Roofs and Walls Policy Implementation Plan (2014) City of Sydney.
Greening Sydney Plan (2013) City of Sydney.
City Transport Strategy (2013) City of Sydney.
Walls and Roofs Green (2014) City of Sydney.
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State of Australian Cities report (2013), Department of transport and Infrastructure
Benchmarking Australia's Urban Tree Canopy (2013), Institute for Sustainable Future
Public Green Space and Life Satisfaction in Urban Australia (2012), Ambrey Ch. & Christopher Fleming

Other LGA strategies and plans:

Marrickville Council Biodiversity Strategy 2011–2021 and Action Plan 2011–2015
Leichhardt Municipal Council Draft Native Revegetation and Biodiversity Management Plan (in preparation)
Woollahra Municipal Council Biodiversity Strategy (in preparation)
Randwick City Council Draft Biodiversity Strategy (in preparation)
Greenway Revegetation and Bushcare Plan
Biodiversity Study of the Waverley Local Government Area

National, state and regional strategies and plans:

Australia's Biodiversity Strategy 2010–2030
Draft NSW Biodiversity Strategy 2010–2015
Hawkesbury–Nepean Catchment Action Plan;
Adapting to Climate Change: Green Infrastructure.

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