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Preface

Today, 55% of the world’s population live in cities, and this figure is expected to be 68% by 2050 (UN, 2018a). Australia’s population is expected to grow by 60% by 2050, with over 90% residing in the cities. Future urban design and infrastructure changes in the built environment resulting from this substantial growth and urban development will significantly influence the way we consume energy and will be reflected in our carbon signatures.

At present, the urban, ecological and carbon footprints of Australia’s cities are among the highest in the world, as are its per capita CO₂ emissions. Two of the most recent United Nations (UN) reports on carbon emissions and resource consumption highlight the unsustainable nature of this situation and stress the urgency for transformative change (UN, 2018b; IRP, 2018). Accordingly, the Low Carbon Precincts Program (LCPP) in the Cooperative Research Centre (CRC) focused on pathways for reducing energy use and the carbon footprint of our urban systems, with key consideration being given to the sectors of energy, water, waste, transport and buildings – all of which have significant resource impacts and carbon signatures.

The Urban Design Protocol (Department of Infrastructure, 2011) outlined a clear set of performance goals for Australian cities that extend beyond the planetary boundary issues of resource use and greenhouse gas emissions to include productive, competitive, liveable, sustainable, inclusive and resilient built environments. If Australia’s cities are to achieve these goals, then it will be necessary for the large metropolitan regions and their constituent precincts to demonstrate performance outcomes that align with and add to rather than detract from these goals.

Furthermore, the added challenges associated with planning for more sustainable urban development in fast growing cities requires the creation of more compact built environments rather than continued sprawl – directing population and development inwards rather that outwards. In turn, this introduces new challenges associated with infill development – how our cities are rebuilt and regenerated – but gives greater attention to the process by which neighbourhoods and precincts (the building blocks of cities) are renewed as smart, low carbon, liveable and sustainable places.

Accordingly, the LCPP of the CRC created new urban design tools and planning instruments for performance assessment across multiple domains and at multiple scales – buildings, precincts and cities – but with a particular focus on precincts (the ‘missing middle’). They include tools that can be used by the property industry during the design process and by local and state governments in the development assessment process. They provide a basis for integrated assessment on an emerging precinct information modelling platform.

The workflow structure adopted for the LCPP is outlined in Figure P.1. It includes six connected work packages, which also link to the other research programs in the CRC. To achieve the objective of low carbon living, it is necessary to extend the focus beyond individual buildings and technologies (Program 1) to the neighbourhood as a whole (Program 2), and to consider human behaviour and social practices (Program 3).
This guide encapsulates outcomes from research undertaken in the LCPP. It assembles research undertaken between 2013 and 2018 on precinct design assessment tools and processes in a single volume to showcase a set of advanced methodologies, instruments and knowledge capable of application to assessment of precinct design for Australia’s cities, as well as internationally.

It represents an important first step towards addressing a major deficit that exists in relation to the performance assessment of precinct design. A major scoping study was undertaken at the outset (Newton et al., 2013) in order to evaluate best practice internationally and identify where applied research should be focused in relation to new tool development. It provides the background to this guide.

Finally, we would like to acknowledge the support we have received in leading the program and assembling this guide from all of the researchers and industry and government partners linked to the contributing projects. We also acknowledge the collegial and co-operative environment within which this program operated over the life of the CRC, with particular thanks to Deo Prasad (CEO), fellow Program leaders Alistair Sproul (Program 1) and Stephen White (Program 3), and members of HQ – Stephen Summerhayes and Stewart Wallace.
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Professor Michael A.P. Taylor, Emeritus Professor of Transport Planning, School of Natural and Built Environments, University of South Australia and Program Leader of the LCPP, CRCLCL, 2012-2014
Introduction

Peter W. Newton, Swinburne University of Technology
1. Introduction

This guide has been developed to help speed a transition to sustainable urban development in two key environmental domains related to resource consumption and greenhouse gas emissions (GHGE) – where levels of both are seriously challenging the planetary boundaries of a finite earth experiencing rapid population growth and urbanisation.

This requires an urban development transition that is demonstrably regenerative, low carbon, adaptive and smart and that will underpin the emergence of a green economy that has renewable energy at its core, but is multi-sectoral in its involvement with new modes of transport, construction, manufacturing and service industries (Newton and Newman, 2015).

It requires urban development that is based on a critical set of planning and design principles and objectives for cities capable of delivering the environmental outcomes listed above, as well as a set of co-benefits linked to human health and well-being. It encompasses a new urban design paradigm for city development – and redevelopment – that focusses on people, in contrast to previous eras when demands of manufacturing industries and automobile transport dominated metropolitan planning and its restrictive and prescriptive zoning practices. In the 21st century, jobs are attracted to those high amenity locations and neighbourhoods that are places where the skilled information, knowledge and creative workers want to live. Greater emphasis is required on place-making.

Urban development also needs to be based on smart decision-making and new urban governance models and practices that have a capacity to address the multiple objectives of 21st century city performance; that is, cities that are productive, environmentally sustainable, liveable, resilient and socially inclusive. This needs to be achieved at multiple scales, ranging from building to precinct to city.

The precinct represents a critical scale for urban planning, design and management across all three contemporary urban development arenas: greyfields, brownfields and greenfields. Currently there is a lack of an analytical and engagement platform capable of assessing the performance of precinct-scale design-led development in these arenas within a time frame and across all the dimensions of city performance now considered fundamental to cities in the 21st century.

A clear urban design assessment deficit exists. Sustainable urban development in the 21st century, across all scales, needs to be demonstrably regenerative, low carbon and resilient, as well as efficient, equitable and liveable. The design assessment deficit is particularly acute, however, at precinct scale.

A convergence of digital innovation with advanced knowledge from the fields of urban planning and design, social science, computer science, engineering and construction has been harnessed in this guide to create an advanced information platform for transformative built environment planning and design focused on precinct scale modelling and performance assessment. This platform can enable the transition from a system of built environment assessment that is largely prescriptive in nature to one that is more innovative and performance-based.
1.1 Why Precincts?

Precincts are the acknowledged building blocks of cities – the scale at which our built environments have been historically conceived and constructed (Newton et al., 2013; Frater, 2013; EIT and Climate-KIC, 2018; Infrastructure Australia, 2018). In advanced economies, they reflect the influence that dominant transport technologies have had in the resultant urban forms and fabrics that have been laid down: the walking city, the transit city and the automobile city (Thomson et al., 2019), the latter being a major force in the low-density sprawl of cities over the past century and the associated unsustainable growth in urban footprints as well as ecological and carbon footprints that has accompanied this pattern of urban development (IRP, 2018; OECD, 2018; for Australia, see Newton, 2012, 2017).

Advances in material science, design science and construction engineering have continued to drive increases in building heights in urban precincts where land values are high. Urban precincts have also reflected the spatial imprints of successive global revolutions, from agricultural to industrial, and post-industrial (reflecting the emergence of service, information and creative-based economies (Jones, 1982; Brotchie et al., 1991; Florida, 2009); and major population, housing market and labour market shifts that have radically altered the social and cultural geographies of cities, suburbs and neighbourhoods (Knox and Pinch, 2010).

Until relatively recently in human history, settlements have also evolved during a long era of relative global climate stability (Steffen et al., 2015) and freedom from resource constraints (Rees and Roseland, 1991).

In the 21st century there are several new drivers that require a fundamental change in the way our cities and precincts are planned and designed in order to respond to:

• Climate change (and its associated increasing frequency of extreme rainfall events, heat waves, local flash flooding, megafires in peri-urban areas, sea level rise and storm surges in coastal settings, increased urban heat; Newton et al., 2018) and the need for more adaptive urban design that delivers greater urban resilience to vulnerable localities;

• Resource constraints (water and food security; reliable and affordable renewable energy) and resource waste, and the associated challenge of regenerative urban development that can radically shrink the ecological and carbon footprints of cities in advanced high income societies and increase the resource self-sufficiency of neighbourhoods (Newton, 2017);

• Mobility challenges for an increasing proportion of residents in big cities where there is increasing geographic separation of home and workplace and a dependence on longer commutes in congested traffic, requiring renewed efforts at integrated land use–transport planning and a focus on low carbon mobility requiring extension of public transport as well as designing-in active transport and shared mobility services that deliver the 20-minute neighbourhood and the 30-minute city (Newton et al., 2017);

• Provision of appropriate and affordable housing supply to accommodate rapidly growing urban populations without traditional reliance on greenfield development; requiring high levels of urban infill development in established greyfield and brownfield suburbs preferably undertaken as precinct scale medium density redevelopment – the ‘missing middle’ – compared to suboptimal small lot subdivision knock-down-rebuild (KDR) (Newton, 2018; Newton and Glackin, 2018);

• Deficiencies in urban governance associated with planning and implementing development in major Australian cities that reflect a planning deficit: lack of horizontal integration across those multiple agencies responsible for metropolitan strategic planning as well as vertical integration between the three tiers of government and local communities, requiring real engagement (Tomlinson and Spiller, 2018). Technological innovation can provide advanced digital platforms and instruments for more effective interaction and participation in decision-making but they also require new and more effective process
innovations related to urban governance and optimising the life cycle performance of urban development projects (Newton and Burry, 2018);

- The increased complexity of cities and human settlement systems and the pace at which urban change is occurring requires the development and use of more advanced digital tools that can bring evidence from integrated modelling of urban development scenarios or urban precinct development designs into decision-making in a timelier manner than is currently the case. Building, Precinct and City Information Modelling (BIM, PIM, CIM) provides an environment where integrated performance assessment can more effectively occur.

If cities are to achieve the international performance goals and objectives outlined by the UN’s Sustainable Development Goals and the New Urban Agenda as well as those identified at a national level (see Chapter 2), then it will be necessary for their constituent precincts to demonstrate performance outcomes that align with and add to, rather than subtract from, these objectives.

Table 1.1 provides a set of performance objectives for 21st century urban precincts that need to be the focus of urban design and assessment.

Table 1.1:

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<thead>
<tr>
<th>Domains</th>
<th>Benefits of Precinct Scale Planning and Design</th>
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<tbody>
<tr>
<td>Housing</td>
<td>Greater dwelling yield; variety and flexibility in designs, floor areas, layouts; underground parking</td>
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<tr>
<td>Energy</td>
<td>Zero carbon energy; distributed renewable energy and storage and electric vehicle (EV) recharging; microgrids; community renewable energy opportunities, including peer-to-peer energy trading; electricity self-sufficiency/export to grid</td>
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<tr>
<td>Water</td>
<td>Opportunities for integrated water system: stormwater capture, rainwater harvesting and greywater recycling for non-potable uses; water sensitive urban design</td>
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<tr>
<td>Waste</td>
<td>Optimise recycling of C&amp;D waste from demolitions; introduce food waste composting systems</td>
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<td>Mobility</td>
<td>More walkable neighbourhood designs; less area devoted to cars on private property and in public realm; greener streets and raingardens on verges seamlessly meshed to private green spaces; car sharing; ride sharing</td>
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<tr>
<td>Communications</td>
<td>High speed fibre network to the node and ubiquitous broadband services to neighbourhood premises</td>
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<tr>
<td>Green space</td>
<td>Maintain rather than lose canopy trees associated with urban development and redevelopment; activate local streets and nearby pocket parks</td>
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<tr>
<td>Safety</td>
<td>Designing in safety and security at a neighbourhood scale; over-sight of walkways and public spaces; neighbourhood watch</td>
</tr>
<tr>
<td>Distributed urban services</td>
<td>Distributed energy systems; integrated water systems; waste micro-factories; food waste composting; car sharing systems; all linked with a precinct scale of urban development – precincts as micro-utilities</td>
</tr>
<tr>
<td>Integrated design</td>
<td>Precincts can be an integrator of all the built environment objects and flows that feature in urban design at this scale; e.g. buildings + land use + open space + transport systems + utility infrastructures (water, sewerage, electricity, gas, communications) etc.; BIM + PIM + CIM</td>
</tr>
</tbody>
</table>
### Domains | Benefits of Precinct Scale Planning and Design
---|---
Place-making | Place-based approaches to urban planning and design need to draw on new precinct-scale knowledge, frameworks and instruments to deliver neighbourhoods where people want to live
Precinct, neighbourhood, district performance rating | Industry supported voluntary rating systems are emerging in Australia and overseas that are designed to guide and encourage the development of more sustainable urban communities; e.g. NCOS-Precincts, Green Star Communities, EnviroDevelopment, and One Planet Communities in Australia; LEED – Neighbourhood Development, EcoDistricts, and BREEAM for Communities all operate internationally. Many elements of these need to become mandatory if a transition to sustainable urban development is to be realised in the 21st century

### Structure of the Guide

The critical relationship between precinct design and precinct assessment is outlined in Figure 1.1, providing core elements in the conceptual framework developed for this guide.

![Figure 1.1: Key processes underpinning smart sustainable urban development](image)

Chapter 2 focuses on the transformational goals, objectives and targets established for the design of a sustainable precinct. At present, many are values-based and aspirational in a strategic planning context, recognising that there are a significant number of barriers to be overcome in implementing change. But they are achievable!

Chapter 3 identifies the multiple phases in the design and development process where more rapid information access to aid decision-making on project performance is critical – none more so than in the design stage. A number of new processes and instruments are identified here that are capable of enhancing project outcomes from a local government development assessment perspective (The Fifth Estate, 2018) and as a consequence become part of future precinct rating schemes.
Chapters 4 through 10 introduce the new methods and tools created in the CRC for Low Carbon Living (CRCLCL) to assess the performance of precinct design against key dimensions of sustainable urban development: resource regenerative, low carbon, climate adaptive and smart (Table 1.2). They also feature use cases which illustrate the new insights that emerge from the application of these tools to contemporary urban problems.

Integrated assessment for precincts, the bringing together of the methods and tools into a full methodology for urban planning and design, is illustrated in Chapter 11.

All tools are smart – reflecting the digitalisation of knowledge and data – producing numerical indicators of precinct performance (see Chapter 13) as well as visualisations of precinct design outcomes. They constitute the building blocks of an integrated PIM (see Chapter 12). The ultimate objective here is to develop PIM to a maturity where there can be near-to-real-time evaluation of precinct designs from the earliest stages in the development process, delivering the advantages that are now achievable for buildings with BIM (Newton et al., 2017).

<table>
<thead>
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<th>Performance Assessment Tool</th>
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<th>Low carbon</th>
<th>Climate adaptive</th>
<th>Smart</th>
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<td>AMoD-Autonomous mobility</td>
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<td>PSUMC-Precinct mobility</td>
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<td>ESP-Precinct assessment</td>
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<td>PIM-Precinct Information Model</td>
<td>Chapter 12</td>
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<td>iHUB-National digital collaboration platform for urban planning &amp; design</td>
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Assessment that can be relied on requires diagnosis of performance using suitable, scientifically validated and generated performance indicators as well as benchmarks of precinct performance. The development and use of suitable indicators and comparisons between alternative designs for a given precinct, and between different precincts, is discussed in Chapter 13.

Chapter 14 provides an inventory of precinct design assessment tools, focusing on those developed in the LCPP of the CRCLCL, but also including tools developed in the CRC for Water Sensitive Cities (CRCWSC) and the CRC for Spatial Information (CRCSI).

Presently, the tools can be effectively employed in integrated precinct assessment, as illustrated in Chapter 11 for the Fisherman’s Bend brownfield regeneration project in Melbourne. In this way, business-as-usual urban design visioning and assessment models are rendered obsolete. They will become core features of precinct information modelling and assessment that are discussed in greater detail in Chapter 15. Here, the additional potential of a new national urban digital engagement, decision-making and governance platform is outlined; it represents a step-change in how future planning and design at building, precinct and city scale can be undertaken. It is a critical response to the growing urgency in calls for a more rapid transition to sustainable urban development.

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Section 02

Precinct Design Objectives

Peter W. Newton, Swinburne University of Technology
2. Precinct Design Objectives

2.1 Context

Precincts represent an optimal scale at which sustainable urban development objectives for cities can be envisaged and realised. They provide the critical link between building and city scale thinking as well as a focus for multi-disciplinary engagement between architects and engineers, urban designers and city planners. They are ‘places’ that need to be planned and serviced, requiring a governance structure incorporating state and local governments as well as community residents. Precincts also require an alignment of local needs with global goals for cities and sustainable urban development goals more generally.

The global context for urban development is one where the world’s current urban population is forecast to double by 2050 (IRP 2018) where global resource use is exceeding the earth’s ecological capacity (WWF, 2016; GFN, 2018) and threatening critical planetary boundaries (Steffen et.al. 2015), most clearly in relation to increased greenhouse gas (GHG) concentrations in the atmosphere.

The modelled trajectory of these concentrations is capable of driving global warming 2-4°C above pre-industrial levels triggering potentially irreversible climate change, unless reductions in GHG emissions of the order of 70% to 80% are locked in by 2050 (IPCC, 2014; WRI, 2018; Levin and Tomkins, 2014). City development patterns along with current modes of industrial production and consumption form a driving force for these trends.

A growing body of international studies highlight the unsustainable nature of current development trajectories, unless there is systemic intervention across multiple sectors. To this end, the UN has been attempting to redress growing environmental problems on a global basis since the 1970s (Ward and Dubos 1972; UN, 1987; UN 1992; UN 2000). These efforts have accelerated this century, culminating in the release of the UN Development Program’s Sustainable Development Goals (SDG) in 2015 (UNDP, 2018). They outline a collaborative global roadmap with 17 Goals and 169 targets, which are meant to be achieved by 2030 (see Figure 2.1).

The Australian Government is a party to the agreement and has provided a first Voluntary National Review (Australian Government, 2018) and a first assessment of 86 targets and 144 indicators for Australia (DFAT, 2018), where a significant lag has been identified in performance against targets, especially in relation to the goals of cities and climate action.
Goal 11 is directly focused on sustainable cities and communities although it is clear that cities and urban development are linked with many of the 17 goals (see Chapter 13, Table 13.1). A further set of 175 objectives are outlined in the UN New Urban Agenda (UN Habitat III, 2016) that are centred on cities and communities. These global goals and objectives are values-based and have been designed to raise awareness and create an understanding of the complex challenges facing societies and their development in the 21st century. They require a shift from ‘siloed thinking’ to an integrated approach designed to ‘put to rest the futile debates that pit one dimension of sustainable development against another … each goal should be analysed and pursued with full regard to the three dimensions of sustainable development: economic, social and environmental’ (SDSN, 2015, p.9).

The significance of the UN SDGs is this: if these values are broadly shared they can provide a basis for all stakeholders pursuing solutions to these challenging goals. There are numerous examples of how these global goals are being used to frame future planning strategies in multiple sectors, especially those related to building and construction (Bioregional, 2018) and transport (IST, 2018), the two most intensive resource consuming and GHG emitting urban sectors (Newton, 2017) where mitigation potential is high but lagging (Climateworks, 2018).

A major contributor to this is the fact that there is no uniform commitment in Australia across all tiers of government (especially at federal level; Newton et al., 2018) or private sector built environment organisations (Newton and Newman 2015; Giesekam et al., 2018) to appropriate renewable energy goals, climate change mitigation strategies, green economy transition policies and sustainable urban development objectives. This inhibits development and alignment of public and private sector strategies and investment capable of more rapidly and confidently driving the urban, infrastructure and industrial transformations required in the 21st century.

Moreover, there is no clear and consistent message being communicated to the Australian population capable of building social norms around sustainable behaviours/sustainability. Surveys of public attitudes reflect this (Leviston, 2014).
The local context is critical to any national alignment and implementation of broader global goals related to sustainable urban development. Australia's cities have among the highest population growth rates within the OECD and these are projected to continue. The high growth rates have exposed multiple deficiencies in the capacity to plan for urban change at all levels of government (Newton et al., 2017).

The high liveability ratings that Australia's largest capital cities have received for the past decade (EIU 2018) mask the unsustainable dimensions of metropolitan development (Newton, 2012). Their ecological and carbon footprints are among the highest in the world (GFN 2018), as are their urban footprints (Coleman, 2017), property prices and household indebtedness, and there are increasing levels of spatial disadvantage that are concentrating in the outer suburbs (Randolph and Tice 2015).

A major contributing factor has been the failure of metropolitan planning since the 1950s to curb low density sprawl and invest in more integrated land use and (public) transport development that supports more sustainable low carbon living (Newton 1997; 2000), what has been termed a planning deficit (Gleeson et al., 2012). Issues of governance are also at the heart of what has been termed a democratic deficit (Williams 2018) referring to the multiple levels of government that are disconnected horizontally (e.g. inter-departmental) as well as vertically (e.g. federal-state-municipal-community) in relation to metropolitan urban planning (see Figure 2.2). There is no metropolitan planning authority accountable for urban development, much less precincts, which can be seen as encompassing 'district', 'neighbourhood' and 'street' levels – the building blocks of cities (Newton et al., 2013; Tomlinson and Spiller, 2018).

The current problems facing Australia's cities are a combination of joint failures to undertake and implement integrated land use – transport planning at a metropolitan scale (with particular reference to public transport, services and jobs) and the finer grained urban design of neighbourhoods that are required to accommodate a growing number and diversity of residents. Here it has been argued that the unsustainable nature of today's cities is due in part to poor planning and development assessment at the precinct level (Cadoban and Kennedy, 2007) as well as lack of horizontally and vertically integrated planning at city scale (Newton et al., 2018).

The challenge for 21st century urban planning and design is to discover effective ways to RE-develop/ renew/ retrofit/ regenerate our cities in a way that redresses deficiencies in past planning and development by pursuing the objectives outlined in the following section.
Performance Concepts and Models Related to Urban Environmental Sustainability Challenges

A transition pathway for Australian cities in the 21st century has been emerging over recent decades that is seeking to close the door on a model of city development that has been demonstrably ‘exploitative’ by putting economic objectives ahead of social and environmental concerns.

An ‘eco-efficiency’ framework has emerged over recent decades that represents an attempt to assess both the positive and negative environmental impacts associated with a development project with a view to incorporating the results in urban decision-making processes (see Figure 2.3). It recognises that environmental as well as economic calculations need to be involved in built environment decision-making (the genesis of the term ‘eco-efficient’; Newton 2009). The objective is to reduce environmental impact, subject to cost, but the primacy of economic performance is typically evident – to some extent due to challenges associated with measuring the positive economic values of urban ecosystem services as well as the negative externalities linked to different types of urban development, and incorporating both in the development project spreadsheet.

An inhibiting factor is that neo-liberal governments are typically not disposed to regulation requiring additional measurement; rather, they tend to favour industry-supported voluntary (often check-box) schemes when it comes to performance assessment.

‘Regenerative urbanism’ has emerged as a new objective for urban development that presents the opportunity and challenge to go beyond minimal reductions in environmental impact to a new vision of how cities can be designed and operate in an ‘eco-positive’ manner, while maintaining or enhancing liveability (Birkeland, 2008); i.e. removing negative environmental impacts from development and providing ecological
gain. This requires regenerative development that is based on ‘giving back as well as taking’ (Girardet, 2015, p.11) and needs to operate across all urban sectors and all urban scales: building, precinct and city.

Regenerative urbanism is embodied in the technologies, design thinking and new process approaches represented in the Factor 4 and Factor 5 paradigms that outline pathways to achieve reductions in resource and energy use by up to 80% (von Wieszacker et al., 1997; von Wieszacker et al., 2009).

Regenerative urbanism also relies heavily on the use of the urban metabolism model framework for representing (and measuring) the flow of resources into and waste outputs from built environments. This model was employed by Newman et al., (1996) and extended by Newton and Bai (2008) for State of Environment Reporting to include the exogenous pressures on human settlement as well as the endogenous urban systems and processes that are designed to manage large complex urban systems. It also recognised the two dimensions of urban liveability that are linked with human well-being and urban environmental quality.
The latest version of this framework is presented in Figure 2.4.

This framework can be used to highlight the transformational changes that need to occur in our urban systems:

- **reduction** in use of natural resources: dramatically shrinking ecological footprints by dematerialising industrial and construction processes by the adoption of eco-efficient technologies. This involves cities creating more renewable energy than they need (energy from the city) and significantly reducing the need to import potable water that has been traditionally diverted from environmental flows in the hinterland of cities.

- **reduction** in emissions and waste streams, with particular focus on decarbonisation of energy and deep mitigation of greenhouse gases; capturing and treating stormwater and wastewater for non-potable urban water uses; and creating zero-waste pathways for industrial, construction and domestic waste streams linked to transition to a circular economy based on industrial ecology principles.

- **substitution** of smart urban systems and processes for those currently in use to achieve more effective and efficient economic, social and environmental planning and management of cities (smart strategies as well as smart technologies).

- **improvement** in urban environmental quality of the public realm (e.g. waterways, green space); as well as responding to the environmental stressors linked to reduced private green space associated with the intensified urban retrofitting and densification of cities. For example, changes in surface permeability and
stormwater run-off and increased urban heat, and more effective integration of biophilic design and natural urbanism principles into city planning, especially in the face of global warming.

- **improvement** in liveability and well-being across the entire metro region. Long established urban planning concepts such as equity and access are being lost in a neo-liberal era where significant privatisation of urban services has occurred and where housing affordability is a challenge for residents of large globally connected cities.

- **increase** in the resilience of cities to the array of exogenous and endogenous pressures now evident. Foremost among these is adaptive capacity to climate change threats of flooding, drought, extreme temperatures, sea level rise, storm surges and mega bushfires.

Smart, sustainable urban development strategies are needed that are capable of delivering transformative change to cities. Table 2.1 begins to flesh these out in the context of **performance objectives** capable of guiding design thinking at building, precinct and city levels. It is clear that there are cross-domain and cross-scale interactions that need to be accommodated in the design process.

Regenerative urban development requires engagement with a new generation of urban infrastructure technologies, more sustainable materials and more innovative design thinking supported by a rapidly evolving digital information platform. It also will require a new generation of built environment assessment tools capable of rapidly and comprehensively assessing the performance of development projects, especially those at a precinct level – the focus of this guide.

Table 2.1: Current and emerging best practice performance objectives, technologies and systems at building, precinct and city scale

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<tr>
<th>BUILDING</th>
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<tr>
<td><strong>Building Metabolism:</strong> Apply life cycle analysis (LCA) to buildings to minimize their resource use (energy, raw materials, water etc.) and emissions (to air, water and land associated with building material manufacturing processes, transport and disposal; as well as during building operation). Environmental Product Declarations to ISO standards provide a scientifically validated labelling system that can be used for product selection. A combination of 3D BIM modelling with LCA and building and construction costings databases provides the basis for automated eco-efficiency assessment for buildings.</td>
<td><strong>Neighbourhood Metabolism:</strong> Develop precincts that display greater self-sufficiency in the local provision of key services such as mobility, renewable electricity and integrated water (that is a mix of reticulated mains water, harvested rainwater and recycled greywater) delivered by distributed, decentralised and shared infrastructure systems, reducing pressure on centralised systems of supply; and reduced natural material resource consumption and GHG emissions by recycling and re-use of waste; creating a more sustainable built environment as context for more sustainable patterns of resident behaviour and consumption.</td>
<td><strong>City Metabolism:</strong> The ecological footprints of Australia’s large cities are more than twice the global average and significantly above their European counterparts, reflecting their high levels of resource consumption and GHG emissions. The urban footprints of Australian cities are also large by world standards, reflecting the low density ‘suburban’ fabric of city development. Future city planning policies must be directed towards more compact urban forms involving a transition from ‘suburban’ to ‘urban’ forms of regenerative infill development in both brownfields and greyfields capable of ‘shrinking that footprint’. Metabolism modelling becomes a necessary component of metropolitan strategic planning.</td>
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<td><strong>Energy:</strong> Zero carbon/carbon neutral/carbon negative buildings created from a 'staircase' of measures including renewable energy (electricity from a set of local energy generation systems applicable to buildings e.g. solar PV on roof; but also integrated with facades); linked with highly energy efficient shell (&gt; 7 stars) and built-in appliances.</td>
<td><strong>Energy:</strong> Low carbon/zero carbon/carbon neutral/carbon negative precinct; emergence of smart grid/micro-grid networks; using wider range of options for distributed renewable energy generation applicable to precincts, especially in higher density city neighbourhoods. Community-scale energy networks emerging involving blockchain peer-to-peer energy trading technology.</td>
<td><strong>Energy:</strong> Emerging hybrid energy system for city – i.e. existing centralised electricity systems (commonly fossil fuel or nuclear based, providing electricity into national grids; with emerging large-scale solar thermal &amp; wind farms substituting for fossil fuel-based plants) beginning to accommodate rapidly emerging, distributed energy generation and storage systems; requires smart energy management systems to integrate multiple sources of electricity supply with demand.</td>
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<td><strong>Water &amp; Sewerage:</strong> Rainwater harvesting (rainwater tanks); greywater recycling; water sensitive design of building and immediate surrounds; negligible black water recycling at present.</td>
<td><strong>Water &amp; Sewerage:</strong> Integrated water system that minimises importation of potable water into a precinct; involving stormwater capture and use (rainwater tanks, creeks, swales, natural retention); precinct greywater recycling, potentially via third pipe system; water sensitive design of buildings, streetscapes and landscaping; limited sewer mining at present. Reconfiguring streets to be more walkable; greening public realm footpaths and meshing with space at front of buildings to enhance neighbourhood amenity and reduce urban heat.</td>
<td><strong>Water &amp; Sewerage:</strong> Existing linear system involving water capture, storage, treatment, distribution, use and discharge via sewerage system to regional recycling plants or discharge to receiving waters will need to be connected with decentralised systems that enable emergence of an integrated urban water system for a metro region: a water sensitive city.</td>
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<td><strong>Waste:</strong> Zero waste to landfill for a selected range of items e.g. paper, plastics; currently limited composting of food waste but in-situ composting technologies emerging as are FOGO systems for municipal collection and composting. C&amp;D waste from knock-down rebuild of individual buildings often goes to landfill and needs to be better managed at development planning permit stage.</td>
<td><strong>Waste:</strong> Zero waste to landfill for increasing range of items e.g. paper, plastics; opportunity for increased locality-based composting of food waste and organic waste; prospect for precinct vacuum waste collection system; construction and demolition waste recycling more likely for precinct scale retrofit projects.</td>
<td><strong>Waste:</strong> Household waste generation increasing at a rate often overtaking pace of recycling, resulting in continuing use of landfill; slow increase in rate of recycling C&amp;D waste; green waste collection &amp; composting growing; limited composting of food waste. Waste-to-resources transition/circular economy/eco-industrial development in its infancy: a significant green economy sector awaiting development.</td>
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<td><strong>Indoor Environment Quality:</strong> Established standards and benchmarks for thermal comfort, energy efficiency, indoor air quality, lighting, noise etc., that can be required to be met or exceeded by building owner; leads to significant health and productivity benefits; older stock likely to be poor environmental performers. Significant opportunity for building retrofitting.</td>
<td><strong>Local Environmental Quality:</strong> Encompasses critical factors that contribute to quality of life of local residents, e.g. ambient air quality, solar access, low environmental noise, open green space and blue space, good tree canopy etc., but can be difficult to monitor and enforce quality across an entire precinct (unless master planned or local community establishes standards and maintenance).</td>
<td><strong>Urban Environmental Quality:</strong> Critical to the amenity and liveability of cities; represents an aggregate of the local environmental quality of urban precincts, plus the quality of urban waterways and public realm spaces that make critical contributions to natural urbanism; government monitoring of UEQ is patchy and needs to be augmented by social media applications that facilitate crowd sourcing of data (humans as sensors).</td>
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<td><strong>Occupant Mobility:</strong> Dependent on building design/layout for disability access, social interaction as well as privacy; space allocated on site for car parking and bicycle storage can affect mode choice; some local governments in inner city jurisdictions with good public transport access are beginning to impose parking restrictions on new buildings as well as on local streets.</td>
<td><strong>Low Carbon Resident Mobility:</strong> Objective is to create/develop attractive, safe, mixed use, walkable and cycle-able neighbourhoods close to public transport. These neighbourhoods are attracting premium prices and rents reflecting their increasing desirability. Precinct design can optimise these features as well as minimise the amount of space allocated to the automobile (driveways, parking, roads and traditional footpaths) that can be allocated to other uses such as open space, precinct furniture and community meeting places; nucleus for a more self-contained city of villages/20-minute ‘cities’; critical to direct urban planning and design thinking to ways of providing low carbon mobility for people rather than planning for vehicles; car sharing and autonomous electric vehicles represent emerging opportunities for low carbon mobility in suburban precincts.</td>
<td><strong>Population Mobility:</strong> The extent to which a city’s transport and land use planning has been integrated will dictate the extent to which housing is accessible to employment and other key services, and whether residents have access to public transport or are car dependent (the latter characteristic of much post World War 2 urban development in Australian and North American cities). Increasing penetration of hybrid and electric vehicles will reduce GHG emissions but not congestion unless attractive car rental/sharing and ride-sharing schemes emerge. High speed rail (&gt;250kph) is capable of underpinning decentralization of capital city development and more sustainable mega-metro regional planning.</td>
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<td><strong>Food Production:</strong> Limited at a building level unless associated with a detached house and land for garden; or vertical gardening.</td>
<td><strong>Food Production:</strong> In addition to what is possible at building scale, neighbourhoods offer opportunities for communal/community gardens using composted food waste; part of a circular economy.</td>
<td><strong>Food Production:</strong> Many metro areas have important agricultural and horticultural activities in their peri-urban regions; areas that are under threat from urban sprawl and need to be protected.</td>
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<td><strong>Biophilic Buildings:</strong> Vegetation opportunities for roofs and some facades (e.g. green walls) with multi-storey buildings; in competition with other building elements e.g. solar PV.</td>
<td><strong>Biophilic Precincts:</strong> Introduce green infrastructure to re-connect built environment with nature (nature-based urbanism) e.g. raingardens, green walls and roofs; integrated with water features; provide greater scope for a range of vegetative plantings that are attractive to native bird species, provide shade, food; significant potential for reducing heat island effect via green open space and canopy trees.</td>
<td><strong>Biophilic Cities:</strong> Are those that provide nature in close proximity to where the urban population lives and needs to be an intentional feature of a metro plan, but is often traded off or overlooked in urban development and redevelopment, unless planning guidelines and controls are in place.</td>
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<td><strong>Housing:</strong> Individual dwellings can range from the small percentage of architect designed ‘bespoke’ products to the mass-produced ‘project’ homes and high-rise apartments. Low- to medium-rise medium density is yet to create a positive impact on Australian cities. The only areas where minimum performance is required for new housing is in relation to thermal performance of the shell (and in some jurisdictions, rainwater tanks). Housing in Australia’s largest cities are among the most expensive and least affordable in the world representing a challenge for urban planning and property development industry.</td>
<td><strong>Housing:</strong> Precincts provide the opportunity for introducing a variety of dwelling types (especially medium density) and architectural styles, dwelling sizes and price points. In combination with other precinct elements listed above, they can create distinctive, attractive and more sustainable ‘places’ to live – contributing to the development of a new ‘neighbourhood character’.</td>
<td><strong>Housing:</strong> At metropolitan scale, suburban housing capacities, residential densities, housing mix and housing affordability tend to dominate urban planning agendas for housing; urban ‘infill’ now an important feature of metropolitan development strategies, with associated targets, but lacking effective processes for implementation (e.g. municipal development approval for precinct scale greyfield regeneration and densification in the established suburbs: the ‘missing middle’).</td>
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<td><strong>Smart House:</strong> Broadband access, sensors on all domestic built-in and plug-in appliances, lighting etc., combined with smart meters, provides a platform for real-time monitoring and management of a safer, more sustainable home as well as a highly functional small office-home office work environment.</td>
<td><strong>Electronic Village:</strong> Prospect of neighbourhood intranets identified in 1990s are unlikely to materialise due to explosive growth and massive functionality of the internet and social media; proximity and face-to-face contact remains the ‘glue’ for local communication and creation of local social capital, augmented by internet Apps.</td>
<td><strong>‘Wired’ City:</strong> High-speed wireless and cable communications infrastructures are now ubiquitous in global cities and provide platforms for telepresence and telecommuting opportunities as they project themselves into the future. The challenge is to avoid a ‘digital divide’.</td>
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### BUILDING

**Virtual Building Design:** BIM has emerged as a powerful platform for architects that enables innovative design in 3D coupled with automated eco-efficiency performance assessment (cost plus environment) and an enabler of more effective co-design and engagement with prospective occupants/owners. An as-built BIM database provides a valuable platform for facility management over the building life cycle. BIM provides the basis for electronic lodgement of planning and building permits and more automated building and project assessment.

### PRECINCT

**Virtual Urban Design:** PIM is an emerging platform for urban designers where the scale of built environment requiring representation is that of a precinct (neighbourhood, district) and where the objects involved are those relevant to precinct performance assessment; e.g. energy demand, water demand, embodied carbon, waste generation, walkability, rainwater harvesting, precinct energy generation, waste treatment, urban microclimate etc. (requiring seamless data exchange with BIM and CIM systems). It also provides a new digital platform for co-design and decision-making in statutory planning and development assessment processes at neighbourhood and municipal level.

### METRO REGION

**Virtual City Planning:** CIM encompasses a spread of spatial technologies supported by basic Geographic Information System (GIS) functionality and specific analytical and modelling frameworks and tools that represent significant elements of an urban system (e.g. transport sub-system) and their interaction with other inter-dependent elements (e.g. land-use).

It provides a platform for scenario analyses of possible/probable/desirable metropolitan futures based on alternative population assumptions, infrastructure investments (including issues of centralised vs. decentralised operations), housing densities, job locations, economic growth expectations etc. – all fundamental to strategic metropolitan planning.

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### Building Resilience

Building risk can be expressed as a combination of building design and material attributes as well as site and locality attributes. The Insurance Council of Australia has developed a tool capable of assessing local hazards and how a particular building may perform when exposed to those stressors. Currently in prototype stage of development but could expect to be linked in future with municipal building and planning regulations and development application assessments. (www.resilient.property)

### Precinct Resilience

**Precinct Resilience:** Precinct resilience is focused on a neighbourhood’s ability to respond and adapt to change from threats that can be either rapid (e.g. storm event) or slow burn (e.g. urban infill) in ways that are proactive and positive. It has been relatively overlooked in comparison to building and city scale initiatives, but increasingly the responsibility for climate change adaptation and preparedness is devolving to household and community levels (www.resilientneighbourhoods.ca).

### Metropolitan Resilience

**Metropolitan Resilience:** Planning for metropolitan resilience with particular reference to climate change requires an ability for governments to develop clear policies and strategies for adaptation capable of operating across scales and jurisdictions as well as particular categories of threat (e.g. extreme heat, flooding, sea level rise, storm surge, bushfire). Current jurisdictional boundaries (e.g. local government) are inappropriate for planning purposes and require a metropolitan governance approach. Comprehensive metro-wide climate change vulnerability assessment at individual cadastral (property) level is a critical pre-requisite for planning the climate resilient city – at building, precinct and city scale.

Source: Developed from a table outlining sustainability objectives for buildings, precincts and cities (Newton, 2018)
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Precinct Design and Development Process

Peter W. Newton, Swinburne University of Technology
3. Precinct Design and Development Process

Precinct development in cities occurs in three principal arenas: greenfields, brownfields and greyfields (Newton, 2010). Greenfields has been the traditional arena for urban development of Australian cities in response to population growth, but over the past decade strategic metropolitan planning in the largest capital cities has encouraged a significant shift to infill development (inwards and upwards rather than outwards) in an attempt to inhibit suburban sprawl. Re-development, re-newal, retrofitting, re-generation represent the most important 21\textsuperscript{st} century challenges for cities. Infill targets have been established for all of Australia’s major capital cities, ranging from 85\% (Adelaide) to 47\% (Perth). Until recently there had been no attempt to differentiate between brownfield and greyfield redevelopment arenas, yet attempts at precinct-scale development in each require different development models (Newton and Glackin, 2014; Newton, 2018).

The precinct development processes, however, have a commonality: multiple stakeholders engaged in a complex process that operates through multiple phases that have traditionally been represented as linear and sequential (even separate), but are increasingly seen as needing to be more integrated and iterative. The phases of a development project have been recognised as comprising:

1. concept (as conceived-envisioned-required): involves discussing and recording needs, aspirations and performance targets
2. design: includes sketch planning and a design phase where various design concepts and development scenarios are initially tested for viability, impact and feasibility; where the contributions of new technologies and construction processes are explored, as well as subsequent detailed design and delivery specifications and assessments
3. development and construction: involves the scheduling and management of the process of assembling labour, materials and equipment off-site as well as-on site to deliver the precinct development
4. operation and maintenance: involves the phase of occupancy where behaviours of occupants can have a significant influence on how a building ‘performs’
5. deconstruction: at the end of service life, decisions need to be made about retrofitting, re-use and disassembly to minimise waste to landfill. Ideally, these options should be designed-in to the project from the outset.

Ability to positively influence the cost and performance of a built environment project is always highest at the front end, in the concept-design-feasibility stages, a period during which information to aid decision making in a timely manner has proven more difficult to assemble (Figure 3.1).

The design assessment tools outlined in this guide attempt to redress this information deficit, to lift the information base for decision-making higher during concept/feasibility/design phases.
Figure 3.1: Information and decision-making context over the project life cycle

It is for this reason that increasing attention is being paid to new processes, instruments and platforms that can be introduced for smarter precinct planning and design at the concept phase. The Urban Reboot Model (Sanderson, 2018) is a project planning model that focuses on what needs to be done before detailed design and delivery (Figure 3.2).

The concept needs to come together via multiple workstreams that:

- describe the underlying enduring premise of the precinct in the context of the site and its spatial context
- identify its economic and sustainability foundations
- sketch the type of place it will be (e.g. use mix, building typologies, open spaces etc.)
- specify how it will be connected and serviced, and
- outline the required social infrastructure.

In short – how it will look and perform. This guide is focused on new tools and platforms that support rapid precinct design assessment and visualisation at concept design stage.
The Urban Reboot Model also envisages critical roles for Project Enablers that work on governance, implementation and sequencing strategies, investment and procurement strategies and activation and marketing strategies – all working together, with the flexibility to change and iterate in the face of changes in the economy, government and technology. They need access to the interactive engagement and decision-making digital platform envisaged for the iHUB platform, outlined in Chapter 15.

The CRCLCL has developed a framework and tool for the built environment sector to help facilitate strategic conversations within a project team about project impacts (positive and negative), and help conceptualise, prioritise and enhance its capacity to deliver greater value for the environment, society and economy (Haas-Jones and Balatbat, 2017).

The Built Environment Impact Guidance Tool is applied in facilitated sessions with the project team in the process of developing a vision for the precinct development. The team will prioritise the thematic areas and issues of significance to its stakeholders and identify the associated tangible goals and indicators (see Figure 3.3).
Precinct sketch planning and design follows with additional disciplinary skills being assembled for a range of tasks associated with realising the development concept. In the context of greyfield and brownfield precinct renewal this will involve designs that deliver more regenerative, resilient, low carbon neighbourhoods, responding to the urban performance objectives listed in the previous chapter (Table 2.1; Newton, 2018).

Australia lacks an appropriate suite of government-endorsed best practice performance standards for precinct scale urban development. Outside a limited set of prescriptive local government statutory planning regulations and Building Code of Australia specifications, there is little stimulus for sustainable (regenerative and adaptive) urban development where more extensive performance assessment is required to be built into the development assessment process.

Government inertia has prompted industry to develop a number of building and precinct rating and certification systems that ‘brand’ developments according to preferred criteria and weightings to help promote projects’ environmental credentials, create market profiles and create a return on investment premium for the property owners.


Leading international precinct rating tools have also emerged from North America (LEED-Neighbourhood Development), Europe (BREEAM) and Japan (CASBEE-Urban Development) and are reviewed in Säynäjoki et al., (2012) and Sharifi and Murayama (2015).

The consensus from these studies is that a single global tool and associated standards is not viable given the specificities of different geographic locations, jurisdictions, sites and stakeholder needs.
There is growing global consensus, however, around themes, issues, goals and indicators linked to sustainable urban development where scientifically validated assessment is required. If aspirations for city liveability and sustainability are to be realised and global 21st century sustainable urban development challenges met, then assessment of the building blocks of the built environment must be advanced beyond current practice.

The Precinct Scoping Study (Newton et al., 2013) undertaken at the beginning of the CRCLCL concluded that the quality and veracity of neighbourhood/precinct ratings were only as good as the performance assessments made for each of the built environment issues being rated (see Figure 3.4). The lack of transparency currently associated with the voluntary project rating systems (e.g. the assessment techniques and processes employed) limits their capacity for the type of transformational change required of the built environment.

Table 3.1 illustrates the alignment of the performance assessment tools and the Impact Categories in the GBCA Green Star Communities Rating System.

The research focus for CRC Program 2 (Low Carbon Precincts) was subsequently centred on developing precinct design assessment tools associated with key sustainable urban development objectives that could be directly employed in the development assessment processes of private sector design teams and municipal governments as well as design and development rating of precinct scale projects.

Table 3.1 illustrates the alignment of the performance assessment tools and the Impact Categories in the GBCA Green Star Communities Rating System.
Table 3.1: Alignment of Environmental Impact categories in Green Star Communities Rating System and CRCLCL Performance Assessment Tools

<table>
<thead>
<tr>
<th>Environmental impact categories in Green Star Communities Rating System</th>
<th>Name of CRC performance assessment tools relevant to Rating impact category and Project Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governance</td>
<td></td>
</tr>
<tr>
<td>• Adaptation, resilience</td>
<td>UHI-DS (2023); ETWW (RP2002); PCA (RP2007); ESP (3034)</td>
</tr>
<tr>
<td>• Sustainability awareness</td>
<td>ICM (RP2007); ESP (RP3034)</td>
</tr>
<tr>
<td>• Community participation</td>
<td>CBC (RP2028); ESP (3034)</td>
</tr>
<tr>
<td>• Environmental management</td>
<td>ICM, ECE (RP2007); ETWW (RP2002); UHVI, UHI-DS (RP2023); CBC (RP2028); ESP (3034)</td>
</tr>
<tr>
<td>Liveability</td>
<td></td>
</tr>
<tr>
<td>• Healthy living</td>
<td>CBC (RP2028)</td>
</tr>
<tr>
<td>• Sustainable buildings</td>
<td>ICM, ECE (RP2007)</td>
</tr>
<tr>
<td>• Community development</td>
<td>ESP (RP3034); ETWW (RP2002); PCA (RP2007); CBC (RP2028)</td>
</tr>
<tr>
<td>• Walkable access</td>
<td>ETWW (RP2002); CBC (RP2028)</td>
</tr>
<tr>
<td>• Access to fresh food</td>
<td>CBC (RP2028)</td>
</tr>
<tr>
<td>• Safe places</td>
<td>CBC (RP2028)</td>
</tr>
<tr>
<td>Economic Prosperity</td>
<td></td>
</tr>
<tr>
<td>• Affordability</td>
<td>ESP (RP3034)</td>
</tr>
<tr>
<td>• Peak electricity</td>
<td>ETWW (RP2002); PCA (RP2007)</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
</tr>
<tr>
<td>• Integrated water</td>
<td>ETWW (RP2002)</td>
</tr>
<tr>
<td>• GHG strategy</td>
<td>ETWW (RP2002); ICM, ECE, PCA (RP2007); PSUMC (RP2021)</td>
</tr>
<tr>
<td>• Materials</td>
<td>ICM, ECE (RP2007)</td>
</tr>
<tr>
<td>• Sustainable mobility</td>
<td>ETWW (RP2002); AMoD, ABM-TMC, PSUMC (RP2021); CBC (RP2028)</td>
</tr>
<tr>
<td>• Sustainable sites</td>
<td>ESP (RP3034)</td>
</tr>
<tr>
<td>• Ecological value</td>
<td></td>
</tr>
<tr>
<td>• Waste management</td>
<td>ETWW (RP2002)</td>
</tr>
<tr>
<td>• Heat island effect</td>
<td>UHVI, UHI-DS (RP2023)</td>
</tr>
<tr>
<td>Innovation</td>
<td></td>
</tr>
<tr>
<td>• Market transformation</td>
<td></td>
</tr>
<tr>
<td>• Innovative technology</td>
<td>All listed CRC tools</td>
</tr>
<tr>
<td>• Global sustainability</td>
<td></td>
</tr>
</tbody>
</table>
The set of CRC tools listed in this table are the focus for the chapters that follow, where their underpinning methods are explained in some detail and use cases provided. Some have the capacity for integrated assessment (i.e. across more than one domain/issue), a topic taken up in much greater detail in Chapter 11 when performance assessment tools from both CRCLCL and CRC for Water Sensitive Cities are applied to concepts for regenerative precinct redevelopment at Fishermans Bend in Melbourne.

PIM, outlined in Chapter 12, has yet to reach the maturity of BIM and provide an information platform for the entire life cycle of a precinct project, whereby information and data related to all phases of a project are retained for use by the teams of professionals involved (Figure 3.5; Plume et al., 2017a, b).

![Table](image)

Source: Plume et al., (2017b)
Figure 3.5: PIM provides a definitive repository of information at all stages in PRECINCT design and management based on open standards

Attaining this level of information management on built environment projects provides the basis for understanding why there are significant gaps in performance being identified: as conceived-as designed; as designed-as built (e.g. Pitt and Sherry and Swinburne University (2014); as built-as operated (e.g. gaps that inhibit achieving sustainable urban development goals). The value of PIM to urban planning and design in a digital age is clear: a means of responding to Peter Drucker’s oft-quoted challenge, ‘If you can’t measure it, you can’t improve it’.

References


Pitt and Sherry and Swinburne University (2014) National energy efficient building project. Report prepared for the Department of State Development, Adelaide


Integrated Carbon Metrics

Thomas Wiedmann, Soo Huey Teh, University of New South Wales, Robert H. Crawford and Monique Schmidt, University of Melbourne
4. Integrated Carbon Metrics

4.1 Introduction

Buildings produce a significant amount of carbon in their day-to-day use, with operational emissions contributing an estimated 9.5 megatonnes of greenhouse gas emissions (GHGE) towards Australia’s annual national total (Yu et al., 2017). Carbon mitigation strategies and standards developed by industry and government generally focus on these “direct” emissions. For example, companies and organisations are required to report Scope 1 and 2 emissions under the National Greenhouse and Energy Reporting (NGER) scheme in Australia. Scope 1 emissions include GHGE from sources located within the boundary of study (e.g. the study could be a company, organisation, precinct or city), and Scope 2 emissions include GHGE occurring as a result of the use of grid-supplied electricity, heating and/or cooling within the boundary of study (Figure 4.1).

Another important part of the picture is the carbon emissions created during other stages of a building’s life, such as from the production of materials, transport, maintenance and disposal. These are known as “indirect”, “embodied” or Scope 3 emissions which include all other GHGE that occur outside the boundary of study as a result of the activities within the study’s boundary (e.g. the study could be a company, organisation, precinct or city) (Figure 4.1).

This “embodied” emissions contribute an additional 90.3 megatonnes of GHGE emitted in constructing new buildings and infrastructure as well as maintaining the existing ones (Yu et al., 2017). Companies and organisations are currently not required to report Scope 3 emissions under the NGER scheme. However, quantification of Scope 3 emissions can benefit built environment industries by identifying carbon hotspots for emission mitigation strategies across the supply chain, making it an enormous opportunity to boost built environment carbon reductions.

Figure 4.1: Operational and embodied emissions from a precinct (C= carbon)

Embodied emissions play a significant role in the built environment. This may not always be evident when considering just one level. However, when taking into account all four levels (building materials, buildings, precinct, and city level) in one consistent framework, sensible and integrated solutions can be derived.
Integrated Carbon Metrics (ICM) project (RP2007) built knowledge about both the direct and indirect carbon emissions in the building process, to better inform those making decisions about our future built environment. Carbon accounting tools that can be scaled to the building, precinct or city level have been developed, to provide a complete picture of the carbon lifecycle in the Australian built environment (Figure 4.2).

Furthermore, there are currently no tools in the market directly targeting assessments under the National Carbon Offset Standard (NCOS) Precincts that was recently released by the Federal Department of the Environment that provides new guidelines on carbon neutral precinct (Department of the Environment and Energy, 2017a).

The ICM project has developed tools (i.e. Embodied Carbon Explorer and Precinct Carbon Assessment tools) that are distinctive from existing carbon accounting software, because of its integration and focus on Scope 3 carbon emissions and optimal alignment with NCOS standard.

In particular, the ICM project has developed:

- hybrid life cycle assessment database: A database where users can find information about the carbon embodied in different construction materials used in Australia
- integrated framework for life cycle environmental and economic assessment: A framework to enable the integrated optimisation of the environmental and economic performance of buildings
- embodied Carbon Explorer tool: The tool rapidly evaluates embodied carbon on a precinct-scale project and shows in detail how different industries contribute to carbon emissions
- 3D Precinct Information Extension tool: The tool calculates and visualises carbon emissions during the planning of precincts
- precinct Carbon Assessment tool: The tool examines whole life cycle of carbon emissions on a precinct scale and calculates low carbon scenarios
- city Carbon Footprints: A framework that provides a picture of the embodied carbon emission flows in and out of cities.

This chapter provides more description the integrated framework for life cycle environmental and economic assessment, Embodied Carbon Explorer tool and City Carbon Footprints, that are employed in the use cases. The Precinct Carbon Assessment tool is described in Chapter 5.

![Figure 4.2: Levels of carbon emissions and Integrated Carbon Metric project database and tools](image-url)
Accounting for the multitude of contributions from supply chains is usually a complicated and a time intensive task using a bottom-up approach. A common bottom-up approach used in the building sector is process-based life cycle assessment (LCA), which calculates the environmental input and output along the life cycle stages of a product, and provides high accuracy assessments for specific products. However, the need to set a system boundary for the study means this bottom-up approach can produce incomplete results of an unknown magnitude.

Alternatively, ICM database and tools uses a top-down approach that quantifies Scope 3 emissions easily and rapidly by using data from the Industrial Ecology Virtual Laboratory (IELab) that are readily available, making it a more efficient technique. This top-down environmentally-extended input-output analysis (IOA) provides an alternative, economy-wide approach, by linking economic activities to environmental impacts in order to calculate embodied impacts related to the built environment, without system boundary cut-offs.

Another method that ICM database and tools use is the hybrid life cycle assessment (hLCA) method that combines the advantages of both process-based LCA and IOA by connecting detailed primary data (e.g. from LCA) with input-output data. More information on environmentally-extended IOA and hLCA methods are available in Wiedmann (2009) and Crawford et al., (2018).

These decision support tools will assist building designers, manufacturers, planners and developers in the future planning of our buildings, precincts and cities. By arming them with comprehensive information about how carbon is created over a building’s lifecycle, the ICM project can inform more effective planning and mitigation strategies to reduce carbon, helping to meet national targets. They are open source and publicly available.

4.2 Objectives

The objectives of the umbrella ICM project methods and tools are to:

- enable the analysis of the ‘carbon fabric’ of the built environment
- assess the carbon performance of materials, buildings, precincts and cities
- quantitatively evaluate low carbon scenarios
- cooperate with governments and industry

The following ICM methods and tools are employed in the use cases section, and the objectives and strengths of these particular methods and tools are described in Table 4.1.

<table>
<thead>
<tr>
<th>ICM methods and tools</th>
<th>Scale</th>
<th>Objectives and key strengths</th>
</tr>
</thead>
</table>
| Integrated framework for life cycle environmental and economic assessment | Buildings | • integration of environmental and economic evaluation into one comprehensive single assessment  
• consideration of a broad range of life cycle stages  
• applicability to building scale evaluation  
• applicability to early stage design  
• visual integration of the results  
• ability for the final selection of design solutions to be based on the user’s personal preferences. |
ICM methods and tools | Scale | Objectives and key strengths
--- | --- | ---
Embodied Carbon Explorer tool | Precincts | • serve as user-friendly online platform with NCOS-compliant functionality  
• act as a quick-check tool at the beginning stages of a project  
• quantify Scope 3 carbon emissions related to precinct project life  
• identify main contributors to the Scope 3 carbon emissions.

City Carbon Footprints | Cities | • provide a consistent accounting framework that allows for the unambiguous identification of direct, indirect GHGE on a city scale  
• identify all different scopes described in the standards and introduce additional consistency with national and regional accounting frameworks.

4.3 Description of Project Methods and Tools

4.3.1 A framework for integrating life cycle environmental and economic assessment for buildings

4.3.1.1 Introduction and description of the framework for integrating life cycle environmental and economic assessment of buildings

There is growing concern about the effect that buildings are having on the environment. Mitigation strategies tend to focus on one life cycle stage, usually the operational stage, largely ignoring the other stages, such as manufacturing and construction. The slow uptake of whole life cycle design is further hindered by the uncertainties associated with the economic implications of life cycle environmental optimisations, as is evident by a survey completed as part of the ICM project (Fouche et al., 2015).

Evaluating building design options with a focus on simultaneously optimising life cycle environmental and economic performance is difficult due to a lack of comprehensive and accessible tools (Fouche et al., 2015). Integrating life cycle assessment (LCA) and life cycle costing (LCC) can help address this uncertainty and demonstrate the trade-offs between economic and environmental considerations, ultimately aiding the decision-making process.

This project developed a framework for integrated building evaluation. It has been used to demonstrate that solutions for improving the environmental performance of buildings are not always the most expensive, as previously thought, especially when assessing the building’s performance from a life cycle perspective. It also shows that building design strategies that aim to decrease environmental impact can also have a beneficial effect on the economic performance of buildings. The framework allows building designers to investigate different design options and base their final selection on options that maximise environmental performance, while providing an understanding of the economic implications of this optimisation.

The integrated framework uses a combination of LCA, LCC, decision-making (DM) and multi-criteria decision-making (MCDM) tools (Figure 4.3). The LCA method, in comparison to the others, provides a comprehensive approach for evaluating a building’s environmental performance based on all relevant life cycle stages. LCA is also widely acknowledged as an appropriate method for evaluating and comparing environmental impacts of building designs.
LCC analysis provides a means to counteract the tendency of previous studies to focus either on only the initial capital or operational costs. LCC includes all relevant life cycle stages (i.e. initial capital, operational and replacement costs) in order to provide a more comprehensive form of analysis. The MCDM approach is used as it can help the DM process when multiple variables have to be considered (such as GHGE and cost).

The individual steps from each individual framework have been combined to form the integrated framework (Figure 4.4). This shows the nine steps, the sequence of their application, and reference to their origin.

**Step 1**, which is similar to the first step of LCA, MCDM and DM, defines the goal, scope and aim of the assessment. This step is critical as it determines the objectives of the study. The scope determines which life cycle stages that are to be considered.

**Step 2** establishes the base case (BC or business as usual) option against which other design options can be evaluated. The need for this will depend on the goal of the study.

**Step 3** defines the alternative design/building/product options that are to be assessed in the study. These options depend on the BC and its performance and are compared against the BC to determine whether they perform better or worse (as determined by the objective of the study).

**Step 4** determines the economic and environmental data required for the assessment. These data elements, which are required to complete the calculations, can be referred to as input parameters and can be broadly classified as pre-defined (i.e. remains a constant parameter and does not change, regardless of assessment type) and user defined (i.e. dependant on the user, the type of project, and the location, changing with each assessment). These input parameters have been discussed in greater detail below.

**Step 5** requires the selection of an environmental and economic impact category, such as GHGE (in comparison to energy or water, for example) for the LCA and AUD (in comparison to another currency, for example) for LCC.

**Step 6** is where the methods for quantifying LCA and LCC are applied in order to generate results.

**Step 7**, which is the critical step missing from most previous tools, requires the LCA and LCC results to be integrated. This step is vital for the demonstration of the relationship between the two results and their associated trade-offs.

**Step 8** is where the final results are interpreted and evaluated against the original aim of the study to determine if there is an acceptable outcome. A sensitivity analysis is a vital component of this process (as life cycle studies have a significant level of uncertainty). If the outcome is acceptable, the user can move onto the next step. If not, the user will have to return to Step 1 and refine the aim and determine alternative strategies. If the assessment has provided acceptable results in line with the original aim of the study, an optimal option (as defined by the user) can be selected and implemented into the final building design as part of **Step 9**. This final option can be very subjective due to the decision-makers own judgement and priorities and will be limited by the knowledge of the user and the scope, criteria and level of detail of the assessment.
4.3.1.2 Scope of Application

Environmental optimisation of buildings can include several categories, such as GHGE, energy and water. The Australian building sector represents one of the key areas for the mitigation of GHGE (World Resources Institute, 2013). This framework is particularly ideal for identifying optimal solutions to reduce building life cycle emissions. The life cycle stages included in a GHGE analysis would be the initial embodied GHGE, recurrent embodied GHGE and operational GHGE. Other life cycle stages, such as demolition could also be included. The life cycle cost stages included would be capital cost, operational cost and replacement cost. The framework can easily be applied to any building typology in any location, given the right data is available.
4.3.1.3 Input Data and Sources

The input data requirements can be divided into two categories, namely user-defined inputs and pre-defined inputs. User-defined inputs refer to the type of data that would usually change in relation to the user and the building being assessed. The data will thus be building/project specific. Examples of such data include the size of the building, type of materials to be used and period of analysis. Other variable data, for example, price of goods, price of electricity and discount rate assumed, are also included in this category as these depend on the supplier selected, the year of the available data, and the location and context of the building. Pre-defined inputs refer to data that will not change for different users or buildings. This type of data remains constant for any project and does not require manually entered variables. Examples of such data include the material embodied energy coefficients, primary energy conversion factors and emission factors. The user can manually override all data if specific data relating to their project is available.

Table 4.2 provides a summary of the key input data required within the framework. Each input has been colour-coded and reference made (by a cross) to the life cycle stage and relevant calculation where each input is required.

Table 4.2: Key inputs requirements for the integrated environmental and economic framework

<table>
<thead>
<tr>
<th>Input</th>
<th>Life cycle stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
</tr>
<tr>
<td>Building size (m²)</td>
<td>x</td>
</tr>
<tr>
<td>Period of analysis (years)</td>
<td>-</td>
</tr>
<tr>
<td>Material type</td>
<td>x</td>
</tr>
<tr>
<td>Material quantity (m²/m³)</td>
<td>x</td>
</tr>
<tr>
<td>Cost of material (AUD)</td>
<td>x</td>
</tr>
<tr>
<td>Cost of building (AUD)</td>
<td>x</td>
</tr>
<tr>
<td>Annual fuel source demand (GJ)</td>
<td>-</td>
</tr>
<tr>
<td>Cost of fuel source demand (AUD)</td>
<td>-</td>
</tr>
<tr>
<td>Sum of total energy requirements of all materials in building (GJ/AUD1000)</td>
<td>x</td>
</tr>
<tr>
<td>Discount rate</td>
<td>-</td>
</tr>
<tr>
<td>Interest rate</td>
<td>-</td>
</tr>
<tr>
<td>Global warming potential</td>
<td>-</td>
</tr>
<tr>
<td>Emission factor</td>
<td>x</td>
</tr>
<tr>
<td>Primary energy conversion factor</td>
<td>-</td>
</tr>
<tr>
<td>Constraint factor</td>
<td>-</td>
</tr>
<tr>
<td>Replacement rate of material (years)</td>
<td>-</td>
</tr>
<tr>
<td>Material wastage coefficient</td>
<td>x</td>
</tr>
<tr>
<td>Material embodied energy coefficient (GJ/unit)</td>
<td>x</td>
</tr>
<tr>
<td>Building cost index</td>
<td>x</td>
</tr>
<tr>
<td>Total energy requirement of building sector (GJ/AUD1000)</td>
<td>x</td>
</tr>
<tr>
<td>Total energy requirement of material (GJ/AUD1000)</td>
<td>x</td>
</tr>
<tr>
<td>Total energy requirement of all IO pathways not associated with the installation or production process of each material (GJ/AUD1000)</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 4.5 provides an example of the type of data inputs required for the quantification of life cycle GHGE, and Figure 4.6 shows the data inputs required for the LCC. Examples of typical data inputs (either user-defined or pre-defined) are provided along with the expected output categories and visuals.

<table>
<thead>
<tr>
<th>Data type</th>
<th>Data Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building type</td>
<td>Residential / Commercial etc.</td>
</tr>
<tr>
<td>Period of analysis (yrs)</td>
<td>20 yrs / 60 yrs / etc.</td>
</tr>
<tr>
<td>Area of building (m²)</td>
<td>150 m² / 1500 m² / etc.</td>
</tr>
<tr>
<td>Material type</td>
<td>Concrete / timber / etc.</td>
</tr>
<tr>
<td>Material quantities (m³/m²/m²)</td>
<td>80 m³ / 5 / etc.</td>
</tr>
<tr>
<td>Embodied energy coefficient</td>
<td>4.44 / 0.546 / etc.</td>
</tr>
<tr>
<td>Wastage multiplier (%)</td>
<td>1.1 / 1.05 / etc.</td>
</tr>
<tr>
<td>Replacement rate of material (yrs)</td>
<td>10 yrs / 20 yrs / etc.</td>
</tr>
<tr>
<td>Cost of material (AUD)</td>
<td>0.4 AUD / 0.29 AUD / etc.</td>
</tr>
<tr>
<td>Cost of building (AUD)</td>
<td>700 AUD / 600 AUD / etc.</td>
</tr>
<tr>
<td>Total energy requirement of building sector (GJ/AUD1000)</td>
<td>10.62 GJ/AUD1000 / 9.07 GJ/AUD1000 / etc.</td>
</tr>
<tr>
<td>Total energy requirement of material (GJ/AUD1000)</td>
<td>0.96 GJ/AUD1000 / 0.228 GJ/AUD1000 / etc.</td>
</tr>
<tr>
<td>Total energy requirement of all input-output pathways not associated with installation of each material (GJ/AUD1000)</td>
<td>3.66 GJ/AUD1000 / 4.404 GJ/AUD1000</td>
</tr>
<tr>
<td>Annual fuel source demand (GJ)</td>
<td>48 GJ / 98 GJ / etc.</td>
</tr>
<tr>
<td>Cost of fuel source demand (AUD)</td>
<td>2.45 cents / MJ / etc.</td>
</tr>
<tr>
<td>Global warming potential</td>
<td>1 / 0.5 / etc.</td>
</tr>
<tr>
<td>Emission factor</td>
<td>20° / 92.7° / etc.</td>
</tr>
<tr>
<td>Primary energy conversion factor</td>
<td>3.40 / 1.46 / etc.</td>
</tr>
<tr>
<td>Constraint factor</td>
<td>0.40 / 2.4 / etc.</td>
</tr>
</tbody>
</table>

**Output**

<table>
<thead>
<tr>
<th>Result (tCO₂e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial embedded GHGE</td>
</tr>
<tr>
<td>Recurrent embedded GHGE</td>
</tr>
<tr>
<td>Operational GHGE</td>
</tr>
<tr>
<td>Life cycle GHGE</td>
</tr>
</tbody>
</table>

Figure 4.5: Example of the data inputs for the quantification of life cycle GHG
4.3.1.4 Key Outputs and Performance Measures/Indicators

The output of the LCA component of the framework can include a variety of results that range from metrics relating to water and energy consumption or GHGE. The output of the LCC component is Australian dollars (AUD) but this can be altered depending on the location of the building being assessed. To integrate both the environmental and economic results, the Marginal Abatement Cost (MAC) method is used. The MAC approach provides the results in terms of cost per tonne of GHGE abated, for example, which is in the form of $/tCO₂e abatement. This provides a simple way of identifying which option is the most cost effective per unit of CO₂e abated and which option provides the greatest abatement potential. A negative cost (-$) does not incur any extra financial cost to the user and possibly leads to financial savings, whereas a positive cost (+$) incurs an additional financial cost to the user.

4.4 Embodied Carbon Explorer Tool – for precincts

4.4.1 Introduction and description of Embodied Carbon Explorer tool

The recently published National Carbon Offset Standard (NCOS) for Precincts (Department of the Environment and Energy, 2017a) provides guidance on how to attain carbon neutral certification for precincts. The Embodied Carbon Explorer (ECE) tool has been aligned with the requirements under the NCOS for Precincts to maximise the compatibility of the tool with NCOS requirements so that standard-compliant assessments of various precinct projects can be made.

The ECE online tool has been developed specifically to enable the rapid evaluation of embodied carbon for a precinct project. It is well suited as a quick-check tool at the beginning stages of a precinct project before full, detailed assessments are undertaken using other methods/tools such as LCA.
A particular strength of this ECE tool is the provision of embodied carbon estimates for the full Scope 3 under NCOS. Users may use the tools specifically to quantify their Scope 3 emissions to be rated under NCOS. This is done through a comparison of Scope 3 emissions of the analysed precinct (e.g. university) with a benchmark precinct (e.g. average Scope 3 emissions of all tertiary educations in Australia). The main contributors to embodied carbon emissions of the analysed precinct can then be identified and quantified. Scope 1 and 2 emissions can be assessed separately via other tools and emission factors that are readily available, such as from the National Greenhouse Account Factors (Department of the Environment and Energy, 2017b).

Typical sources of Scope 3 emissions that are currently listed and deemed to be relevant in the NCOS precincts are from electricity consumption, fuel use, waste, water supply, wastewater treatment and all other emissions identified (which are assessed for relevance according to the relevance test). The ECE tool complements the NCOS standard by aligning ECE tool categories with these NCOS categories as well as its comprehensive coverage of all other Scope 3 categories that are not listed in the NCOS precincts yet, such as from services, raw materials, building products etc.

NCOS precinct mentions that tools based on IOA can be useful as an initial way of determining whether an emissions source meets the materiality threshold. Any contributors (e.g. product or service) can be tested for Scope 3 emissions relevance and materiality (i.e. >1% of the total emissions), allowing to pre-select and include only inputs that are above the standard’s threshold. All of Scope 3 emissions playing a relevant role (in accordance with NCOS materiality threshold) can be selected to be reported.

The ECE tool is based on detailed environmentally-extended IOA. IOA documents all monetary flows of products and services between industry sectors within an economy, usually in the form of an input-output table. Environmentally-extended IOA is a method that assigns impacts (such as GHGE) to financial transactions, and is presented as the Scope 3 emission multiplier (also known as total impact multipliers) which is the amount of GHGE indirectly embodied in each of the products supplied from each specific industry. Embodied emissions are calculated by multiplying the Scope 3 emission multiplier with the expenditure data.

The ECE tool is hosted on the IELab research platform which is based on Australia specific input-output and hybrid database (ABS, 2012a) and GHGE (AGETS, 2008) data that are readily available. Data of input-output and environmental information data are based on 2009-2010 and 2014-2015.

The ECE tool will contribute to CO₂ emissions reductions via its connection to NCOS Precincts, which is directly targeted towards the development of carbon neutral precincts. The ECE tool supports the realisation of this standard. The tool has the theoretical potential to realise carbon neutrality for all new precinct developments and refurbishments. Low to zero carbon buildings and precincts play an important role in the implementation of the Paris Agreement targets to reduce climate change.

4.4.2 Scope of Application

Whilst the ECE tool was developed with NCOS precinct assessment in mind, it is by no means restricted to precincts only. Top-down analyses of GHGE in the supply chain of any organisation or activity can be undertaken, as long as adequate financial data on expenditure for goods and services are available. Within the realm of built environment, the ECE tool can be applied to buildings, construction projects, construction services and materials manufacturing.

The ECE tool can be applied in two ways: 1) applying the tools to a new or ongoing project to analyse carbon reduction scenarios for precinct development, and 2) applying the tools to completed projects for carbon performance assessment. The results can then be compared and benchmarked against the reference or target values for checking the carbon neutrality positions of the projects.
4.4.3 Input Data and Sources

The ECE tool is hosted on the IELab website (https://ece.ielab-aus.info). The ECE tool can be accessed after registering for an account on the IELab website. The main sections and features of the ECE tool are listed below:

1. Insertion of annual expenditure data in basic prices for the analysed precinct project sourced from your precinct project item costs, e.g. cost of construction materials, services rendered
2. Input project details, e.g. financial year of analysis
3. Selection of precinct project benchmark by selecting from the 344 ECE tool categories
4. Selection of indicators, i.e. environmental indicators (CO₂, N₂O, CH₄, CO₂e)
5. Building the analysis (refer to Figure 4.7)
6. Presentation of results, including precinct project benchmarking.

The input data required are annual expenditure data of the analysed precinct project (in AUD). Common sources of input data are bill of quantities, project ledgers, expenditure accounts, etc. Each expenditure data item of the analysed precinct project needs to be mapped to an appropriate category from the list of 344 ECE tool categories. For example, if alloy steel flat-rolled products were purchased for the precinct project, they would need to be matched with the most appropriate ECE tool category. In this example, it would match the ECE tool category of Iron and steel semi-manufactures from the 344 categories available. This should to be repeated for every item in the analysed precinct project.

The category classifications used in this tool are the industry sectors from the National Accounts published regularly by the Australian Bureau of Statistics (ABS). The ABS publication (ABS, 2017) can be referred to for more category descriptions. The accuracy of results depends on the amount of data on material purchases available.
4.4.4 Key Outputs and Performance Measures/Indicators

The ECE tool includes a range of environmental indicators, including CO₂, CH₄, N₂O, and CO₂e, as the main focus is on carbon. Results are generated in the “Results” section after pressing the “Build” button. Results are presented as graphs and tables (Figure 4.8), described below:

1. **Total impacts table** shows the total Scope 3 emissions of the analysed precinct project against the total Scope 3 emissions of the benchmark precinct (e.g. in kt of CO₂e)

2. **Total intensities table** shows Scope 3 emissions per dollar’s worth of precinct project. This is done by dividing the total economic output of the precinct project by the total Scope 3 emissions of the precinct project (e.g. in kt/$million)

3. **Benchmark spider diagram** depicts the relative performance on all selected indicators in one integrated way to quickly understand if the analysed precinct project is performing better or worse than the benchmark precinct project

4. **Commodity breakdown table and graph** shows the ranking of major contributors and which expenditure carries the most impact (e.g. in kt of CO₂e). Contributions of less than 1% of the total impact are not shown

5. **Impact by layer table and area graph** breaks down the total Scope 2 and 3 emissions into production layers to reveal the contribution made by different production layers responsible for those impacts. Emissions occur in every layer of the production chain to produce the item (e.g. construction materials) that is used in your precinct project. The graph answers the question “Where do emissions/impacts ultimately come from?” and “How far up the supply chain are the suppliers that contribute most to our impact?” (e.g. in kt of CO₂e) (Figure 4.8).

![Figure 4.8: Examples of 1) Total impacts table, 2) Total intensities table, 3) Benchmark spider diagram, 4) Commodity table graph, and 5) Impact by layer area graph showing cumulative impact by production layer for CO₂ emissions](image-url)
4.5 City Carbon Footprints – for cities

4.5.1 Introduction and description of City carbon footprints method

The decarbonisation of cities is increasingly being seen as a crucial contribution to limiting global warming (IPCC, 2014). More cities are signing up to a commitment of addressing climate change as exemplified by the agendas of C40 Cities Climate Leadership Group (http://www.c40.org) or ICLEI Local Governments for Sustainability (http://www.iclei.org), both global networks of cities. As a basis for action on climate change, cities need to quantify and report their GHGE.

The territorial (direct) emissions of cities are well understood, and so are those from some of their infrastructure supply chains as well as their full energy and material requirements. However, their full out-of-boundary emissions, i.e. those attributable to all goods and services imported to a city, are not comprehensively reported or understood. Neither are emissions that can be attributed to exports of cities.

The Global Protocol for Community-Scale (GPC) standard follows the well-established format introduced by the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard (WRI et al., 2011) but only provides guidance for a limited number of Scope 3 emission sources.

The Consumption-Based methodology described under PAS 2070, on the other hand, (BSI, 2013, p.1) captures both the direct and the life cycle GHGE for all goods and services consumed by residents of a city, i.e. all possible Scope 3 emissions. It is equivalent to a city’s carbon footprint (Minx et al., 2013) and does not include emissions that are associated with goods and services exported from the city for consumption elsewhere (so-called emissions embodied in exports, EEE). Two different types of footprints have been described in the literature:

- production-based Carbon Footprint (PBCF) = Scope 1 + Scope 2 + Scope 3
- consumption-based Carbon Footprint (CBCF) = Scope 1 - EEE + Scope 2 + Scope 3

Note that PBCF double-counts emissions, while CBCF does not. Both types of footprints are presented in this work.

The city carbon map is based on standard Leontief-inverse demand-pull input-output calculus. The city carbon map constitutes a consistent accounting framework that allows for the unambiguous identification of direct and indirect GHGE. It clearly identifies all different scopes described in the standards and introduces additional consistency with national and regional accounting frameworks.

4.5.2 Scope of Application

Cities with a population over one million can be considered in this analysis (Table 4.3). The metropolitan area boundaries follow the greater capital city statistical areas (GCCSAs) published by the Australian Bureau of Statistics (ABS, 2012b).

Table 4.3: Example of Australian cities selected for city carbon footprint use case

<table>
<thead>
<tr>
<th>City</th>
<th>Population in 2009</th>
<th>Area</th>
<th>Number of SA2 Regions Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>4.6 million</td>
<td>12,138 km²</td>
<td>249</td>
</tr>
<tr>
<td>Melbourne</td>
<td>4.0 million</td>
<td>7693 km²</td>
<td>265</td>
</tr>
<tr>
<td>Brisbane</td>
<td>2.0 million</td>
<td>5964 km²</td>
<td>137</td>
</tr>
<tr>
<td>Perth</td>
<td>1.6 million</td>
<td>5386 km²</td>
<td>164</td>
</tr>
<tr>
<td>Adelaide</td>
<td>1.2 million</td>
<td>1827 km²</td>
<td>109</td>
</tr>
</tbody>
</table>
4.5.3 Input Data and Sources

Input data are in the form of specific city-scale, multi-region input-output data with environmental extensions derived from the IELab (Lenzen et al., 2014a). These are combined in the IELab with GHG data at the state level from the Australian Greenhouse Emissions Information System (AGEIS) database (AGEIS, 2017). All values of economic transactions and embodied carbon flows are imputed top-down, using proxy data and location quotient methods for the regionalisation of data (Lenzen et al., 2014a).

Industrial sectors are aggregated into the nine categories used in the Global Protocol for Community-Scale (GPC) Greenhouse Gas Emission Inventories (ICLEI et al., 2014). These are: agriculture, construction, electricity, energy, food, goods, services, transport, and waste. The construction sector includes construction materials and services. The electricity sector is separated from other energy sectors to enable standard Scope 2 accounting. Industrial process emissions are allocated to industrial products (i.e. goods). Processed food products are separated from agricultural products to enable more detailed examination of the embodied emissions of food production, as these make up a significant proportion of the food-related CF.

4.5.4 Key Outputs and Performance Measures/Indicators

Three GHGs are considered in the city carbon footprint analysis: carbon dioxide, methane and nitrous oxide. Direct household emissions, e.g. from heating homes or driving cars, are included in the footprints. All data and results refer to the year 2009.

The output is in a form of a carbon map, which is a two-dimensional decomposition of the carbon footprint of a city’s final demand. It splits up the total carbon footprint into the industry sectors from which the GHGE originate as well as into the product groups in which the emissions become embodied (Wiedmann et al., 2016).

References


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Monique Schmidt, University of Melbourne
4A. Integrating Life Cycle Environmental and Economic Assessment of Building Material Products

Monique Schmidt and Robert H. Crawford, University of Melbourne

4A.1 Outline and Rationale

The framework developed by Integrated Carbon Metrics enables the integrated optimisation of the environmental and economic performance of buildings. A case study building is used to demonstrate how the framework can be used to assess the life cycle costs and greenhouse gas (GHG) emissions associated with different design and material selection options. This provides an indication of how the framework results can be used to inform the building design decision-making process. It does this by simultaneously communicating environmental and economic results, side by side, enabling more holistic building design decisions. This can help to clarify the economic costs and benefits of potential strategies being considered for life cycle GHG emissions reduction.

4A.2 Data and Inputs

The case study used here is a 4-bedroom residential house of 230m² in Melbourne. Data requirements include details about the building being assessed as well as cost, energy use and GHG emissions-related data from various public sources. The input data is categorised as either user defined (data that would usually change in relation to the user and the building being assessed) or pre-defined (data that will not change for different users or buildings).

Table 4.4 below provides an outline of the inputs required for each life cycle stage covered by the framework (based on the European Standard 15978/EN, 2011).

<table>
<thead>
<tr>
<th>Data inputs</th>
<th>Life cycle stage (as per EN 15978)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building size (m²), material type, material quantity (m², m³)</td>
<td>Product</td>
</tr>
<tr>
<td>Cost of material (AUD), cost of building (AUD)</td>
<td>x</td>
</tr>
<tr>
<td>Annual fuel source demand (GJ), cost of fuel source demand (AUD)</td>
<td>-</td>
</tr>
<tr>
<td>Sum of total energy requirements of all materials in the building (GJ/AUD) (ielab-aus.info)</td>
<td>x</td>
</tr>
<tr>
<td>Discount rate, interest rate, period of analysis (years)</td>
<td>-</td>
</tr>
</tbody>
</table>
4A.3 Outputs, Findings and Implications

Figure 4.9, below, illustrates the life cycle cost (LCC) results (in AUD) and life cycle GHG (LCGHGE) results (in tCO₂e) for the case study building based on different insulation scenarios (EPS-expanded polystyrene, straw and fibreglass). The integrated LCC and LCGHGE results are placed in the relevant quadrants (Q1-4). Q1 refers to insulation options that lead to an increase in LCC and LCGHGE, while options in Q3 lead to a decrease in both LCC and LCGHGE. The base case (BC) is represented by a black dot in the centre of the graph. The highlighted area for each insulation option demonstrates the range of possible results based on sensitivity parameters (such as discount rate (DR) and period of analysis (POA)). The use of the framework, in this specific instance, shows that R3 fibreglass wall insulation (an improvement on the R2 fibreglass wall insulation), provides the most consistent decrease in LCGHGE and LCC, in comparison to the other options, indicating it may be the preferred option from both an economic and GHG emissions perspective.
Figure 4.9: Life cycle cost results and life cycle GHG results for the case study building based on different insulation scenarios

This analysis shows that the most expensive solutions for improving the environmental performance of buildings are not always the most beneficial, especially when considering the building’s performance from a life cycle perspective. It shows that building design strategies that aim to decrease environmental impact can also have a beneficial effect on economic performance. The findings indicate the large amount of uncertainty associated with life cycle studies which must be considered. This analysis demonstrates just one example of the use of the integrated framework. It can also be applied to other building typologies and scales and used to assess a broad range of design options.

References


4B. Modelling the Carbon Neutrality of UNSW University Precinct using the Embodied Carbon Explorer Tool

Thomas Wiedmann and Soo Huey Teh, University of New South Wales

4B.1 Outline and Rationale

With the recent publication of the National Carbon Offset Standard (NCOS) for Precincts (Department of the Environment and Energy, 2017a), the Embodied Carbon Explorer (ECE) tool from the Integrated Carbon Metrics (ICM) project can serve as a useful screening tool for Scope 3 emissions in precinct projects. The University of New South Wales (UNSW) precinct currently reports Scope 1 and 2 emissions but not Scope 3 emissions because the latter is not compulsory and the quantification process is a complicated task (UNSW Sydney, 2016).

Using the UNSW precinct as a case study, the full carbon footprint (Scopes 1 to 3) of the university was established to investigate its carbon neutrality using the ECE tool. The ECE tool was aligned with the NCOS Precinct categories to enable standard-compliant assessments, and was used to establish Scope 3 emissions and to identify the main contributors of Scope 3 emissions in this case study. The results of this case study are useful in guiding actions to reduce or offset emissions for precincts in order to achieve carbon neutrality.

4B.2 Data and Inputs

The UNSW precinct occupies 38 hectares in Kensington, New South Wales, Australia. Inputs needed for this case study are the university’s annual expenditure (in AUD) for the year of study (2017), such as expenditure on transport, consumables, equipment and services. Expenditures were deflated to 2015 equivalents to match the ECE tool emissions data. Consequently, the deflated purchase prices were converted to basic prices.

Within the ECE tool, these expenditures in basic prices were matched with the most appropriate ECE tool categories (from the list of 344 product categories available; e.g. manufactured wood, paints, bitumen, plastic products etc.). The expenditure data in basic prices (in AUD) were multiplied with Scope 3 multipliers (in $/ kg CO₂-eq) of the mapped ECE tool categories to obtain the total Scope 3 emissions. Scope 1 and 2 emissions were calculated separately using UNSW activities data (e.g. energy use, fuel use, electricity use, etc.) and emission factors from National Greenhouse Account Factors (Department of the Environment and Energy, 2017b).

4B.3 Outputs, Findings and Implications

The total carbon footprint of the UNSW precinct consists of the summation of Scope 1, 2 and 3 emissions, which amount to 242 kt CO₂-e. Results show that Scope 3 emissions comprise the largest proportion (67%) of the total carbon footprint, and are around two times that of combined Scope 1 and 2 emissions (81 kt CO₂-e). This highlights the importance of accounting for Scope 3 emissions for a more comprehensive sustainability reporting.
The ECE tool provides a full breakdown and ranking of total Scope 3 emissions into emission sources. The top 10 contributors for this case study are summarised in Figure 4.10. Approximately 50% of Scope 3 emissions were embodied in “Other Services” and “Business Services”, which include contract services such as catering, waste removal, portage and courier and insurance services. Another major contributor (11%) was “Furniture, Equipment and IT” (e.g., furniture, computers, printers, software purchasing). Attention should be paid to these areas that provide the greatest potential for emissions reduction.

Figure 4.10: Total carbon footprint of UNSW and top 10 contributors of Scope 3 emissions

ECE tool aligns these Scope 3 emissions to the categories listed by NCOS Precincts (Figure 4.11) to meet the carbon accounting requirements for carbon neutral certification reporting. Apart from the Scope 3 emissions from NCOS categories, emissions from “other sources” constitute 56% of the total Scope 3 emissions (a more detailed breakdown of categories is available via the ECE tool).

UNSW is currently still far from being carbon neutral. However, UNSW has recently committed to have all of its energy supplied by photovoltaic solar energy, which will completely offset Scope 2 emissions. Scope 1 emissions could be reduced by energy efficient measures. Scope 3 emissions could be reduced by substituting products with low carbon products or products with less emission-intensive supply chains and choosing more sustainable practices and behaviours. Remaining Scope 3 emissions could be offset by funding carbon offset projects. The ECE tool can serve as a rapid and early screening tool for NCOS reporting to assess any project at a precinct scale by determining full Scope 3 emissions and identifying areas of high embodied emissions to assist in devising strategies for sustainable procurement.

Figure 4.11: Scope 3 emissions by NCOS categories

References


4C. Carbon Footprint Analysis of Five Major Australian Cities

Thomas Wiedmann, Guangwu Chen and Soo Huey Teh, University of New South Wales

4C.1 Outline and Rationale

Based on previous work under the ICM (Wiedmann et al., 2016; Chen et al., 2016), this case study presents a consistent and complete reconciliation of direct and indirect city greenhouse gas emissions from different perspectives with sufficient accuracy and detail. Carbon footprints (CFs) of the five largest cities in Australia were analysed, based on the concept city carbon maps (Wiedmann et al., 2016). These are the fastest growing regions in Australia and where 60% of the nation’s population lives.

A particular emphasis was placed on an evaluation of out-of-boundary emissions and on the relationship between a city’s territorial carbon emissions and its wider CF. The cities’ carbon profiles were compared and discussed and pathways to carbon neutrality were explored. This will help direct efforts for greenhouse gas mitigation and zero carbon target setting.

4C.2 Data and Inputs

For this case study, all Australian cities with a population over 1 million were included – Sydney, Melbourne, Brisbane, Perth and Adelaide. Input data in the form of a multi-regional input-output (MRIO) table were derived from the online platform, Australian Industrial Ecology Virtual Laboratory (IELab).

The MRIO table comprises region-specific input-output (in AUD) and greenhouse gas (in kg CO₂e) data derived from locally specific business turnover, employment and income census data. The metropolitan area boundaries follow the greater capital city statistical areas (GCCSAs) published by the Australian Bureau of Statistics (ABS, 2012).

4C.3 Outputs, Findings and Implications

The analysis reveals several interesting aspects of embodied emission flows of cities. Perth has the highest per-capita Consumption-based Carbon Footprint (CBCF) (35 t CO₂e/cap) of the five cities studied, followed by Melbourne (25 t CO₂e/cap), Adelaide (22 t CO₂e/cap), Sydney (21 t CO₂e/cap) and Brisbane (16 t CO₂e/cap).

Generally, Scope 1 and 3 emissions make up the largest proportions of the cities’ CFs (Production-based Carbon Footprint (PBCF) shown in Figure 4.12). A significant proportion of Scope 1 emissions in all cities are exported to other regions within Australia and the world; less than half ‘remain’ in the cities, i.e. are directly related to consumption in the cities themselves. In all cities except Perth, imported emissions (Scope 3 and imported electricity) are larger than the remaining Scope 1 emissions that are used within the city. This means that all cities, except Perth, rely more on GHG emissions from elsewhere in Australia and the world than from their own industries, to satisfy their final demand. This reflects the density and extent of supply chain networks that cities in the eastern part of Australia rely on.
For the five cities studied, the top three sectors driving CF emissions are services, goods and construction (Figure 4.13). While Scope 1 and 2 emissions contribute substantially, it is also the Scope 3 emissions in these sectors that need attention if full carbon neutrality is to be achieved, because Scope 3 emissions make up about one third to over half the CFs of all sectors. This is particularly the case for goods where Scope 3 emissions can contribute as much as 80% to the CBCF this sector (in Sydney and Brisbane). Most of the manufactured goods consumed in Australia and its cities come from overseas. This is reflected in the very high proportion of Scope 3 emissions from imported goods. Perhaps contrary to common belief, the use of fossil fuels for energy in homes and waste only has minor contributions to the overall CFs.

Figure 4.12: Relative breakdown of all city-related emissions (PBCF) into Scopes 1, 2 and 3. Scopes has further been separated into those that relate to products produced within the city and those that relate to imported products.

More than half of the Australian national CBCF is attributable to consumption in the five large cities, (Wiedmann et al., 2016) with many of those GHG emissions embodied in international imports of goods and services. Neglecting this latter part of emissions would lead to underestimation of the national CF by an order of one quarter. This suggests that the current focus on territorial emissions would be ineffective at reducing city, national and even global emissions in the absence of mechanisms to monitor and report emissions embodied in imported goods and services.

Cities are traditionally seen as drivers of emissions but there are signs that cities can act as frontrunners of positive change (Wigginton et al., 2016).
Carbon footprint analyses should be routinely undertaken by cities, with both the emissions embodied in imports and exports being monitored (Hsu et al., 2016), especially for embodied emissions of goods and services that have been shown to make up substantial parts of city CFs. This would complement the approach that focuses on Scopes 1 and 2 already implemented by most current city carbon accounting standards.

References


Precinct Carbon Assessment
Ke Xing, Bin Huang and Stephen Pullen, University of South Australia
5. Precinct Carbon Assessment

5.1 Introduction

The Precinct Carbon Assessment (PCA) Tool has been developed as part of the Integrated Carbon Metrics Project (RP2007). The main focus of the PCA tool is to examine the whole life cycle of carbon emissions at a precinct scale by assessing different low carbon development scenarios, including alternative travel modes and renewable energy systems.

Unlike many existing precinct tools (e.g. PrecinX, SSIM and Green Star-Communities), the PCA tool is intentionally designed to be transparent (i.e. ‘non-blackbox’) and not bound by data sources. It is flexible for users to adjust precinct morphological settings, renewable system options and carbon intensity data of precinct objects for conducting quantitative analysis and finding best-practice solutions.

5.2 Objectives

The PCA tool is developed to analyse the ‘carbon fabric’ of the built environment across different urban settings, assess the life cycle carbon performance of buildings, precincts and cities, and evaluate predicted versus operational performance. It aims to:

- be an operational precinct carbon rating tool aligned with the ‘National Carbon Offset Standard for Precincts’ (NCOS-Precincts)
- provide both highly aggregated as well as more detailed assessment of operational and embodied carbon of precinct objects (residential and commercial buildings, infrastructure), building appliances, transport vehicles, and discrete energy generation and storage units
- identify and quantify the effects of occupancy and morphological factors on precinct carbon profile
- assess the offset potential of climate rendering and green energy systems at the precinct scale
- support the analysis of different precinct types and urban development scenarios.

5.3 Schematic Representation and Description of Tool

PCA can be used as an assessment tool at the final phase of a development project or as a planning tool applied at an early stage of a project. Users may use it in either of the following two ways:

1. applying the tool to a new/ongoing project to analyse carbon reduction scenarios for precinct development
2. applying the tool to completed projects for carbon performance assessment.

The results from the tool can be compared with a reference or target value established by the user for checking performance of the project (with respect to carbon neutrality).

It offers three levels of precinct carbon modelling: building, product and material. Modelling can range from rapid assessments using highly aggregated data and standard/typical precinct object types (provided by the built-in database), to more detailed analysis using refined data and user-defined precinct object types. Such features can accommodate users with different technical competence, resources and objectives. Figure 5.1 presents a schematic view of the functional features of the PCA tool.
Figure 5.1: Schematic representation of Precinct Carbon Assessment tool functions
The precinct-scale carbon assessment is underpinned by an integrated model that consists of three key phases as shown in Figure 5.2.

At Phase 1, carbon intensities for embodied, operational and transport-related emissions are identified. The embodied carbon intensity of each precinct object type is determined by the life-cycle carbon intensities of the main construction materials, the amount of each material required for construction, replacement and waste ratios of building components, and the carbon embodied in construction activities (e.g. material and equipment transportation, equipment use, onsite assembly, etc.).

The recurrent embodied carbon is measured as the replacement ratios of major building components over the lifespan of precinct objects. As for operational carbon, operational energy intensities of precinct objects are assessed, then emission factors (with the unit of kg CO₂-e/MJ) determined by local energy production are used to convert into operational carbon intensities. Transport-related carbon intensities are calculated from the fuel consumption, considering multiple fuel types, measured as kg CO₂-e/km/passenger.
Phase 2 is designed for the evaluation of precinct baseline emissions associated with buildings and vehicles, as well as infrastructure services including energy, water and waste. In this stage, parameters inter-linked with the environment, local climate, and occupant life-style preference (e.g. total floor area of each building type, schedule of appliances, travelling frequency and distance, etc.) are identified to support the calculation of precinct baseline emissions, together with the carbon offsetting contributed by renewable energy units.

Phase 3 is developed to improve the accuracy of precinct carbon evaluation. At this stage, precinct baseline emissions are moderated by morphological factors reflecting the ambient surrounding natural and built environment. The occupants’ life-style preferences are considered and integrated into the baseline carbon measurement by affecting operating hours of appliances, maintenance and refurbishment cycles of precinct objects and transport mode selections.

The impacts of actual precinct morphology or master plan of an urban precinct are analysed to define characteristic factors such as urban density and solar potential. Finally, these factors are modified iteratively in order to improve the overall carbon profile of the precinct.

More detailed information about the precinct carbon model and the assessment methods can be found in Huang, Xing and Pullen (2017a,b)

5.4 Scope of Application

The target users for the PCA tool include government planning agencies and private companies (such as developers and consulting firms), sustainability development consultants, and urban and infrastructure planners.

The tool can be applied to greenfield, greyfield or brownfield developments for residential or mixed-use precincts. The spatial scales in modelling and assessments include street, neighbourhood, subdivision and suburb, as well as CBD and corridor. The tool is particularly useful in supporting ‘as designed’ or ‘as built’ carbon assessment and scenario analysis on infill or renewal types of precinct (re)development with medium- or high-density housing. With its Transport and Renewable Energy modules, the tool can also support analysis of various scenarios in relation to transit-oriented development (TOD) and deployment of renewable energy harvesting units at a precinct-scale for the zero-carbon or carbon-positive target.

This PCA tool is currently implemented as both Excel spreadsheet and a custom software operating in the Matlab environment with Graphical User Interfaces for inputs and outputs. The results are presented in tables, graphs and charts. Potentially, the tool can also be converted as web-based and an app (for tablets) to support open access. Figure 5.3 shows the home screen for the PCA tool interface, annotated to indicate its main functions.
5.5 Input Data and Sources

The PCA tool performs flexible, customized, multi-scale assessments of precinct carbon performance. To satisfy the requirements of different assessment types, the input parameters are structured into three levels as shown in Figure 5.4.

Figure 5.3: The main menu and modules of the PCA tool
Level 1 assessment is designed for urban planners and government agencies. It predominantly focuses on early stage planning and resource allocation at a macro level. Therefore, highly aggregated data on energy/carbon intensity per m² of each object type is used as the primary input for assessment. Level 2 assessment is targeted at building and construction developers. It aims to improve the carbon performance by material/components selection and optimal scheduling of operations for precinct objects. Hence, the data on MJ or tCO₂-e per m² used in the assessment is built up from the product level, including detailed volumetric data of materials used, energy/carbon intensity of each material/product type, as well as units of use and operating schedule of each appliance type (built-in and plug-in).

In Level 3 assessment, more detailed information about precinct object designs and travel mode selection is required as input data to support the examination of overall carbon performance from the perspective of design and development.

Detailed descriptions of input data types are summarised in Table 5.1.
Table 5.1: Description of PCA input data

<table>
<thead>
<tr>
<th>Precinct attributes</th>
<th>Location (latitude &amp; longitude, degrees), time meridian, local albedo, precinct land size, population size and number of households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic attributes</td>
<td>Age groups, employment types (e.g. employed full-time, part-time, casual), income levels and household sizes (e.g. one person, two-person family, etc.)</td>
</tr>
<tr>
<td>Land use</td>
<td>Building types (detached house, semi-detached townhouse); numbers (public buildings, offices, schools, retail, medical buildings); infrastructure types and units (area of driveways, length of pipeline, area of garden &amp; green space, water, gas and power plants); floor area and occupied land size of each building and infrastructure type</td>
</tr>
<tr>
<td>Precinct morphology</td>
<td>Dimensions and orientation of buildings, total area of land used for building and infrastructure construction, population density, dimensions of construction site</td>
</tr>
<tr>
<td>Embodied intensity data</td>
<td>Per m2 embodied energy and carbon of each building type (or per m2 material use of each building type, lifespan of each building component, recurrent/maintenance cycle, percentages of raw and reuse materials used in the manufacturing of building component)</td>
</tr>
<tr>
<td>Operational intensity data</td>
<td>Hourly per m2 energy load for heating, cooling, ventilation and lighting based on standard occupancy assumptions, occupancy and hourly energy consumption of appliances (e.g. white goods, computers, TVs), temperature setting of indoor environment, infiltration and air change (max and min) of ventilation, people load, operation schedule of appliances (weeks per year, days per week and hours per day), annual consumption of different energy types</td>
</tr>
<tr>
<td>Travel intensity data</td>
<td>Transport mode types (e.g. bus, tram, train, car), fuel type, engine size and built year of each vehicle, travel frequency, average travel distance per trip, travel diary of residents, annual transport energy consumption and carbon emissions</td>
</tr>
<tr>
<td>Water and waste</td>
<td>Daily household water and hot water consumption, daily household waste generation (recyclable and non-recyclable), non-residential building water use and waste generation, non-residential building occupancy (m2 per capita)</td>
</tr>
<tr>
<td>Renewable energy generation</td>
<td>Installation of PV systems (number and kWp), grid energy loss in electricity uploading (%), PV panel type (including panel efficiency, per m2 embodied energy and carbon of panels, lifespan of panels), battery storage systems (including installed amount, size of battery bank in kWh, per kWh embodied energy and carbon intensities of batteries), number of solar water heaters installed, efficiency of solar water heaters, annual solar energy harvesting (kWh) or cost saving (A$)</td>
</tr>
</tbody>
</table>
5.6 Key Outputs and Performance Measures/Indicators

To support scenario analysis and decision making, the main precinct performance indicators include:

- **operational Energy**: Buildings (residential and commercial), appliances, infrastructure (transport, energy, water, and waste)
- **initial and Recurrent Embodied Energy**: Buildings (residential and commercial), appliances, infrastructure (transport, energy, water, and waste) and vehicles
- **transport Energy**: Vehicle use (commute, lifestyle), and
- **renewables**: Solar PV, solar hot water.

Based on local power mix and fuel types, these indicators are converted from energy (MJ) to the carbon metrics as detailed in Table 5.2. Furthermore, life-cycle cost (in dollar value), cost-carbon intensity (in dollar per tCO2e) and payback period (in years) can also be incorporated for analysis and decision making.

### Table 5.2: Carbon metrics for PCA tool output measures

<table>
<thead>
<tr>
<th>Carbon Metrics</th>
<th>Life Cycle</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Carbon</strong></td>
<td>For the whole precinct</td>
<td>tCO2-e</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per annum</td>
<td>tCO2-e per annum</td>
</tr>
<tr>
<td></td>
<td>For object/building types</td>
<td>tCO2-e per object type</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per type object per annum</td>
<td>tCO2-e per type object per annum</td>
</tr>
<tr>
<td></td>
<td>For occupancy</td>
<td>tCO2-e per capita, tCO2-e per household</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per capita per annum, tCO2-e per household per annum</td>
<td></td>
</tr>
<tr>
<td><strong>Embodied Carbon</strong></td>
<td>For the whole precinct</td>
<td>tCO2-e</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per annum</td>
<td>tCO2-e per annum</td>
</tr>
<tr>
<td></td>
<td>For object/building types</td>
<td>tCO2-e per object type</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per object type per annum</td>
<td>tCO2-e per object type per annum</td>
</tr>
<tr>
<td></td>
<td>For occupancy</td>
<td>tCO2-e per capita, tCO2-e per household</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per capita per annum, tCO2-e per household per annum</td>
<td></td>
</tr>
<tr>
<td><strong>Operational Carbon</strong></td>
<td>For the whole precinct</td>
<td>tCO2-e</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per annum</td>
<td>tCO2-e per annum</td>
</tr>
<tr>
<td></td>
<td>For object/building types</td>
<td>tCO2-e per object type</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per object type per annum</td>
<td>tCO2-e per object type per annum</td>
</tr>
<tr>
<td></td>
<td>For occupancy</td>
<td>tCO2-e per capita, tCO2-e per household</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per capita per annum, tCO2-e per household per annum</td>
<td></td>
</tr>
<tr>
<td><strong>Transport Carbon</strong></td>
<td>For the whole precinct</td>
<td>tCO2-e</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per annum</td>
<td>tCO2-e per annum</td>
</tr>
<tr>
<td></td>
<td>For transport modes</td>
<td>tCO2-e per vehicle type</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per vehicle type per annum</td>
<td>tCO2-e per vehicle type per annum</td>
</tr>
<tr>
<td></td>
<td>For occupancy</td>
<td>tCO2-e per capita, tCO2-e per household</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per capita per annum, tCO2-e per household per annum</td>
<td></td>
</tr>
<tr>
<td><strong>Carbon Offsets</strong></td>
<td>For the whole precinct</td>
<td>tCO2-e</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per annum</td>
<td>tCO2-e per annum</td>
</tr>
<tr>
<td></td>
<td>For occupancy</td>
<td>tCO2-e per capita, tCO2-e per household</td>
</tr>
<tr>
<td></td>
<td>tCO2-e per capita per annum, tCO2-e per household per annum</td>
<td></td>
</tr>
</tbody>
</table>
The assessment process in PCA for energy generation and carbon offsetting is illustrated in Figure 5.5, while Figure 5.6 shows an example of the customised reporting capabilities of the PCA tool.

Figure 5.5: PCA renewable energy generation and carbon offsetting assessment
Figure 5.6: Customised reporting in PCA (including numerical and graphical results output)

References


5A. Scenario Analysis for Low Carbon Densification of a Residential Precinct

Ke Xing, Bin Huang and Stephen Pullen, University of South Australia

5A.1 Outline and Rationale

This use study demonstrates how the PCA tool developed from the Integrated Carbon Metrics project [RP2007] can be applied to analyse solutions for a greyfield urban infill precinct (re)development directed towards a low carbon/carbon neutral target. In this study, an established low-density residential suburb is a candidate for densification with new medium-density dwelling types introduced to cater for projected population increase and associated demand for housing. The challenge for precinct planning is to have the (re)development meet a set of functional needs and carbon reduction simultaneously (with more occupants, dwellings and activities).

The PCA tool provides decision support for the precinct (re)development assessment, considering building types, infrastructure (energy, transport, water and waste), travel modes, local renewable energy generation, and land use pattern and demographic characteristics of occupants. The tool can explore different scenarios about how and to what extent a low carbon outcome can be achieved within the context of a particular precinct.

5A.2 Data and Inputs

The precinct selected for this study, Andrews Farm, is 30 km north of Adelaide’s CBD. It represents a typical outer residential suburb that can be found in any Australian city. Based on 2011 Census data, the precinct had a population of 7197, with 48.6% of the occupants being less than 25 years old. There were 2034 dwellings within the 273-hectare precinct, which were predominantly single-storey, detached houses. In this study, it is anticipated the precinct’s population will grow 15%. This will require subdivision of land, replacing some existing low-density dwellings with medium-density dwellings, and adding 680 new townhouses (two-storey, semi-detached) as part of the densification process. It will increase transport activity and infrastructure for essential services.

In addition to the precinct attributes (e.g. location, land use, climate zone, local albedo) and the characteristics of the occupants (e.g. population size, age groups, employment status), the key parameters required for modelling and analysis in this use study include the type and number of buildings and infrastructure, total footprint of each building/infrastructure type (in m² or km), average daily travel distance of each transport mode use (in km per capita), and PV capacity installed (in kWp per dwelling/household).

For planning purposes, the options for achieving low carbon outcomes for this development are: 1) highly energy-efficient buildings (7-star rating equivalent assumed); 2) precinct scale renewable energy system deployment (increase of roof-top PV installation to 90% with an average of 5kWp per household assumed); and 3) change of occupants’ travel mode choice to low-carbon transport for commuting (increased use of public transport by 35% with an average of 30km per round trip per day assumed). Two main scenarios are examined for the carbon reduction potential in comparison with the current ‘Baseline’– Scenario 1 (based on Option 1) and Scenario 2 (with a combination of Options 1-3).
5A.3 Outputs, Findings and Implications

By using the PCA tool for modelling and scenario analysis, it was found that the total carbon emissions from the current precinct (i.e. the ‘Baseline’ scenario) were assessed as $3243.1 \times 10^3$ tCO$_2$e over 60 years or $54.1 \times 10^3$ tCO$_2$e per annum, including $775$ tCO$_2$e per annum of onsite offsetting from rooftop PV.

Table 5.3 summarises the comparison among different scenarios in their carbon signatures.

<table>
<thead>
<tr>
<th>Carbon Measure</th>
<th>Baseline (in tCO$_2$e)</th>
<th>Scenario 1 (in tCO$_2$e)</th>
<th>Scenario 2 (in tCO$_2$e)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per annum</td>
<td>per capita</td>
<td>per annum</td>
</tr>
<tr>
<td>Embodied Carbon</td>
<td>$14.9 \times 10^3$</td>
<td>2.1</td>
<td>$18.2 \times 10^3$</td>
</tr>
<tr>
<td>Operational Carbon</td>
<td>$21.7 \times 10^3$</td>
<td>3.0</td>
<td>$25.7 \times 10^3$</td>
</tr>
<tr>
<td>Transport Carbon</td>
<td>$18.2 \times 10^3$</td>
<td>2.5</td>
<td>$19.1 \times 10^3$</td>
</tr>
<tr>
<td>Carbon Offsetting</td>
<td>-775.0</td>
<td>-0.1</td>
<td>-989.4</td>
</tr>
<tr>
<td>Total Carbon</td>
<td>$54.1 \times 10^3$</td>
<td>7.5</td>
<td>$62.1 \times 10^3$</td>
</tr>
</tbody>
</table>

It shows the carbon signature of Scenario 1 increases by $8.0 \times 10^3$ tCO$_2$e per annum, despite new dwellings being more energy efficient. This is mainly due to the increased embodied carbon (more houses and expanded infrastructure) and operational carbon (more energy use by occupants and more services for water and waste management), up 22% and 18%, respectively. Consequently, these also result in a slight increase of carbon per capita, while Scenario 1 includes a 15% population growth. As the demographical changes anticipated are in forms of more small households with young children, it contributes to a marginal increase of total transport carbon and a slight decrease of transport carbon per capita.

Meanwhile, Scenario 2 presents potential for a significant reduction in total carbon, i.e. $3.3 \times 10^3$ tCO$_2$e, or 6%, less than the ‘Baseline’, which can be attributed to onsite offset from a large increase of precinct-scale PV deployment and more uptake of public transport for commuting, as illustrated in Figure 5.7 below.
The study findings can provide some insights for low-carbon urban renewal of residential precincts. Firstly, it is clear that population increase will have a major impact on a precinct’s total carbon signature due to increased housing, travel and services. Secondly, increasing the provision of high energy-efficient houses to reduce operational energy alone has a limited effect on carbon reduction, especially when used as infill in greyfield development and urban densification. In the meantime, the contribution of embodied carbon to the total carbon can rise significantly when infrastructure, especially transport infrastructure (e.g. roads, driveways, paths and pavements), is considered in the assessment.

Thirdly, transport emissions represent a very large part of a precinct’s carbon signature and can be as much as operational carbon, particularly for outer suburbs (as shown in this study). Encouraging and helping occupants to adopt carbon-efficient travel modes for commuting can be the most effective way of reducing transport carbon, which underscores the importance of Transit-Oriented Development (TOD) and more incentives for the uptake of electric vehicles in urban planning.

Furthermore, the effect of solar PV on carbon abatement is not as powerful as expected (e.g. contributing an 8.5% reduction with a 90% uptake rate). A precinct-scale deployment of renewable energy harvesting systems (with and without energy storage) needs to be strategically planned and analysed for carbon and economic effectiveness.

Overall, the application of the PCA tool in this use study demonstrates that there is no silver bullet when it comes to planning for a low-carbon precinct development. A combination of solutions for housing, infrastructure, travel and renewable energy is required to address all carbon measures (i.e. operational carbon, embodied carbon, transport carbon and carbon offsets) holistically.
Section 06

Precinct Infill Assessment

Stephen Glackin and Peter W. Newton, Swinburne University of Technology
6. Precinct Infill Assessment

6.1 Introduction

This project is focused on activating Greyfield Precinct Regeneration (GPR) as a viable process for land owners and municipalities to achieve more sustainable housing and land-use outcomes. Greyfield refers to areas where housing has reached the end of its life-cycle and is demolished and replaced with new housing. Precinct regeneration is where redevelopment occurs simultaneously on multiple lots (a precinct) and where there is some form of additional benefit provided to the community or local environment as part of the development (regeneration).

The core issue that the project aimed to address was the proliferation of knock-down-rebuild (Wiesel et al., 2013) as the main form of infill development in Australian cities. These developments are largely low on the radar of strategic planning governance, and while metropolitan authorities indicate the need for more infill housing (of the order of 60-80% of all new residential construction), small lot subdivision and KDR will not help to deliver this target.

Research (Newton and Glackin, 2014) has indicated that without strategic intervention, the current rate of infill will not be enough to tackle the ongoing urban sprawl of Australian cities and the attendant social, economic and environmental externalities (Trubka et. al, 2010). Precinct scale redevelopment and the higher densities that can occur on larger amalgamated lots has the capacity to significantly advance infill housing by optimising the land available for dwellings, and through the profits made on these larger precincts, provide additional infrastructure, environmental and community benefit, which cannot be achieved on smaller lot subdivisions. Greyfield precinct renewal is a new planning directive in Plan Melbourne 2017-2050 (Department of Environment, Land, Water and Planning, 2017).

However, precinct scale lot consolidation has its difficulties (Newton and Glackin 2017) and is yet to be implemented into a systematised, coherent and formal planning process. Before a model of Greyfield Precinct Regeneration can be initiated a number of challenges need to be overcome, namely where should these precincts be, who should be responsible for their implementation, and how should they be implemented.

This project and its predecessor in the CRCSI (Greening the Greyfields) address these complexities, illustrating the methodologies and instruments behind each of these development questions.

6.2 Objectives

The high level strategic outcomes of the project are to make greyfield precinct regeneration accessible to land-owners and municipalities in large, fast-growing cities. This entails far more than simply advocating for lot amalgamations at the municipal and parcel level. To advance the process beyond the academic forum, far more than proof of its benefit is required. A regeneration process needs to be risk managed and documented in a methodology that can be easily replicated across all cities.

This includes addressing the geographical context of a location and future development pathways (linked to strategic vision and plans); the redevelopment potential of established properties; the size of lots and their potential future function; community attitudes and the level of resistance to change; statutory tools that will enable precinct property owners to increase the dwelling density of their land holdings if they comply with the additional requirements of the precinct development (for example additional tree canopy, flood mitigation, greater walkability); the financial aspects, such as additional profits that can be made, and how they should be distributed; and outlining the commitment that precinct developers have to produce some form of
additionality; the range of contractual agreements (legal, financial) among landowners also needs to be addressed.

A range of tools and instruments need to be created to ensure that all aspects of the development process are dealt with effectively and can be implemented by stakeholders unfamiliar with the process.

The objectives of the project are as follows:

- **identification of potential precincts for redevelopment.** The project requires a tool that can illustrate the range of options to municipalities (and potentially landowners) so that the most prospective precincts can be located and that only land that has a reasonably high redevelopment potential be included. This involved the creation of the ENVISION tool.

- **demonstration of precinct redevelopment benefits.** Another critical aspect for precinct regeneration is presenting the range of potential outcomes to relevant authorities and landowners. Envision Scenario Planner (ESP) was developed to achieve this.

- **formal municipal uptake.** For a GPR project to be initiated, it needs to be fully endorsed by a land-use authority (typically a municipal government), that is, taken up as a statutory planning process. For this to happen there needs to be:
  - Pathways for statutory change and introduction of a new planning scheme
  - Formal planning processes specified for precinct planning to be developed and gazetted
  - Community and local government engagement processes regarding the forms of precinct additionality needed in each potential precinct to achieve planning approval via a modification to the local planning scheme for such areas.

- **engagement methodologies.** This relates to the range of methods required to engage landowners at the macro (mainstream media, municipal public relations) and micro (individual landowner group or neighbourhood) levels; as well as the risk mitigation exercises required to realise a new planning scheme. These methodologies include:
  - Political engagement strategies to inform key stakeholders and de-risk the process for local government councillors and state government ministers
  - Effective media campaigns
  - Effective processes for engaging and informing residents
  - A set of validated instruments to engage with landowners, specifically the legal, financial, design and project management tools that will advance the project, and that need to be available for use in “kitchen table” meetings of neighbours
  - A trusted broker for resident engagement.
6.3 Schematic Representation and Description of Tool

ENVISION is an online tool for identifying potential regeneration precincts. It has three features:

- multi-criteria analysis (MCA), which allows users to select the features that are important for locating precincts and weighting their significance
- a precinct identification tool that allows users to query housing stock in relation to such features as the redevelopment potential, distance to services etc., producing maps that identify where precincts are viable (in terms of identifying attributes of adjacent housing), and
- a financial calculator that illustrates the cost of building specific housing typologies in the area as well as displaying the median sale price for existing dwellings of that type in the surrounding suburb (Glackin, 2013; Newton and Glackin, 2013).

The most challenging issue with ENVISION is managing the data behind it (which will be covered in the section below). The MCA feature offers users a range of socio-demographic and geospatial data to select from, which can be weighted and signed (+ or -) to show the significance of that field for the purposes of the analysis. The weights are summed, the selected values normalised to between zero and one, the values are then multiplied by its weight divided by the total weight of the query. The sum of these values is then given to the representative polygons as output. For example, if the SEIFA (socio-economic advantage/disadvantage) is selected with a weight of +5 and Age 0-19 is selected with a weight of +10, then output will identify areas that have high SEIFA and high numbers aged 0 to 19 years old, but the age category will be identified as twice as significant (See Figure 6.1, sub-image 2).

The precinct identification feature is a simple query builder. The interface shows all the variables, including property valuation, distance and zoning data. Users select criteria relevant to the problem and then set the threshold value of what they would like to see displayed, e.g. houses within 500m of a train station with a high redevelopment potential, and not in a flood zone. The tool queries only these data and presents output to users (See Figure 6.1, sub-image 3).

The costing tool takes the cost of developing specific housing typologies from Rawlinson's Construction guide (Rawlinsons, 2017) adds this to the value of the land, and estimates the cost of developing those dwellings. Users can compare this to the median sale price for similar types of property in the suburb, which is sourced from property sales data linked to the suburb the user is exploring.
Figure 6.1: Envision workflow

1. Select research area
2. Run MCE
3. Identify precincts
4. Run feasibility
ENVISION SCENARIO PLANNER (ESP) is the second tool used in the greyfield precinct redevelopment project, and builds on output from the first. ESP (Glackin et al., 2016) was designed to allow for quick sketch-up scenario design assessment of a precinct, by selecting and placing pre-assessed housing typologies onto a virtual globe. Initially programmed in Cesium (a full virtual 3D globe), it now uses Mapbox (a 2.5D API) to generate a viewing window out of a shape file exported from ENVISION (the shape file being the identified precinct). Users can then amalgamate or subdivide lots, change the land use (to residential, public space, commercial and so forth) and then populate the lots with a range of housing typologies. These housing typologies range from detached dwellings to high-rise blocks of units and have been assessed with ‘basic’, ‘efficient’ and ‘advanced’ materials and designs (see Input and Data Sources section). Users can then access a range of dwelling and precinct metrics associated with the ‘performance’ of the precinct. Figure 6.2 illustrates the initial and final outcomes of a precinct design assessment exercise.

Figure 6.2: ESP workflow
6.4 Engagement

The final phase of the project involves engagement with multiple stakeholders in the precinct regeneration process and draws on multi-disciplinary inputs (social sciences, architecture, planning, economics, property development etc.). It also requires significant technical ability to produce a tool kit and set of instruments and processes to enable political buy-in, statutory change, feasibility assessment and community engagement, all of which activate the above software packages and begin to implement change. Figure 6.3 simplifies this complexity by illustrating the interaction between the governance/planning and engagement aspects of the method.

![Figure 6.3: Methodology of the governance and engagement toolkit, indicating the processes, sub processes and documents produced, all of which lead to landowner engagement.](image)

The top right of the diagram encapsulates the risk mitigation and political management of critical stakeholders that needs to be undertaken throughout, but initially to realise the project as a potential policy response for a municipality and state government charged with the responsibility of future strategic planning and the associated task of identifying areas that are potential candidates for area/precinct renewal.
The next element is design, which comes in two forms. The first form will eventually lead to the development of a new planning scheme; the second will be used in community engagement to show the development options available to landowners.

The first form of design will include the precinct additionality sought from the redevelopment (e.g. improved walkability and stormwater management), which will, through a viability analysis of the cost of this additionality, largely define the required massing of the precinct. In this GPR model, the expectation is that the cost of precinct additionalities should be covered by development (or developer) contributions enabled by greater densities and profits.

The massing will therefore inform a new planning scheme. Once the scheme is established as a legal land-use tool, there is an opportunity to engage with landowners about realistic options for more intensified redevelopment of their land. Due to the political sensitivities associated with land-use change, a communications package needs to be developed that identifies all stakeholders and how to best engage with them. This will be both at a macro level (mainstream media, municipal public relations, “town hall” meetings) and a micro level (the specifics of internal municipal planning process and intimate “kitchen table” style engagements among property owning neighbours). The “kitchen table” style engagements require a further range of tools, including the legal instruments and processes for the various methods of lot consolidation, basic feasibility analysis, some design and development options, and a formally established internal municipal policy and design guidelines, allowing landowners to follow through with the planning process to initiate the precinct project.

6.5 Scope of Application

The key issues that these tools address relate to sustainable, low-carbon regenerative development outcomes. Firstly, promoting the uptake of precinct scale redevelopment provides the prospect for reducing future urban sprawl by allowing land to be optimised in larger lots enabling greater densities to be achieved.

Secondly, the economies of scale that precincts create generates additional housing and community benefits, such as higher energy- and water-rated housing and additional hard or soft infrastructure for the surrounding community, which could not be achieved in a KDR. Specifically, and as related to each tool, the geographic and functional coverage is as follows:

ENVISION: Currently has data for Greater Melbourne, Perth and Christchurch (NZ). There is also pilot data for NSW, in the form of entire coverage for the City of Blacktown. ENVISION is currently used in two Victorian councils, Maroondah and Knox (refer to use case).

ENVISION SCENARIO PLANNER: ESP is being trailed in Maroondah City to help planners identify the sustainability metrics of business-as-usual redevelopment versus precinct scale regenerative redevelopment. The outcomes from this analysis will, in conjunction with the Victorian Built Environment Sustainability Scorecard, provide indicators for the level of environmentally sustainable design that a precinct must demonstrate. Both Maroondah and Knox municipalities, as well as Blacktown in NSW, have received training in ESP, and all are using ESP for precinct design assessment.

A Governance and engagement toolkit has been developed in Maroondah and is being trialled in Knox and Blacktown councils, to ensure broad applicability. A GPR ‘playbook’ and associated manuals and design guides are core outputs from this project.
6.6 Input Data and Sources

ENVISION: The dataset for ENVISION includes the following datasets:
- metropolitan cadastre data sets, typically public, but in some jurisdictions it has been commercialised (e.g. SA)
- metropolitan property valuations sourced from the Valuer-General of each state (or municipal government for localised roll-out)
- Government-owned land (Federal, state, various housing/service organisations)
- Locational data from public “feature of interest” shape files
- Socio-demographic data (ABS census)
- Cost of building and construction from Rawlinson’s construction manual
- Flood, environment and land-use data from public land-use records.

ESP: All data for ESP comes from CSIRO’s AccuRate housing energy rating software, and from some internally generated algorithms. Inputs to AccuRate are exhaustive libraries of construction elements and materials. AccuRate allows users to construct a virtual (though non-visual) dwelling by applying these construction elements and materials to the zones and rooms of a dwelling. When run in assessment mode AccuRate can assess:
- energy (electricity/gas) use for heating, cooling and lighting (based on climate zone, conditioned area and building orientation)
- energy use for appliances and water heating (based on occupants)
- embodied and operating CO2
- stormwater runoff (based on roof size and climate zone)
- internal and external water use.

Additional algorithms were created to:
- enable stormwater run-off calculations to take the porosity of the surrounding open space into account for the entire lot and precinct
- generate costing and CO2 assessments for roads and paths
- estimate the number of trips associated with a precinct
- assess the number of jobs created within the precinct associated with mixed-use redevelopment by applying indicative job numbers to non-residential typologies, and
- cost buildings from Rawlinson’s construction guide.

Governance and engagement toolkit: The vast majority of data is qualitatively derived from government officers, public policies, community members, property and planning lawyers and local developers. Quantitative data for feasibility and valuations data is also required. More explicitly, this data pertains to:
- the range of statutory tools available to planners to implement precincts, and how they might be altered to accommodate various developments and contexts
- communications solutions, to inform relevant stakeholders and also to de-risk the process (politically and economically)
- the range of engagement solutions for landowners so the project becomes accessible to them
- planning solutions for municipalities, to provide landowners with a formal passage through the planning process
• design guides for precincts, to assist with the statutory proposals and provide a basis for the feasibility assessments

• feasibility assessments for new dwellings and the precinct additionality.

6.7 Key Outputs and Performance Measures/Indicators

ENVISION: As Envision is primarily a GIS tool, maps are its major output, which can be downloaded as shapefiles. Other than by visual inspection there is no way to currently assess or compare these shape files within the tool.

ESP: Allows for precincts to be compared, where the output and the comparison data consists of the following (see Figure 6.4 for details):

• summary data: total precinct area, total building area, total pathway length, total residents, total jobs (including non-residential typologies), dwelling density, population density and net population increase

• environmental impacts per inhabitant: energy demand, water demand, embodied carbon, operating carbon. All can be obtained from AccuRate assessments

• economic impact: total cost of property construction, total operating cost, total number of services created, business created. Derived from AccuRate calculations and Rawlinsons construction data

• amenities per inhabitant: open space, commercial space, institutional space, trees, parking spaces. Derived from the design of the precinct and the population of the precinct with the range of typologies currently available

• energy: total operating energy demand, total PV generation, operating energy demand per inhabitant, total co-gen energy used. All are derived from AccuRate software application to a particular urban precinct design

• CO2: total embodied CO2, total CO2 sequestration, breakdown by surfaces, material and parking

• water use per inhabitant, total water demand, total water captured, stormwater runoff.
I. Built environment

<table>
<thead>
<tr>
<th></th>
<th>II. Socio-economic outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total site area</td>
<td>Operating and Property costs:</td>
</tr>
<tr>
<td>Total site area for redevelopment</td>
<td>- Total operating costs (use) $/year</td>
</tr>
<tr>
<td>Total buildings footprint</td>
<td>- Operating costs (demand) $/year</td>
</tr>
<tr>
<td>Number of dwellings</td>
<td>- Surplus - Energy generated $/year</td>
</tr>
<tr>
<td>Dwelling density (total area)</td>
<td>- Total operating costs per inhabitant $/year/p</td>
</tr>
<tr>
<td>Population density</td>
<td>Social benefits:</td>
</tr>
<tr>
<td>Job density</td>
<td>- Total number of residents P</td>
</tr>
<tr>
<td>Open space</td>
<td>- Total number of jobs N</td>
</tr>
<tr>
<td>Commercial GFA</td>
<td>- Jobs per inhabitant jobs/p</td>
</tr>
<tr>
<td>Institutional GFA</td>
<td>- Open space per inhabitant m2/p</td>
</tr>
<tr>
<td>Trees</td>
<td>- Commercial GFA per inhabitant m2/p</td>
</tr>
<tr>
<td>Parking spaces</td>
<td>- Institutional GFA per inhabitant m2/p</td>
</tr>
<tr>
<td></td>
<td>- Trees per inhabitant n/p</td>
</tr>
</tbody>
</table>

II. Environmental outcomes

|                        | - Parking spaces per inhabitant n/p |

Energetic outcomes:

- Total operating energy use MJ/year
- Total operating energy demand MJ/year
- Total PV energy generation MJ/year Vehicle Kilometres Travelled (VKT):
- Operating energy per inhabitant MJ/year/p
- Total Embodied CO2 kgCO2e
- Total greenhouse gas emissions kgCO2e/y
- Total Embodied CO2 / inhabitant KgCO2e/p
- Total annual trips trips/year
- Total operating CO2 kgCO2e/y Mode Share:
- Operating CO2 per inhabitant kgCO2e/y/p
- Total Car as Driver trips trips/year

Water management:

- Total potable water use kL/year
- Total Transit trips trips/year
- Total water demand kL/year
- Total Active trips trips/year
- Total water captured kL/year
- Water use per inhabitant kL/year/p
- % water from renewables %
- Stormwater runoff (buildings) L/second
- Stormwater runoff (pathways) L/second

Figure 6.4: A selection of variables assessed in an ESP scenario

6.8 Governance and engagement toolkit

The outputs of the toolkit include:

- methods for establishing the policy aims of regeneration precincts within a municipality, including workshop details and expected outcomes at each stage of the Whole-of-government processes
- guidelines for precinct design and methods for precinct assessment
- design guides for precinct housing and streetscape typologies and replicable issue-specific precinct objectives (flood mitigation, canopy tree coverage, street activation, affordable housing target etc.)
- guidelines and tools for feasibility assessment, including precinct additionality
- templates for developing community communication and media strategies
- guidelines to develop internal (municipal) planning processes and their integration with state planning authorities
- comprehensive engagement methodology, including legal and financial options for landowners
- worked examples of the toolkit application.
References


6A. Identifying Precincts with High Redevelopment Potential

Steven Glackin and Peter W. Newton, Swinburne University of Technology

6A.1 Outline and Rationale

*Greening the Greyfields* was a project funded by the CRCSP (2012-18) with the objective of developing two software tools. The first was a multi-criteria spatial analytics model for identifying the most prospective set of contiguous residential properties with high redevelopment potential in the established, ageing middle suburbs of Australian cities for precinct scale regeneration. The second was a software tool to assess the design performance of a medium-density redevelopment that would provide output data on dwelling yield, financial feasibility and the additional neighbourhood benefits that could be designed-in to a project at precinct scale, compared with single-lot subdivision and KDR.

With the development of these two spatial tools, and Greyfield Precinct Renewal being introduced as a new Policy Directive in Plan Melbourne 2017-2050, funding from CRCLCL [RP3034 Community Co-Design] and a Federal Smart Cities and Suburbs grant, it was possible to move towards implementation. Pilot greyfield renewal precincts needed to be identified in collaborating municipalities (City of Maroondah in Melbourne and Blacktown in Sydney). This was so that supportive statutory land-use planning legislation and development overlays could be established for these areas and a targeted communications and engagement plan developed for property owners.

Given that these would be the first precincts implemented, it was deemed necessary to identify dwellings in areas that were close to shops, public transport, and primary schools (for walkability), and had a high concentration of dwellings with a high redevelopment potential to ensure that the pilot areas would have uptake.

This use case illustrates one iteration of this precinct identification process, which is being further advanced through community engagement and municipal workshops with relevant officers and management to be followed by resident engagement.

6A.2 Data and Inputs

The precinct identified in this use case was in Maroondah, an established middle-ring suburb of Melbourne, 20km east of the CBD. This area has a high concentration of ageing detached housing and residents who were expected to resist development because of concerns about loss of trees and how this would alter the area’s character. To ensure the policies for precinct formation had a significant opportunity of uptake, precincts needed to incorporate areas of roughly 20 hectares (200,000 m²) or approximately 300 dwellings (dependent on the scale of redevelopment), acknowledging that not all dwellings would be part of the final precinct/project.
The full range of ENVISION data required for analysis included local social and demographic data on households provided by the ABS, property data on land dimensions and dwelling valuations that would enable calculation of the redevelopment potential of each parcel (ratio of land value to capital improved value), distance measures for each property from an activity centre, and/or a strip of shops, and public transport and schools.

6A.3 Outputs, Findings and Implications

Figure 6.5 provides an example of one of a range of options presented to municipal officers of precincts containing a significant number of contiguous properties with high redevelopment potential, and (in this instance) with good walking access to local shops.

Figure 6.5: Dwellings close to shops and services with high redevelopment potential
After presenting a range of options to officers, and based on their strategic development priorities for the municipality and incorporation of local infrastructure challenges (e.g., in this instance related to local flood mitigation), one precinct was selected for further investigation and more detailed urban design (Figure 6.6).

Figure 6.6: A pilot precinct in Maroondah
This pilot precinct has been endorsed by municipal councillors and is now the focus of more detailed urban redesign (Figure 6.7) in preparation for public engagements.

Figure 6.7: Precinct redevelopment options – KDR versus precinct regeneration

References


6B.  Precinct Design Assessment with Envision Scenario Planner

Stephen Glackin and Peter Newton, Swinburne University of Technology

6B.1  Outline and Rationale

One of the objectives of precinct scale regeneration in the established low density greyfield suburbs is the creation of new land-use and urban design configurations that optimise the redevelopment opportunities offered by lot amalgamation beyond that of single lot residential subdivision typical of KDR.

To determine the benefits of precinct scale medium density redevelopment (what can be defined as the ‘missing middle’ – medium density housing and precinct scale projects), which will allow local government planners to determine the level of precinct additionality delivered by the project, ESP can be used to assess the performance of a particular precinct design, beginning with the simple block massing of a prospective precinct.

ESP has a range of pre-assessed archetypal dwelling typologies (Department of Industry, 2013) that can be inserted into a sketch design for the precinct to enable preliminary performance assessment (on a set of attributes listed below). These can be replaced by more detailed bespoke precinct housing designs, if available. This provides the basis on which municipal officers can see if a proposed higher density development can deliver additional benefits to the local community beyond dwelling yield – which established neighbourhoods in Australian cities tend to resist. For example, can additional profits from higher densities be used as developer contributions that improve local amenities (e.g. gifting land parcels adjoining an existing park or creating pocket parks for social and environmental benefit)?

6B.2  Data and Inputs

- The case study was a precinct to the north of a major activity centre in the City of Maroondah, a middle-ring municipality 25km east of Melbourne. The site has a significant slope, draining to the south and is immediately adjacent to a freeway and the Ringwood activity centre. It is assessed for the financial benefits of introducing higher density (3-4 storeys) to provide for a potential developer contribution of three land parcels to augment an existing park within the precinct and assist with stormwater management.

- The site was 13.4 hectares, comprising 324 existing residential property parcels.

- The analysis required a shapefile of the precinct (which was derived from the ENVISION tool). All other inputs (housing typologies) were contained within the residential, non-residential and precinct object typologies within the ESP software. These typologies comprise data relating to the performance of each typology: energy performance, water use, carbon emissions, built form metrics and other data points referred to in the Methods section.

- In the first development scenario, a baseline was established for business-as-usual redevelopment. Only land parcels that were identified as having redevelopment potential (from ENVISION) were used in the analysis. The scenario involved populating the precinct with a 2-for-1 KDR model where a single house became two dwellings with a side driveway, effectively doubling the housing density (see Figure 6.8). These housing typologies did not exceed two storeys and were almost exclusively detached.
• The second development scenario involved testing the performance of medium-density dwellings by populating the land parcels with two, three and four storey dwellings, all of which shared at least one wall with another dwelling (see Figure 6.9). Although ESP allows for the addition of PVs and other additional sustainability features to ensure that only the massing and density were assessed, no additional sustainability features were added to the precinct for this analysis.

6A.3 Outputs, Findings and Implications

Outputs from the precinct scenario assessments detailed above allowed the following comparisons of performance:

• while using less land, the precinct design resulted in an increase in dwelling density from 10.4 to 34.98 dwellings/hectare, and an increase in population density from 37.3 to 96.36 persons per hectare
• energy demand dropped marginally from 7531 to 7042 MJ/year/occupant, all of which related to the built form and orientation, since no sustainability or efficiency measures were added to the precinct’s typologies
• embodied CO2 increased (because of provision of underground parking) from 6503 to 8377 KgCO2e for the development project
• operating carbon dropped from 8625 to 7634 KgCO2e as a result of reduced heating and cooling costs, which was related purely to thermal benefits of greater massing in the built form
• water use dropped from 74 to 52KL/year/occupant due to reduced demand in higher housing densities (lower amount and more efficient use of private open space)
• energy for heating fell by 60%, although energy for appliances increased by 25%, because of better thermal performance of greater massing and the higher population densities of the precinct.

Findings:

• even with no additional sustainability features (beyond current building regulations), medium density living generates better environmental outcomes
• density increases (as modelled) have the capacity to pay for the precinct additionalities tested in this scenario (depending on where profit-taking takes place)
• medium density can reduce stormwater run-off if appropriately planned for
• though minimal building height changes were introduced (a maximum of 5 stories at the south of the precinct) they were sufficient to make the precinct more viable from the perspective of yield and additionalities sought by the municipality.

Due to these analyses (and other scenarios not reported here), council will propose new statutory planning legislation (local planning scheme, development overlay) that promotes medium density redevelopment for selected precincts within the municipality.
Figure 6.8: Business-as-usual redevelopment pattern, assuming all lots with high redevelopment potential are redeveloped as knock-down-rebuild

Figure 6.9: Precinct scale redevelopment allowing greater heights in return for enabling addition to the existing park and providing improved drainage through the precinct

References


Section 07

Forecasting Demand for Precinct Energy, Transport, Water and Waste

Michael A. P. Taylor, University of South Australia, Nicholas M. Holyoak, Flinders University, Michalis Hadjikakou, Deakin University and Steven Percy, Victoria University
7. Forecasting Demand for Precinct Energy, Transport, Water and Waste

7.1 Introduction

New and existing precinct developments require estimates of future demand for informed/evidence-based infrastructure planning, allowing the appropriate levels of service to be provided to the precinct. This allows for an effective operation of the precinct at minimum environmental impact.

The four primary domains for infrastructure provision in precincts are energy, transport, waste and water (ETWW). There are established forecasting methods available for each of these domains, but these are generally applied for each domain independently of the others, often by different agencies and their consultants who may only be interested in specific aspects of the infrastructure.

However, these methods generally require much the same inputs for their application, suggesting that an integrated approach in which demand forecasts are made simultaneously for the domains should have productivity benefits. Further, the integrated approach allows for considerations of potential interactions between the demands across the domains. Interactions between infrastructure systems are now known to be a significant challenge and concern in urban systems planning and management (e.g. Taylor 2017).

CRCLCL funded project [RP2002] with the objective of developing an integrated demand forecasting tool capable of considering household and other land use carbon emissions across the infrastructure domains. Furthermore, the research studied the trade-offs and interactions between the domains from different low carbon initiatives in infrastructure planning at the precinct scale.

7.2 Objectives

The research project had the following objectives:

- deliver a method for the simultaneous estimation of the demands for energy consumption, travel, water consumption and waste disposal facilities by households in residential areas of Australian cities
- implement the method as a software tool for planners and developers
- represent the impacts of behaviour change by households in the tool
- allow planners and developers to assess the total demands for ETWW in the planning, design and evaluation of residential developments, including their carbon impacts.

7.3 Schematic Representation and Description of Tool

Operation of the ETWW tool involves the definition of precinct variables, internal and external routines, data management and display environments and output summary types.

Figure 7.1 provides a flowchart for the operation of the tool. Research conducted in the individual domains has provided much of the model ‘engine’ with integration between domains and feedback processing loops. A GIS environment is used for data management, processing and display purposes associated with input and output data archives, including the final demand and carbon impact results. In the future, PIM could replace or augment the GIS environment, and provide connectivity with other CRCLCL research.
The ETWW tool currently functions through an Excel spreadsheet, with links to external software packages for domain-specific calculations. There are six phases in the use of the ETWW tool, as shown in Figure 7.1: (1) scenario development; (2) input data definitions; (3) preliminary data analysis and processing; (4) domain modelling and domain-specific outputs; (5) collective output collation, and (6) carbon impact estimation.

**Scenario definitions** are the first step in the ETWW tool operation with a requirement for details on the precinct ‘concept’ including dwelling types, density and household types expected, with other land uses for education, retail, commercial, public space etc. Physical attributes of the precinct with respect to support infrastructure, the boundary definition or size of the precinct and location within Australia are required in preparation for the development of detailed input data sets. Assembly of scenario components in a GIS environment is the first stage of this data accumulation. Alternative development scenarios are formulated in this phase by the project development team, for analysis and comparison, and possibly refinement, using the tool.

**Input data** sets are constructed for all precinct forecast scenarios, as required by all of the forecasting domains. Some core inputs (such as the number of dwellings, dwelling type and household size) have multiple domain applications, while some data may be specific to individual domains (such as the transport network configuration). Most attention is paid to defining household types in detail with other inputs for non-household related land uses that are regarded as precinct structure elements such as green space and retail and commercial land uses. Timing components including the forecast year/s, the season and forecast period (which may be a day or a peak period during the day) are defined. The tool has adopted the household typology for the Mosaic household database developed by Experian (2018). Dwelling types relate to the physical attributes of the residence including structure type, number of bedrooms and solar generation capacity.

**Preliminary analysis** involves simple internal models in the spreadsheet, mainly for the purpose of data preparation or support procedures for the detailed domain modelling applications. Simplified calculations that add to domain-specific forecasting routines include those associated with non-residential land use estimations and data formatting with processes such as the application of linear regression equations or factor matrices. Much of the preliminary modelling thus occurs before the domain modelling processes which are more detailed in nature and can rely on external software and analytics to complete the modelling functions.
Domain modelling then generates demand forecasts for each domain. The forecast demands are then collated and assembled as precinct consumption and production estimates. Again, given that the integrated demand model is primarily designed for residential precincts, the focus is on the households, and household types with other land use accounted for using simplified approaches.

The specific domain forecasting models are for:

- energy demand – demand forecast process combined with a microgrid design model
- transport demand – macro and nano-scale modelling approaches for external and internal precinct-travel respectively, using a Strategic Transportation Model (STM) and a person-oriented (nano-scale) model. (Macro-level transport models deal with wide areas such as a metropolitan area or region, and are applied to daily travel demands with variations in demand by time of day). Micro-level models apply to the movements of individual vehicles in a relatively small area (e.g. a precinct and its environs) and over time periods of a few hours. Nano models are cast at the same scale as micro models but model the movement of individuals using the vehicles, and therefore can track to door-to-door movements of individuals including walking, waiting for public transport, and riding in a vehicle
- waste production – regression and factor analysis based forecasts
- water demand forecasting using a linear mixed modelling approach.

The computational system for the ETWW spreadsheet-based forecasting routines is illustrated in Figure 7.2. This figure shows the preliminary analysis (conducted in the spreadsheet) and the linkages to external software modules used in the domain-specific analysis. Waste demand/production forecasts are modelled within the spreadsheet, while external modules are used for the other domains. A GIS software environment is used to manage the input data for the precinct as well as in the spatial analysis and presentation of output data generated by the tool.

![Figure 7.2: Modelling and analysis in the ETWW tool spreadsheet and connections to external domain-specific software packages](image-url)
It is worth noting that the external models can be applied independently for each domain however the real benefit in terms of forecasting ability and accuracy is gained when integration between the model forecasts is achieved.

The collective outputs are collated within the ETWW spreadsheet from domain-specific modules to define the consumption and production or overall demand profile of the precinct. The ETWW tool then specifies the relationships that can potentially exist between the domains with relationships within the precinct demand forecasts. The domain interaction options built into the ETWW tool are listed in Table 7.1.

<table>
<thead>
<tr>
<th>Scenario Interaction Option</th>
<th>Interacting Domains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicle ownership and use</td>
<td>Transport – Energy</td>
</tr>
<tr>
<td>Hot water use</td>
<td>Water – Energy</td>
</tr>
<tr>
<td>Evaporative cooling</td>
<td>Water – Energy</td>
</tr>
<tr>
<td>Rainwater tank water use</td>
<td>Water – Energy</td>
</tr>
<tr>
<td>Wastewater</td>
<td>Waste – Water</td>
</tr>
<tr>
<td>Activities from home</td>
<td>All Domains</td>
</tr>
<tr>
<td>Water consumption behaviour</td>
<td>Water – Energy</td>
</tr>
<tr>
<td>Recycling behaviour</td>
<td>Waste – Transport – Energy</td>
</tr>
<tr>
<td>Water supply</td>
<td>Water – Energy</td>
</tr>
<tr>
<td>Waste removal</td>
<td>Waste – Transport</td>
</tr>
<tr>
<td>Energy use behaviour</td>
<td>Energy</td>
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<td>Solar panels</td>
<td>Energy</td>
</tr>
<tr>
<td>Battery storage</td>
<td>Energy</td>
</tr>
<tr>
<td>Grid energy generation</td>
<td>All Domains</td>
</tr>
</tbody>
</table>

In addition to the scenario interaction types, the structure and development of domain modelling routines allows for the representation of the following technologies and attributes of precinct design and layout, both at the household and precinct scale:

- solar electricity generation technology
- battery electricity storage technology
- various household energy-efficient devices
- supply of energy from renewable resources
- household water capture and re-use
- various household water saving devices
- alternative hot water systems
- water-efficient green spaces at dwelling allotment and precinct scales
- household recycling techniques and technologies
- public transport and non-motorised network alternatives, contained within and connecting to the precinct.
Other behavioural interactions resulting in domain demands and interactions that can be represented are:

- increased recycling behaviour
- reduced waste production behaviour
- increased work-from-home behaviour
- increased shop-from-home behaviour
- reduced water consumption behaviour
- reduced energy use behaviour
- reduced transport demand behaviour
- mode shift behaviour.

The ETWW tool processes the domain interactions with resulting changes to demands as may be required. An example of an interaction between the transport and energy domains is a household with an electric vehicle being charged onsite from the electricity network.

Transport demands that include the use of electric vehicles must first be established in order to estimate the electrical energy required to fully or partially charge the electric vehicle batteries required for a day’s travel. This additional energy requirement from the precinct household can then be incorporated into the energy demand model with the supply of this energy possible from mains, solar PV or battery storage. The revised demand profiles then bring about the need for model re-estimations, with updates of modelling inputs supplied by the feedback routine.

Data feedback processes between the collated output information sets allows for demand interactions and their influence to be incorporated in the forecasting process. Re-estimations of domain forecasts then account for the influence of other domains on consumption and production profiles to reflect scenario definitions. Following this process, final demand profiles can be submitted to carbon estimation routines.

For estimation of carbon impacts, the output datasets from each precinct scenario are collated within the ETWW tool from domain-specific routines to define the overall demand profile of the precinct (consumption and production). The ETWW model specifies the relationships that can potentially exist between the domains with relationships within the precinct demand forecasts, a process which is very much a result of the initial scenario specification. Carbon emission rates per unit activity for the alternative technologies employed in each scenario are then used to estimate carbon performance.

### 7.4 Scope of Application

The ETWW tool is designed to address the following key urban planning and design questions relating to precincts:

- integrated demand forecasts for ETWW infrastructure and services (including their interactions) for different configurations of the precinct, resident household types and domain technologies
- analysis of the operational and carbon performance of the physical layout and structure of a precinct
- potential impact of climate change (temperature and rainfall) on the carbon performance of a precinct for a chosen forecast year
- analysis of different residential population types (based on a typology of households) and their consumption or use of different infrastructure systems and services in a precinct, including the influences of dwelling type and density and the impacts of household behaviour change
while the tool has a focus on residential precincts, it accounts for other land uses, green space and precinct-scale infrastructure, thus allowing for its application to mixed-use precincts

- consideration of alternative behavioural, technological and policy-related options for alternative (re)development scenarios in a precinct

- estimation of the carbon impacts of alternative precinct scenarios, at the individual level, the household level and for the entire precinct, and comparisons between scenarios

- potential synergies and trade-offs in carbon performance due to domain-specific interventions.

In addition, the ETWW tool provides information on precinct structure, layout and performance that will facilitate the estimation of construction and operating costs for the alternative scenarios (e.g. different levels of provision of PV on dwelling rooftops, different resident household types, changes in household travel behaviour, including work-from-home and use of electric vehicles, capture and reuse of stormwater in the precinct, and increased recycling and reuse of solid wastes).

The tool in its current form can be applied to the following types of precincts: greenfield, brownfield, greyfield, residential, and mixed used (predominantly residential).

In terms of spatial scale, the ETWW tool can be applied at the following levels: individual streets or street sections, subdivision, and suburb.

The largest precinct area to which the ETWW tool has been applied to date is the Tonsley brownfields precinct in the south western suburbs of Adelaide (Holyoak et al., 2017). This site has a total area of 60 ha. While the focus on the development and use of the tool has been on the detailed study of residential precincts, the methods incorporated in it could be applied to other land uses, such as retail, commercial and education, given suitable inputs. In its current form, the tool can accommodate these land uses, but not at the same level of detail as for residential land use.

The ETWW tool is designed to address a wide range of scenarios, including a range of alternative technologies and systems for energy supply and distribution, transport/mobility, water use and wastewater disposal. It can accommodate alternative site land use layouts and configurations, as long as they can be adequately described on a spatial basis either in a GIS environment or by using PIM. The tool can also accommodate alternative precinct populations.

As indicated in Figure 7.2, the ETWW tool uses a set of sub-models to estimate the domain demands. These sub-models are held as external custom software modules created for the tool (Energy and Water), through a link, with tailored specifications for precinct application, to a commercial software package (Transport), and as internal routines within the ETWW spreadsheet (Waste). The modelling approaches used for each of the infrastructure domains are summarised in the ‘Technical details’ subsection, following the discussion on input data and key outputs for the ETWW tool. A full description of the ETWW tool and its application to two case studies is provided in the final report of the research project (see Holyoak et al., 2017).

7.5 Input Data and Sources

The basic data requirements for the tool are those that can be obtained from development Masterplans or similar specifications, which is in keeping with the intended use of the tool in scenario evaluation.

The site location and the spatial coverage of the precinct are core requirements. As well as indicating the basic size of the precinct (in terms of land area), the locational data are also required to ascertain the climate and consequent seasonal variations in temperature and rainfall. If information about potential climate change trends for the site are also available, this information can be used in the performance assessment of the
development scenarios. The base year and the planning horizon (resulting in a design year for performance assessment) are also required.

The basic parameters, which may be scenario-specific, are the proposed number of households for residential development and the proposed land use mix. Each scenario will then include specifications for residential density and housing types. Information on housing structures, including attributes such as the number of bedrooms, bathrooms, appliances, internal floor space, external space, and accommodation for vehicles, can be included. The researchers have found this information in both Masterplan documents and by looking at housing types currently being used or specified in the region, so providing a range of relevant types and specifications.

Other precinct structure elements to be included extend to other land uses, green space, road networks, street lighting, and in-precinct water retention and storage. The capacity for inclusion of renewable energy sources, especially solar panels, also needs to be considered.

The final data set is household typology. The ETWW tool uses household types and characteristics based on the Mosaic data structure (Experian, 2018). This structure provides for 49 household types, grouped into 13 clusters, and provides information on household size, composition, income and expenditure patterns (lifestyle clusters). The analyst selects a set of household types to occupy the precinct and the proportions of those household types, thus generating a synthetic residential population for the precinct. Different precinct scenarios may also have different resident populations.

7.6 Key Outputs and Performance Measures/Indicators

The primary outputs from the tool, for each scenario tested for a given precinct, are:

- the levels of demand for the four infrastructure domains
- the estimated carbon emissions for each scenario, including emissions associated with each infrastructure domain.

Carbon emissions are estimated using established and reported emissions rates per unit of activity for different technologies, e.g. electricity generation (rate expressed as CO₂-e kg/kWh for a given generation technology) and travel mode (rate expressed as CO₂-e kg/km for a given mode).

In addition, the data assembled for the study and the output demand levels can be used to assess the likely costs of the precinct development under the scenarios studied. This assessment needs to be carried out externally to the ETWW tool.

Demand levels and carbon emissions may be expressed as totals for the precinct and as rates per dwelling, per household and per capita. Transport/mobility levels are given as passenger-km of travel (PKT) by travel mode (time spent travelling and cost of travel are also available). Energy consumption is expressed in kilowatt-hours (kWh), and cost of energy and cost of solar and battery are given as $/kWh and $ respectively. Water consumption, hot water demand and rainfall yield are expressed in kilolitres (kL), waste is given as kg to landfill, mixed recyclable waste and green waste. Table 7.2 shows this list of performance indicators.
### Table 7.2: Basic performance measures and indicators from the ETWW tool

<table>
<thead>
<tr>
<th>Domain</th>
<th>Performance indicator</th>
<th>Base unit</th>
<th>Rates</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Energy consumption</td>
<td>kWh</td>
<td>kWh/hhld, kWh/person</td>
<td>Can include the source of electrical energy</td>
</tr>
<tr>
<td></td>
<td>Cost of energy</td>
<td>$/kWh or</td>
<td>$/kWh/hhld, $/kWh/person</td>
<td>This uses the cost of solar battery systems and grid used energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$ for the system lifetime</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost of solar and battery</td>
<td>$</td>
<td>$/hhld</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>Passenger-km of travel (PKT)</td>
<td>Person-km</td>
<td>PKT/hhld, PKT/person</td>
<td>For each travel mode (e.g. car driver, car passenger, public transport, bicycle, pedestrian) and (possibly) household type</td>
</tr>
<tr>
<td>Water</td>
<td>Total water demand</td>
<td>kL</td>
<td>kL/hhld, kL/person</td>
<td>Includes monthly profile</td>
</tr>
<tr>
<td></td>
<td>Hot water demand</td>
<td>kL</td>
<td>kL/hhld, kL/person</td>
<td>Includes monthly profile</td>
</tr>
<tr>
<td></td>
<td>Rainfall (water tank) yield</td>
<td>kL</td>
<td>kL/hhld, kL/person</td>
<td>Includes monthly profile</td>
</tr>
<tr>
<td>Waste</td>
<td>Landfill waste</td>
<td>kg</td>
<td>kg/hhld, kg/person</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mixed recyclable waste</td>
<td>kg</td>
<td>kg/hhld, kg/person</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green waste</td>
<td>kg</td>
<td>kg/hhld, kg/person</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>Total CO2 equivalents</td>
<td>kg CO₂-e</td>
<td>kg CO₂-e/hhld, kg CO₂-e/person</td>
<td>By household type and infrastructure domain</td>
</tr>
<tr>
<td>emissions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The key ETWW performance indicators are initially provided in spreadsheet format with summary statistics, which can then be incorporated into an appropriate GIS model. A spatial representation of the study area is required for this task with necessary linkages from data spreadsheet to map references and once this is achieved, mapping outputs can be produced using a range of GIS toolbox functionality. These are illustrated in the Use Studies for the ETWW project.

### 7.7 Technical Details

This section provides a summary description of the technical details of each of the domain-specific sub-models in ETWW. A full description of all of the sub-models, their usage and how they connect to the ETWW tool is given in Holyoak et al., (2017).
7.8 Energy demand

The residential energy sector has opportunities for emissions reduction through improved energy efficiency, distributed generation and demand response (Newton et al., 2012). With falling battery costs, battery storage is likely to be a major component of the future electricity network.

One barrier slowing the emergence of new residential precincts with energy reduction technologies is the difficulty in building a clear business case for technology deployment when the electricity demand is unknown. Also required is an improved understanding of the impacts on network performance, potential network infrastructure savings, and emissions reductions related to distributed energy resource deployment (Kavgic et al., 2010; Suganthi and Samuel, 2012).

Without a meaningful quantification of such costs and benefits, the value proposition for emissions reduction through distributed generation and energy efficiency in residential precincts is unclear. This assessment requires a model that can accurately simulate time-series energy demand. Moreover, to estimate the impact of solar and battery systems on cost, network performance and reliability, the demand model must be able to simulate individual household demands with the required time-series complexity – estimating peaks and daily variability accurately.

An electricity demand model with accurate time-series complexity can be used to evaluate the emissions reduction and costs of installing solar and battery systems in the residential sector. The demand model can also allow the optimal sizing of precinct microgrid systems (consisting of localised precinct generation, storage and loads). The increased understanding of what drives energy demand in a microgrid provides new capability to optimally size solar and battery capacities required to meet emissions reductions or grid autonomy constraints.

To help address this, the ETWW research developed a model of household hourly electricity demand. The model uses a simple set of input parameters to capture the electricity load diversity of homes in Australia and capture summer and winter seasonality, yearly peak events and daily morning and afternoon peaks. Hourly demand allows the user of the model to investigate the time-dependent impacts of solar, battery systems and electric vehicle use, and peak and off-peak energy costs.

The model simulates the interactions between the ETWW domains using common input parameters. Energy demands, after the emissions reductions from solar and battery systems, are aggregated, and grid intensity conversion factors (g CO₂-e/kWh) (see AEMO, 2017) are used to estimate the carbon emissions of the precinct from electrical energy use for both present conditions and future scenarios.

A Machine Learning approach was adopted for the model. The adaptive boost algorithm applied to a regression tree (ABRT) approach was applied in the research, as discussed in Holyoak et al., (2017) and Percy, Aldeen and Berry (2015, 2018). The model was established using the Smart Grid Smart Cities (SGSC) customer applications database (Smartgrid Smartcity, 2014) and the University of South Australia’s Lochiel Park energy demand datasets.

The energy demand model has two components:

1. A household demand model accounting for household demographics (using the Mosaic household typology), appliance ownership and the climate, which simulates the time series energy demand of households in a precinct over a specified time period, and

2. A microgrid design optimisation model which accounts for the trade-offs between solar capacity, battery capacity, carbon emissions and network capacity. This model uses Mixed Integer Linear Programming to simulate power flow in the microgrid and select optimal system capacities while meeting equipment rating limits.
A schematic view of the demand model and the microgrid design model is given in Figure 7.3. The model first simulates the individual household energy demand in 30-minute interval kWh, using the machine learning model, and the set of household characteristics. The microgrid model simulates the optimal power flow between the grid, distributed solar, and battery storage to provide the energy requirements of each household as defined by the simulated demand profiles. The microgrid model outputs the electricity demand for each home in the precinct with solar and battery systems; and can consider household-to-household energy sharing if required. For the precinct, this process quantifies the reduction in total grid import energy, at 30-minute interval kWh, and reduced carbon emissions from installing solar and battery systems. The microgrid model will also optimally design the solar and battery infrastructure required to reduce emissions by a defined percentage, or used to estimate the emissions reduction from installing a predefined microgrid system. The model can be applied to analyse a single household up to a major precinct development accommodating thousands of homes.

The software module for this model incorporated in the ETWW tool is a custom software module implemented in Python code. A full description of the two-part energy demand-microgrid optimisation model for precincts and its application is given in Holyoak et al., (2017).

7.9 Transport demand

Travel demand modelling for metropolitan areas is well established, and every major city in Australia has a Strategic Transport Model (STM). These models are usually operated by the state transport department, although some local government authorities also employ them.

Commercial software packages provide the platforms for the implementation of the models specific to each city. Given the availability of such models which provide full coverage of transport flows and travel conditions, the ETWW tool was designed to interact with the STM for the urban area containing the precinct under study.
The needs for precinct-based studies are not, however, the same as those for which the STM is generally applied. Transport agencies use their STM to forecast the future performance of multimodal transport systems and to indicate the need for transport infrastructure improvements so that the primary outputs required by the agencies are directed at traffic volumes and travel times and costs on the transport network. Precinct studies seek information on the travel behaviour and transport systems usage of precinct residents, and their selections of travel modes and destinations. This information is held in the databases generated by the STM, but requires special procedures for its extraction. Required procedures were developed and included in the ETWW tool.

Figure 7.4 shows a typical forecast estimation process associated with a macro-scale STM with input data (orange) and intermediate outputs (yellow). Key inputs to the forecasting process include population estimates (sourced from the ABS, government planning departments, other forecast models), household attributes (including location, residents, employment status, vehicle ownership and income) and employment and education data (including employees in industry types, and education enrolments).

Transport system operations are also a vital part of the input data for forecasting, providing detail on private and public vehicle networks, operational characteristics, travel times, costs, and so on. In general terms, output data reports on the transport system performance, including network travel patterns and volumes of passenger and vehicle traffic by time period, and can extend to further statistics relating to economic and environmental performance.

To use an STM for a precinct study first requires the specification of the precinct as a unique ‘traffic activity zone’ (i.e. a source/sink of travel demand) in the transport model. The travel activity (by all modes) associated with the precinct can then be extracted from the origin-destination flow matrices generated by the model and the associated travel cost matrices. These matrices are generated for each travel mode and by time of day. The precinct-related information then identifies and specifies all travel movements associated with the precinct, which can be used to estimate the transport carbon emissions associated with that travel. The precinct travel activity can also be broken down by household type.

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**Figure 7.4: Typical strategic-level, macro scale forecasting employing the 5-stage model approach for transport demand**

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<table>
<thead>
<tr>
<th>Socio-demographics [ABS, HTS]</th>
<th>Land uses [Planning Departments]</th>
<th>Policy, planning scenarios, economic forecasts [Experts, Models, …]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Land Use</td>
<td>Forecast socio-demographics, employment, land use…</td>
</tr>
<tr>
<td></td>
<td>Trip Generation</td>
<td>Zonal trip production and attraction</td>
</tr>
<tr>
<td>Transport network configurations [Planning Departments, PT Operators, …]</td>
<td>Trip Distribution</td>
<td>Zone to zone travel demand (trip matrix)</td>
</tr>
<tr>
<td></td>
<td>Trip Timing</td>
<td>AM peak, PM peak, inter-peak, Daily</td>
</tr>
<tr>
<td></td>
<td>Mode Split</td>
<td>Multimodal trip matrices</td>
</tr>
<tr>
<td></td>
<td>Traffic Assignment</td>
<td>Network travel patterns (GIS)</td>
</tr>
</tbody>
</table>

Congested network operations feedback
An important factor to note about travel behaviour and its associated carbon emissions and energy consumption is that the emissions and consumption may actually occur outside the spatial boundaries of the precinct, as the inhabitants and users of the precinct undertake their daily activities across the region. Nevertheless, these emissions are directly associated with the precinct.

A full discussion of the use of the STM for forecasting precinct transport demands and the estimation of the resultant carbon emissions is provided in Holyoak et al., (2017). Theory and mathematical models commonly used in the STM are well described in Ortuzar and Willumsen (2011).

7.10 Water demand

A multivariate statistical approach using linear mixed modelling was developed in accordance with the overall structure of the ETWW forecasting tool and data representative of urban precincts across Australia, from Lochiel Park and other sources. This has ensured that the water and associated energy demand model can be used in most urban precincts across Australia. The approach considers water use as a function of a number of scenario variables, allowing for socio-economic variable inclusions such as Mosaic household data attributes in addition to climatic and other information available with regards to dwelling characteristics and available water infrastructure. The water demand model draws on elements of both end-use models and land-use based models to better capture household energy use and interactions. End-use modelling allows estimation of uses such as hot-water use, an integral part of the carbon emissions estimate given its significant contribution to water-related energy use (Kenway et al., 2015).

Figure 7.5 provides an overview of the overall structure of the water demand forecasting model developed for the ETWW tool. Monthly water demand forecasts take place on the basis of a number of scenario inputs with respect to precinct location, household and population characteristics, climate change (temperature and rainfall) impacts and rainwater tank size. Holyoak et al., (2017) provides a detailed description for each of the individual demand forecasting modules for total water (LMM1), hot water (LMM2), and rainwater (LMM3) (as shown in Figure 7.5). Wastewater volume estimation assumes that outdoor use does not contribute to wastewater collection. A higher percentage of outdoor water use reduces the need for energy associated with wastewater treatment and disposal.

On the basis of water demand forecasts and additional input parameters such as water and wastewater treatment levels, the electricity mix, monthly ambient water temperatures and minimum air temperatures, and water heater efficiency, the model then proceeds to estimate energy and associated carbon emissions (see Figure 7.5). The energy sources (share of different electricity sources and fuels used to heat water) and water supply mix (the share of different water supply options such as surface water, groundwater and desalination) are important and complex determinants of water-related carbon emissions. As a result, the energy required in water and wastewater treatment and piping varies regionally and temporally, since the energy requirements and carbon emissions associated with water and wastewater largely depend on the type of treatment (Cook et al., 2012; Marchi et al., 2014). Household and population characteristics are important driving variables of water demand which in turn determine the energy and associated carbon emissions required to heat, treat and supply water and wastewater in and out of the household.

The model can be used to simulate policy interventions related to grid electricity scenarios and increased share of renewables, technology (more efficient appliances or water heaters), household behaviour (working from home or adopting water-saving measures), and climate change impacts on temperature and rainfall. There are strong interactions with the energy domain. In particular, water heating accounts for about 23% of household-related energy (Kenway et al., 2015), and the pumping of water from rainwater tanks can also contribute significantly to household energy use, as it can often be more energy-intensive per kL of water
compared to mains water supply (Umapathi et al., 2013). A more detailed description of how demand estimates of water supply, use, and wastewater collection and treatment are converted to energy and carbon emission estimates is available in Holyoak et al., (2017).

The current version of the tool is implemented as a custom prototype software module, with the code written in open source R language (R Core Team, 2017). It includes the following associated functions:

- weather data sourcing (retrieves monthly temperature and precipitation for nearest stations from BOM website and uses inverse distance weighting to estimate precinct temperature and precipitation)
- calculates average household socio-demographic characteristics such as household size, income, number of adults/children, based on their mosaic group
- three linear mixed models (total water, hot water, rainwater contribution) with parametric bootstrap uncertainty for each underlying yearly water demand forecast
- energy and CO₂ estimation based on published energy and GHG factors from official government sources (DOE, 2015).

All functions allow the user to modify any of the input variables e.g. household/precinct characteristics, electricity grid, water supply mix, wastewater treatment, climate change scenario, water heater type, indoor/outdoor water use ratio. This provides the necessary modularity to allow further development of the model by introducing more detailed process-based components for individual processes, thus enabling the application of the tool in diverse settings.
7.11 Waste generation

Household waste (generated by the precinct residents and subsequently collected for either treatment or disposal) may be classified into three types, each requiring separate collection, re-use and/or treatment:

- **landfill waste** – household ‘garbage’ that requires transportation to landfill site, dumping and compaction
- **recycling** – mixed materials requiring removal and individual recycling processes for paper, plastics, metals and glass waste types
- **organic** – ‘green’ materials that require bio-degradation processes to create compost, mulch, fertilisers, etc.

Precinct residential waste forecasting therefore requires estimations for each of these three waste streams. Volume and mass estimation processes for each waste type are similar in nature and are based largely on survey data and literature on the waste type composition, collection methods and treatment outcomes. The ETWW tool employs a simplified waste production estimation approach based on the resources developed for the waste domain and allows for residential and non-residential waste forecasting. The approach adopted is thus empirical, using data collected at Lochiel Park in Adelaide as well as published data from Zero Waste SA (2013) and EPA-V (2016).

The process for the estimation of all three waste streams at the precinct level is to first estimate the volume of waste deposited in the bins and the un-compacted mass, each week. Compacted volume and mass is consequently summed for all households for each waste type within the precinct and across one complete week to provide the weekly total. Total precinct masses of each waste type are used to determine the carbon impact, accounting for decomposition, composting processes and recycling processes as appropriate.

Dumping waste into landfill locations creates GHG over time, which can ultimately be represented by a carbon-dioxide equivalent (CO₂-e) production. Australian national greenhouse accounts factors (DoE, 2014) indicate that on average 1.0 kg of solid waste deposited to landfill generates 1.4 kg of CO₂-e.

Organic waste treatment involves the aerobic decomposition of the waste material to a state that suits re-use as mulch or compost. This composting process also generates carbon-dioxide equivalents at an average rate of 1.35 kg of CO₂-e per kg of organic waste (DoE, 2014).

Waste capable of being recycled requires an estimation of the energy involved in this process and subsequently the carbon produced from generating the required energy. Firstly, the proportion of each recycling material contained within the waste is determined along with their respective energy intensities for recycling processes (Cooper and Gutowski, 2017 and Morris, 1996). The resulting energy intensity requirement for household recycling waste is 5.426 kWh of energy per kilogram of recycling waste material. Regression models for waste generation, in which the independent variables reflect household characteristics, are included in the ETWW tool to estimate the amounts of waste by category generated per week.

Transport of waste from the precinct households and other land uses is commonly performed by waste removal/compaction trucks, and the emissions generated by the operation of these trucks is included in the precinct carbon emissions attributable to waste. The ETWW model assumes that trucks are required once a week for landfill waste and once a fortnight for the collection of organic and recycling waste. All vehicles will travel from the ‘home’ location to the precinct, and then repeat the ‘On-site precinct route distance’ plus travel to/from the ‘Dump/recycling treatment location’ until the entire precinct waste volume is removed.

The number of repeating cycles is determined by the total compacted volume to be removed (as estimated previously) and the truck capacity. Once complete, the truck will return to the ‘home’ location. A distinction is made between the fuel consumption of the vehicle when it is travelling full and when it is empty. Total
estimates for organic and recycling are for two-weeks and so are halved to obtain a weekly estimate to match landfill. Total precinct emission estimates (for each waste type) of CO2-e are then allocated to each dwelling or land-use in proportion to the waste volume generated.

The ETWW tool allows the user to modify any of the listed parameters, allowing for the assessment of the carbon impact of:

- waste trucks that use alternative fuel types, including biodiesel and electric battery
- changes to recycling waste treatment energy intensity
- changes to dumping/treatment locations and associated travel distances
- on-site waste treatment, eliminating the need for, or reducing the frequency of, waste collection transport.

References


DoE (2014) National Greenhouse Accounts Factors, Department of the Environment, Canberra

DOE (2015) National Greenhouse Accounts Factors, Department of the Environment, Canberra


7A. Water and Associated Energy-GHG Demand Forecasting for Lochiel Park

Michalis Hadjikakou, Deakin University

7A.1 Outline and Rationale

Water demand forecasting is an essential aspect of urban water infrastructure planning. Water demand also has significant implications for energy use and associated greenhouse gas (GHG) emissions. The combined impacts of increases in the size and affluence of urban populations along with the anticipated need for energy-intensive non-conventional water supply options (in response to climate change), reinforce the need for detailed and reliable water and associated energy and GHG demand forecasting at urban precinct scale.

While several household water demand forecasting models already exist, an integrated framework of water demand and associated energy and GHG emissions encompassing both household and water supply characteristics was lacking. To address this gap, a flexible water demand-energy-GHG model was developed in ETWW to provide household- and precinct-level water demand and associated GHG estimates for possible future scenarios. These encompass concurrent variations in the following key parameters: climate, water and electricity supply mix, wastewater treatment, water heater type and efficiency, precinct population, resident characteristics and behaviour, and rainwater tank size.

7A.2 Data and Inputs

The forecasting tool can be applied to any mixed-use urban precinct of any size, provided the necessary input data are available. The modelling chain combines a water demand forecasting model that calculates monthly water demand, along with an energy-GHG model that estimates water-related GHG emissions at the household level.

The water demand forecasting model requires the following user inputs: postcode (allows matching the precinct to the appropriate weather stations), base year and future year (to identify the climate data time series), climate change scenario (to determine changes in temperature and precipitation), household size and types, dwelling types and lot size, resident characteristics (income, education, household composition), rainwater tank size.

The water-related energy-GHG model uses the following inputs (provided by user or defaults): electricity mix (to estimate GHG emissions from the grid), water supply mix (to estimate GHG emissions of supplying mains water), wastewater treatment type (to estimate GHG emissions of treating wastewater), seasonal estimates of cold water temperature (GHG emission associated with heating water), rainwater pump efficiency (used to calculate GHG emissions of supplying rainwater).

While all inputs to the water demand forecasting model are essential, energy-GHG inputs are optional and can be estimated using state- or city-level GHG intensity coefficients.
7A.3 Outputs, Findings and Implications

This use case presented here is an application of the tool to Adelaide’s Lochiel Park precinct. Lochiel Park is a residential precinct in Adelaide with 106 low-energy homes. Several of the homes have continuously logged water use since 2009 and all households have a rainwater tank, with rainwater fed directly into the hot water system. Several future changes, also likely to occur in other Australian metropolitan areas, will affect the precinct:

1. **Changes in population.** Future plans for the precinct include a possible expansion to 256 houses, a secondary school and a small retail outlet leading to diversification of population characteristics and changes in water demand.

2. **Climate change.** An overall decline in rainfall of between 15 to 30% is projected for most of South Australia by 2050. This is expected to negatively impact rainwater collection and also alter the water supply mix (with higher use of desalination)

3. **Significantly more energy from renewable sources.** South Australia has highly ambitious decarbonisation targets aiming for net zero emissions by 2050. This is likely to reduce emissions associated with water supply and wastewater treatment.

Average results for the following seven scenarios presented in Figure 7.6 are based on a planned total number of 256 households and for IPCC intermediate emission and warming forecasts [RCP4.5]: (a) **BAU** – 2035 RCP 4.5 climate and current electricity (2013/14 grid GHG intensity = 0.67 kg CO₂/kWh) and water supply mix (2009/10 energy intensity = 0.78 kWh/kL) with gas hot water (GHG intensity = 0.19 kg CO₂/kWh), (b) **DESAL** – 2035 RCP 4.5 climate with desalination contributing to 50% of water supply (energy intensity = 2.4 kWh/kL), (c) **RENEW** – 2035 RCP 4.5 climate with 50% desalination and 80% renewable electricity (GHG intensity = 0.2 kg CO₂/kWh), (d) **EHEAT1** – same as BAU but with all-electric water heaters (GHG intensity = 0.67 kg CO₂/kWh), (e) **EHEAT2** – same as EHEAT1 but with 80% renewable electricity (GHG intensity = 0.2 kg CO₂/kWh), (f) **SHEAT** – same as EHEAT2 but with solar hot water (0.1 kg CO₂/kWh) instead of electric, (g) **ALL** – same as SHEAT but with 50% desalination added back; the latter being representative of a plausible best case scenario.

![Figure 7.6: Lochiel Park precinct 2035 water-related GHG emission scenarios for different future electricity, water supply and water heater combinations](image)

Figure 7.6: Lochiel Park precinct 2035 water-related GHG emission scenarios for different future electricity, water supply and water heater combinations
The results in Figure 7.6 highlight the key contributions of water heating (46-86% of total CO2-eq) and the mains water supply (6-38% of total CO2-eq). A combination of solar hot water and an electricity grid with 80% renewables can fully offset the need for more desalination in the future, with the ALL scenario having 45% less overall emissions compared to the BAU scenario. Scenarios with electric hot water have high total GHG emissions (162% higher than BAU in the case of EHEAT1), but this can also be offset when electricity is predominantly from renewable sources (22% less in EHEAT2 compared to BAU).

The use study demonstrates the capacity of the model to provide disaggregated GHG results through the integration of different modelling scales (water supply and household water).

This allows a full quantification of the multiplicative nature of GHG savings, such as when the electricity grid has a higher contribution from renewables. As in the integrated ETWW model, simultaneous estimation of demands for different components of household and precinct water demand and their interactions are fully accounted for in the estimated of GHG emissions, allowing tailoring of potential solution to the specific precinct context.

References


7B. Electricity Demand Forecasting and Microgrid Design for Precincts

Steven Percy, Victoria University

7B.1 Outline and Rationale

Residential electricity energy supply has the potential to move to a low-carbon future through the increased uptake of distributed generation and distributed storage, microgrid systems, new demand response methods, innovative passive building designs and improved energy efficiency of buildings, appliances and transport. The size of many early distributed generation, distributed storage and microgrid trials was often limited by funding, as the financial risk of deployment was minimised by keeping the trial small. Improved modelling and optimisation can reduce financial risk (through higher fidelity estimates of operation and performance) and improve the overall business case (by providing guidance on the best configuration, design and structure of deployments). In this research, we present an integrated modelling and optimisation framework that has new capabilities to design, build and test the business case for low-carbon microgrid precincts with storage and distributed generation technologies at their core. This modelling framework analyses the cost and emissions reduction of low carbon infrastructure when applied to precincts and households.

7B.2 Data and Inputs

The tool is designed to model an inner, middle or outer suburban precinct comprising any number of dwellings.

The modelling tool consists of three components:

1. **The electricity demand model**: this model draws on a 6100 home training dataset to develop a machine learning, half-hourly residential demand model for individual homes. This is a more extensive dataset than used by any other time-series demand model in an Australian context to date. The demand simulation uses nominated outside temperature, estimation of appliance ownership (e.g. air conditioning, type of hot water heating) and household demographic information which can be specified using the Mosaic geodemographic dataset. Where detailed information is unknown statistical estimates can be used.

2. **Microgrid design model**: this model allows for the optimal design and simulation of an urban microgrid. The model formulation allowed a new possibility to model load diversity, network impacts, utility storage and distributed (household) storage in a microgrid. Input data includes the demand profiles from the electricity demand model, the infrastructure costs, tariff structure, battery technology and emissions reduction targets.

3. **Distribution network model**: this model allows for the network analysis of the microgrid, considering aspects such as voltage levels, losses and grid stability. This model requires network layout data such as load locations and line types.
7B.3 Outputs, Findings and Implications

Through the tool, we have gone from a small subset of input data, such as household demographics, temperature, appliance ownership and tariffs through to a fully costed microgrid solution that considers battery deployment, infrastructure costs, optimal resource operation, residential cost benefits, AC and DC power distribution, network performance, network losses, utility, and system lifetimes.

The demand model applies new methodologies to estimate individual household 30-minute energy demand. The half-hourly energy demand allows the modelling tool to simulate the energy reduction that can be achieved from solar generation, battery storage, precinct energy sharing and microgrid operations.

The carbon impact of the precinct was determined using the daily grid emissions intensity factors provided by the Australian Energy Market Operator, converting kWh to t CO₂-e. The model has been validated on the Lochiel Park precinct in Adelaide, South Australia. For the Lochiel Park case study, the demand model achieved a 4.2% difference in total yearly energy consumption (a difference of only 11 GWh) and estimated the yearly peak demand event magnitude with a 1.2% accuracy, a difference of only 1.1 kWh. The model estimated the annual absolute peak demand of 141.8 kWh and total consumption of 581GWh (500 kt CO₂-e/y).

The microgrid and network model were applied and validated on Lochiel Park, a low-carbon, middle suburb precinct development in Adelaide, comprising 106 dwellings, all minimum 7.5 star energy efficiency (see Holyoak et al., (2016) and Holyoak et al., (2017) for a full description of Lochiel Park).

The Lochiel Park analysis considered seven different microgrid configurations and two baseline cases, as shown in Figure 7.7. The costing for the microgrids includes infrastructure investment costs (including all converters, lines and network transformers) and costs associated with converted losses (based on power flows identified in the integrated demand and microgrid model and converter efficiencies). It took approximately 30 minutes to analyse each microgrid configuration using a standard desktop computer. The lowest cost energy supply solution was Scenario 2, with 200kWh of installed distributed battery storage achieving a 54% reduction in emissions (224 kt CO2-e/y). This solution was shown to be cheaper than the solar only and grid only solutions.
Here we have provided a tool that is capable of delivering comprehensive insight into the behaviour and performance of energy supply systems at the household, precinct and network level (irrespective of the availability of metered demand data or detailed occupant surveying). The methods presented in this research provide a new level of utility with the potential to be applied by developers, precinct planners, and local governments for new developments, contributing towards state emissions reduction targets and urban renewal policies.

References


7C. Integrated Energy, Transport, Waste and Water (ETWW) Demand Forecasting and Scenario Assessment for Precincts: The Case Study of Tonsley

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7C.1 Outline and Rationale

Estimating demand for utility services and facilities is required for planning the levels of provision necessary to serve the needs of present and future urban populations. Understanding consumption demands and associated carbon impacts for the ETWW domains is central to planning agencies, local government, infrastructure providers and operators and private developers, who all need to deliver services and facilities to populations resident in urban neighbourhoods.

The research project developed a tool for integrated demand and carbon impact forecasting of ETWW at the precinct level, which is capable of supporting scenario planning for alternative precinct development plans. This unique approach allows for interactions between the different demand domains and can accommodate the impacts of population change, socioeconomic and demographic variability and household behaviour in demand forecasting.

A broad range of demand estimates and related carbon impact estimates can be generated for scenarios recognising the energy, transport, water and waste relationships that occur at a household level.

7C.2 Data and Inputs

The tool has a focus on residential precincts in a mixed-use precinct context, providing a realistic basis for the assessment of the overall carbon impacts of urban development or redevelopment. Given the residential precinct focus, the basic unit of measurement is the household. Applications of the tool to date have been on residential precincts of up to 1,000 households/50 ha (Tonsley, South Australia). Other land use types can be included. The tool can accommodate a wide range of household types (covering household size, socioeconomic status and household behaviour) and dwelling types.

The Mosaic classification of household types (and lifestyles/behaviours) has been used in the applications of the tool. Dwelling types relate to the physical attributes of the structure including house type, number of bedrooms and solar generation capacity. The data required by tool components are compiled by all of the four domains and precinct forecast scenarios. Some data may be specific to individual domains (such as the transport network configuration), with other core inputs (such as number of household residents) having multiple domain applications.
7C.3 Outputs, Findings and Implications

The ETWW tool was applied to Adelaide’s Tonsley precinct, a brownfield development 11 km south west of the CBD. The general objective for redevelopment of the site is as a hub for technical innovation and higher education with residential components as part of a thriving community. The full site is mixed land use, but the application here focused on the residential precinct component of the development. Total land area of the entire Tonsley site, including open areas, roads and public space, is 60 ha. The residential precinct covers about 9 ha, and the Base Case scenario includes 862 residences. These are a mixture of medium-density semi-detached houses (308 dwellings), medium-density apartments (436 dwellings) and high-density apartments (116 dwellings). The dwelling types have comparable floor areas and their physical characteristics are based on recent archetypal residential typologies constructed in the Adelaide metropolitan area. All residential buildings have rooftop PV. Non-residential land use components in the precinct include retail, educational, open space and street network.

Three scenarios were modelled: (1) the Base Case (population 1,923 in 862 households), (2) Scenario A, with the same population but with a 50% adoption of electric vehicles (EVs), working at home (50% of households, 2 days/week), and 25% increase in recycling of household waste, and (3) Scenario B, with the same household behaviour and lifestyle profiles as Scenario A but a different residential population (slightly larger households, population 2,293 living in the same 862 residences).

The households were characterised using the Mosaic classification of Australian households and the socio-demographic characteristics, lifestyle attributes and household consumption patterns corresponding to the chosen household types. Specifically, the Mosaic types included in the Base Scenario and Scenario A largely represent apartment dwelling young professionals (singles or couples), students and, to a lesser extent, small families and retirees. In Scenario B this population is altered to represent a more mature population including a larger proportion of wealthy families and elderly population types. Scenario A assumes that the household structure and installed household appliances have the same performance characteristics as the Base Case.

Changes to energy or water consumption are therefore related to behaviour change by the households. The precinct contains the same dwellings as previous scenarios and the same non-residential land use allocations. The application of ETWW to the Tonsley residential precinct is summarised in Figure 7.8, showing per capita carbon emissions for the three residential development scenarios.

![Figure 7.8: Per-capita residential carbon emissions at the Tonsley precinct](image-url)

The interactions/trade-offs between the carbon performance of the domains, especially Energy and Transport, are clearly visible. Transport emissions reduce considerably in Scenario A (-37.7%), but are offset by a relatively small rise in emissions from energy use (5.7%). This may be attributed mainly to overnight charging of the EVs, along with some increase in daytime energy use by households working at home. There is an
overall reduction (-6.5%) in total carbon emissions under this scenario. In Scenario B, the effect of the larger population and different household structures (e.g. fewer single person households) lead total per capita carbon emissions to reduce (-16.1%), with both emissions from energy and transport reducing (-14.1% and -37.9%, respectively).

The energy domain is the largest contributor to carbon emissions in all scenarios, followed by the waste domain. Transport is similar to waste and the water domain contributes the least to carbon impact. As indicated above, the take-up of electric vehicles and working from home are seen to have significant impacts on overall carbon emissions. Emissions from the waste domain can be attributed to the decomposition of organic material but also to the energy required in many of the recycling processes.

This project provides new insights for precinct design assessment afforded through integrated demand forecasting. The approach provides for the simultaneous estimation of demands for energy, travel, water and waste and includes the interactions between those domains in its estimation of carbon emissions.

A full description and analysis of the Tonsley use case is provided in Holyoak et al., (2016). This includes analysis of the impacts on emissions for the different housing structures and for the different (Mosaic) household types. The ETWW tool when applied to case studies indicates where precinct planning and design innovations are best targeted for carbon mitigation. For residential precincts these relate to the following attributes, largely recognising the significant influence of the energy domain on overall emission generation:

- using renewable resources for grid-based energy, with the source location (state/region) playing a significant role in the emission rates for non-renewable electricity generation. This is not only directly connected to household energy use but also associated use such as energy required for recycling processes and wastewater treatment
- solar PV uptake providing the household with ability to replace grid-based energy consumption with a low emission alternative. This is particularly effective as transmission losses become vastly reduced, especially if used in association with local battery storage mechanisms
- electric vehicle ownership and use providing residents with a low-emission transport alternative, when used in collaboration with the previously mentioned mitigation techniques.

For mixed use precincts, these innovations also extend to:

- intra-precinct travel between the household and workplace, with the application of electric vehicle private and public transport modes and greater potential for walking and cycling. This mitigation impact can be further realised with careful consideration of the residential/non-residential land use mix
- non-residential land uses, which can also contribute significantly to emissions reduction through altered water consumption and waste recycling behaviour of individuals performing activities outside of their home.

References


Greening Urban Mobility

Hussein Dia, Damian Moffat, Swinburne University of Technology, Stephen Cook, CSIRO and John Stone, University of Melbourne
8. Greening Urban Mobility

8.1 Introduction

Transport activity is one of the major sources of GHG emissions in Australia (National Green House Gas Emissions Inventory, 2011). Transport contributed 83.2 Mt CO₂-e, or 15%, of Australia’s net GHG emissions in 2010. Road transport was the main source of transport emissions, accounting for 71.5 Mt CO₂-e, 86% of national GHG emissions from transport. Passenger car usage in urban areas was the single largest transport source contributing 39.7 Mt CO₂-e, i.e. 8.5% of total GHG emissions in 2010 (Taylor, 2014).

Since World War 1, metropolitan planning decisions have strongly shaped the form of the built environment, and lifestyle choices have strongly influenced the use of the private car in urban areas. Newton and Newman (2013) addressed this in their discussion of low carbon urban transition theory. They developed a model framework for low carbon technology interventions in urban and suburban forms of the built environment. The framework was based on consideration of appropriate low carbon technologies applied to transport and housing in suburban and inner urban areas.

Figure 8.1 displays an updated version of the Newton-Newman framework. This identifies suburban transport as the major area of concern in low carbon urban development. For housing, alternative energy sources and new building technologies and maintenance systems offer clear pathways to low carbon futures. Urban transport focused on satisfying travel demands to major activity centres (e.g. the CBD) offers known alternatives in terms of improved public transport. There have been no such established and effective alternatives for inter-suburban travel.

New developments in information and telecommunications technology and vehicle technology, coupled with changing community attitudes to vehicle ownership and use, are now offer viable alternatives for low carbon mobility in suburban areas. Electric vehicles (EV) offer potentially lower carbon emissions, depending on the sources of the electrical power. Autonomous vehicles (AV) offer alternatives to private vehicle ownership as part of car and ride sharing systems, and may lead to reduced requirements for road and parking space. Smart buses and trackless trams using AV technology could provide cost-effective shuttle services for suburban residents using line haul public transport routes.

Increased interest in active transport (walking and cycling), promising improved community health and social contact as well as reduced reliance on mechanised transport, is also relevant for suburban travel.
Figure 8.1: Modified Newton-Newman (2013) framework for low carbon technology interventions in urban and suburban forms of the built environment

The CRC funded research project (RP2021) on ‘Greening suburban transport’ investigated these opportunities for improved suburban transport systems offering efficient, affordable and flexible trips while reducing reliance on private vehicle use and lower carbon emissions in suburban travel. The project comprised three parallel work packages:

- **WP1**: investigations of travel demand and determinants of shifts in travel behaviour from private vehicles to public transport and active transport
- **WP2**: investigations of travel supply including land use-transport modelling of demand for travel modes under different scenarios of infrastructure service supply
- **WP3**: decision support for infrastructure investment in low carbon transport.

The project led to the development of a set of tools for analysing and assessing low-carbon mobility options for suburban travel for use by a range of stakeholders, from individual travellers and transport systems managers to policy makers. These tools may best be seen and related through the ‘Avoid-Shift-Share-Improve’ (ASSI) policy framework for low carbon mobility (Dia, 2017).

### 8.2 Objectives

The ASSI framework is shown in Figure 8.2. For each of the four policy action domains – Avoid, Shift, Share, Improve – it identifies strategies for each domain along with the expected outcomes of domain policy initiatives. The ASSI framework diagram further specifies the systems analytics relating to the domain strategies and core performance indicators for each. The tools developed and/or applied in the research project and described later in this section (SNAMUTS, ABM-TMC, PSUMC and AMoD) are allocated to the policy action domain of most relevance to each. (NB: The project focused on the three action domains involved with travel behaviour change, i.e. Avoid, Shift and Share. The domain ‘Improve’ largely concerns...
technological developments for lower energy consumption and emissions applied to existing transport alternatives).

<table>
<thead>
<tr>
<th>1. (POLICY) ACTION DOMAINS</th>
<th>AVOID</th>
<th>SHIFT</th>
<th>SHARE</th>
<th>IMPROVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. STRATEGIES</td>
<td>Reduce/avoid need for travel</td>
<td>Shift to environmentally friendly modes</td>
<td>Share mobility resources</td>
<td>Improve energy/carbon efficiency of transport/mobility system</td>
</tr>
<tr>
<td>3. SYSTEM ANALYTICS/TOOLS</td>
<td>Land Use Transport Integration (LUTI)</td>
<td>Mode shifts: From car to PT, From car to active modes</td>
<td>Car share, Bus share</td>
<td>Vehicle, engine and fuel technologies, Area-wide Traffic Control (ATC)</td>
</tr>
<tr>
<td></td>
<td>Accessibility</td>
<td>Access to Public Transport (PT)</td>
<td>Bike share, Ride share</td>
<td>Intelligent Transport Systems (ITS), Eco-driving</td>
</tr>
<tr>
<td></td>
<td>Travel Demand Management (TDM)</td>
<td>Autonomous Vehicles (AV)</td>
<td>Shared parking (leading to reduced road space)</td>
<td>SNAMUTS, Financial/feasibility</td>
</tr>
<tr>
<td></td>
<td>Virtual mobility programs</td>
<td>W&amp;G (walking &amp; cycling)</td>
<td>PSUMC (for individuals), AMoD (for system managers)</td>
<td>ABM-TMC, Route optimisation, Bus elasticities</td>
</tr>
<tr>
<td>4. OUTCOMES</td>
<td>System efficiency</td>
<td>Trip efficiency</td>
<td>System and trip efficiency</td>
<td>System, trip and mode efficiency</td>
</tr>
<tr>
<td></td>
<td>→ Less congestion</td>
<td>→ Energy decreases</td>
<td>→ Vehicle ownership decreases</td>
<td>→ Energy decreases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ (all) emissions decrease</td>
<td>→ Capacity to use Apps increases (‘Smart’)</td>
<td>→ Emissions decrease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ Time?, Cost?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ Satisfaction?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ Tipping point(s) (behaviour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. INDICATORS</td>
<td>Vehicle-km of Travel (VKT)</td>
<td>VKT and PKT by mode</td>
<td>Vehicles/hh, by vehicle type</td>
<td>Energy consumption, Emissions levels</td>
</tr>
<tr>
<td></td>
<td>Person-km of Travel (PKT)</td>
<td></td>
<td>Vehicle occupancy (PKT/VKT) for private motor vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Other (Apps)?</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.2: The ‘ASSI’ low carbon mobility policy framework

On this basis the following specific objectives for the project included:

- understanding and assessing the current situation and identifying best practice and trends in suburban travel
- understanding the drivers for travel demand in suburban areas and determinants of shifts in travel behaviour from private vehicles to public transport and active transport
- understanding land-use transport interactions and their influence on the demand for different travel modes under different scenarios of supply of public and active transport infrastructure and service patterns, especially those relating to precinct planning and design
- understanding the impacts of different intervention measures and their benefits in reducing greenhouse gas emissions, reducing social and economic costs of current levels of car-dependence, and providing customers with alternative travel options in suburban areas
- integrating the research outcomes into a discrete set of transport interventions and applicable tools to help end-users deploy and implement green transport initiatives in suburban areas.
8.3  Tools for Modelling the Impacts of Low Carbon Mobility Solutions

This project developed four tools that can be used for assessing the impacts of low carbon mobility solutions. These include:

- a calculator for modelling the impacts of precinct shared use mobility solutions (PSUMC)
- tools for modelling the impacts of shared Autonomous Mobility-on-Demand services (AMoD)
- agent-based tools for modelling transport mode choice (ABM-TMC)
- accessibility tools for public transport planning (SNAMUTS).

8.4  Calculator for modelling the impacts of PSUMC

Although transport emissions have stabilised in Australia in recent years, more needs to be done to reduce transport emissions, especially if current congestion trends continue unabated. According to the 2016 Infrastructure Australia Audit, available data indicates that “without action, this trend will continue and deteriorate, with the cost of congestion in Australia’s major cities set to rise from $13.7 billion in 2011 to $53.3 billion in 2031” (Infrastructure Australia 2016). There is therefore a significant opportunity to reduce carbon emissions by managing the demand for mobility through the reduction of private vehicle transport and through the adoption of alternate modes, whether that be via transitioning to lower carbon emission intense modes such as EV, or through the smart management of available transport options such as using existing private vehicles via rideshare programs.

To help address these concerns, the PSUMC tool was developed to calculate the existing impact of the transport sector, and the benefits of a mode shift, with the aim of ultimately helping decision makers with the development of low carbon precincts.

8.4.1  Precinct Shared Use Mobility Calculator objectives

PSUMC offers a simple tool for end-users to calculate and review existing levels of carbon emissions in the transport sector within a particular jurisdiction and compare it to future use scenarios. The three key objectives of this tool are to:

- quantify existing levels of GHGE for a precinct across all modes of travel
- calculate the mode shift required to achieve a specified carbon emission reduction target
- provide output results to end-users (e.g. councils) to help create evidence-based policy and prioritise infrastructure investment to create a low carbon mobility network.

The applications of PSUMC extend beyond what is documented within this report. The framework behind the calculator has been designed so that it can be developed further and adopted for other regions. For example, other modes such as ferries and EV can be added to the model or a new calculator using the same framework can be developed to solve a different problem at a different scale.

The existing conditions module of the calculator currently covers all of metropolitan Melbourne, and with further research and collection of data, can be easily modified to extend to other Australian and international cities.
8.4.2 Schematic representation and description of tool

The calculator framework includes the calculator component which is currently an Excel spreadsheet and links to travel preference survey data. The survey data is either linked directly to the calculator, or it runs via a traffic model to provide more accurate traffic redistribution and equilibrium calculations. The calculator uses these inputs to profile the carbon emission impacts. The framework consists of the following key components:

- inputs (trip data, cost of emissions, cost of mode, etc.)
- specified carbon emission reduction target (user-driven)
- mode shift calculation/trip redistribution
- outputs and results.

Figure 8.3 demonstrates how all the components of the framework are linked to compute the trip distribution and generate the required outputs.

![Figure 8.3: Simplified framework of the model behind the calculator (Moffatt, 2018)](image)

8.4.3 Scope of application

With PSUMC developed for and targeted at local governments, the end-users and beneficiaries will be councils, which may use it as part of community consultations and in the development of transport carbon reduction policies. Table 8.1 presents a list of potential applications.

Table 8.1: Possible Transport Scenarios

<table>
<thead>
<tr>
<th>Possible Scenarios</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing transport carbon emissions</td>
<td>Precinct, Individual</td>
</tr>
<tr>
<td>Calculate new mode share to achieve carbon reduction goal</td>
<td>Precinct</td>
</tr>
<tr>
<td>Evidence for policies (output quantitative data for inclusion in polices)</td>
<td>Precinct</td>
</tr>
<tr>
<td>Community engagement (calculate personal cost savings and environmental impacts in dollars)</td>
<td>Precinct</td>
</tr>
<tr>
<td>Compare the transport impact between precincts/development scenarios</td>
<td>Individual, Building, Precinct</td>
</tr>
</tbody>
</table>
8.4.4 Model inputs

Table 8.2 outlines the processes and the associated data sources that are used for the calculations.

Table 8.2: Model inputs

<table>
<thead>
<tr>
<th>Inputs/Processes</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions</td>
<td>Studies (e.g. Emissions of Melbourne transport and infrastructure)</td>
</tr>
<tr>
<td></td>
<td>Government publications (e.g. global warming potential values)</td>
</tr>
<tr>
<td></td>
<td>Technical documentation (e.g. manufacturers fuel consumption figures)</td>
</tr>
<tr>
<td>Costs</td>
<td>Government publications (e.g. ATO car operating costs)</td>
</tr>
<tr>
<td></td>
<td>Commercial publications (e.g. public transport fare prices)</td>
</tr>
<tr>
<td>Travel Data</td>
<td>VISTA Travel Survey data (DEDJTR, 2017)</td>
</tr>
<tr>
<td></td>
<td>VicRoads Signalised intersection counts (for calibrating the traffic model)</td>
</tr>
<tr>
<td>Location</td>
<td>User driven (e.g. Port Phillip Council)</td>
</tr>
<tr>
<td>Reduction Target</td>
<td>User driven (e.g. 10%, 20%, 50%...etc.)</td>
</tr>
<tr>
<td>Travel Preference Survey</td>
<td>Historic travel preference information</td>
</tr>
<tr>
<td></td>
<td>New survey (Refer to the PSUMC final report for guidance on developing a survey)</td>
</tr>
<tr>
<td>Traffic Model*</td>
<td>Optional - Microscopic traffic simulation model (factors in capacity constraints and new infrastructure)</td>
</tr>
</tbody>
</table>

As noted above, a Travel Preference Survey will need to be conducted unless an existing relevant survey can be sourced. A traffic model will also need to be prepared if there are major infrastructure changes to consider. For the Melbourne example, the rest of the data is fixed across Metropolitan Melbourne, and the calculator can be replicated without additional investigations for these inputs. For deployment of this calculator in cities other than Melbourne, more relevant data may need to be collected.

8.5 Key outputs and performance measures/indicators

The key outputs and performance measures reported by this tool are listed in Table 8.3.

Table 8.3: Key outputs and measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Unit</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Emissions</td>
<td>T CO₂e</td>
<td>N/A (Dependent on study size)</td>
</tr>
<tr>
<td>Carbon Emissions per km2</td>
<td>T CO₂e / km²</td>
<td>A performance measure to compare carbon emission impact between studies</td>
</tr>
<tr>
<td>Reduction in carbon emissions</td>
<td>T CO₂e %</td>
<td>A performance measure that can be used to compare the performance of multiple scenarios</td>
</tr>
<tr>
<td>Reduction in personal costs</td>
<td>$ (AUD) %</td>
<td></td>
</tr>
<tr>
<td>Reduction in private vehicle kms</td>
<td>Km %</td>
<td></td>
</tr>
</tbody>
</table>
8.6 Tools for Modelling Impacts of Shared AMoD

Shared AMoD systems have been promoted as a feasible solution to address urban mobility challenges in large and fast-growing cities, particularly for the first and last kilometre of travel. One of the key challenges to decision makers is the ability to assess the impacts of these future modes of transport and how they are likely to change travel patterns, car ownership models, and the way transport infrastructure and supporting services are designed in our cities.

The impacts of proposed urban transport interventions have generally been evaluated using a variety of modelling tools ranging from strategic transport models covering large regions, through to dynamic simulation models for metropolitan areas and detailed traffic simulation models for smaller areas. Most of the existing tools, however, lack features that allow for modelling specific aspects of AMoD systems such as pick-up and drop-off operations, minimisation of empty travel, and optimisation of the shared vehicle fleet size. These issues are important to model accurately because they will be critical to the success of commercial AMoD operations.

This research resulted in the identification of more realistic simulation models for traffic flows and network representation compared to the majority of studies in the literature (Javanshour et al., 2018; ITF, 2017; Dia and Javanshour, 2017). In particular, the models developed in this research deploy a real-time optimisation algorithm to redistribute the idle autonomous vehicles within the network.

8.6.1 Objectives

The major objective of this work is to understand the behaviour and performance of AMoD systems as a function of their system characteristics, such as fleet size and induced Vehicle Kilometres Travelled (VKT). The key questions to be addressed in the study include:

- to what extent could AMoD systems reduce the current private vehicle fleet sizes?
- what is the relationship between AMoD fleet sizes, empty Vehicle-Kilometres Travelled (eVKT), and waiting times of customers?
- what is the relationship between the fleet size, customer waiting times, and eVKT?
- what relationship exists between demand distribution within the network and generated eVKT?
- to what extent could the fleet size be reduced by nudging more people into ride-sharing?
- what benefits could be achieved at different levels of market penetration?

8.6.2 Schematic representation and description of tool

The AMoD simulation tool uses an agent-based traffic simulation approach that offers a number of features for modelling network performance, using end-to-end trips made by travellers over multiple modes of transport, rather than single-mode trips made in a vehicle, or by walking. This approach allows for modelling individual traveller behaviour, including dynamic decision processing incorporating a dynamic mode-choice function of individual travellers. This provides capabilities that allow a traveller in the model to make instantaneous choices between available modes as well as choices between available routes.

An agent-based simulation model can represent dynamic mode switching by allowing each individual agent to choose a new mode of transport during a trip. AMoD is based on the Commuter nanoscopic traffic simulator (Duncan, 2010, now part of the Infraworks 360 package from Autodesk) in which travellers and vehicles are represented as agents. In the model, travellers can walk, drive, ride or cycle from their origin to a destination using a model that includes both dynamic mode choice and dynamic route choice.
Building a model in this tool starts with constructing network objects, which define surfaces on which agents move including lanes and intersections for road vehicles, tracks and sensors for rail and trams, and walking and cycling lanes for pedestrians and cyclists. Mode-change areas (these are areas where the traveller can change modes of travel) can also be specified within the model.

The next step is to define origin and destination “zones” for vehicle-trips and “areas” for person-trips, and to connect those to the network objects. Demand can be specified as person-trips between origin and destination areas, and/or vehicle trips between origin and destination zones. A diagram demonstrating the real-time optimum rebalancing algorithm is shown in Figure 8.4.

### 8.6.3 Scope of application

This tool is scalable and can be implemented at a precinct scale through to suburbs or even metropolitan areas. The data requirements and amount of time for model development, calibration and validation will, however, increase substantially when the area is increased.

### 8.6.4 Input data and sources

Microscopic traffic simulation is characterised by a high level of modelling detail. The accuracy of the model will also depend on the availability and quality of the input data. Data for model development includes data on network layout (e.g. digitised maps and raster images showing locations of both signalized and un-signalized intersections, road centrelines, number of lanes in each section of road, width of each lane, gradient of road etc.).

![AMoD modelling framework](image)

**Figure 8.4: AMoD modelling framework**

Public transport routes are modelled according to the timetable schedule. The number of trips between each O-D pair for each vehicle type can be extracted from strategic models and manipulated based on local traffic counts to produce the required O-D matrices in 15-minute time-sliced intervals.
The model can be applied for specific periods of the day (e.g. AM or PM peak traffic flows), or for the entire day. The traffic signal groups, control plans, phase sequences and cycle durations are coded for each signalised intersection based on field data obtained from local road authorities.

The travel demand data required for the model can be sourced from a variety of sources such as the Victorian Integrated Survey of Travel and Activity (VISTA), which is a survey of travel and activity in Victoria. Other states in Australia conduct similar surveys, which include a sample of personal travel activities that occur from home to a range of activities. The traffic data, including traffic counts and signal timings, are available through road authorities such as VicRoads.

8.6.5 Key outputs and performance measures/indicators

The key outputs include total kilometres of travel in the entire network, average customer waiting times for services, emissions, fuel consumption, average travel speeds and time, throughput through the network, and optimal allocation of AVs to stations. The models have a highly developed visualisation interface as shown in Source: Duncan (2013) Figure 8.5.

Source: Duncan (2013) Figure 8.5: Example visualisation of station locations and mode changes from walking to other modes of transport

8.7 Agent-based tools for modelling transport mode choice

Continued population growth, and policies designed to limit sprawl, has seen a shift from growth occurring primarily at the urban fringe of Australian cities to renewal of suburban precincts through greyfield and brownfield infill development. This has resulted in increased population density and employment opportunities in these suburban precincts.

However, these suburban precincts are often poorly serviced by infrastructure for active transport and public transit, which as meant that cars are still used for the majority of trips with resulting increases in congestion and GHGE. Therefore, there is the need for targeted interventions that can improve the accessibility in suburban precincts and support the transition to low carbon transport modes.

A barrier to improving accessibility infrastructure is understanding the different behavioural responses of travellers to interventions that improve the accessibility of low carbon transport modes. The agent-based tool for modelling transport mode choice (ABM-TMC) is designed to model the uptake of low carbon transport modes in a suburban precinct under different scenarios in a way that considers realistic models for commuter behaviour, and their responses to supply interventions that improve accessibility for active and public transport.
8.7.1 Objectives
The development of ABM-TMC has the following objectives:

- understand the factors that influence travel mode choice and the determinants of shifts in travel behaviour from private vehicles to public transport and active transport choice
- develop a model that represents travel data, demographics, urban infrastructure, and travellers’ behaviour and response to low carbon transport infrastructure investment options.

8.7.2 Schematic representation and description of tool
A schematic flowchart of the tool is provided in Figure 8.6. This research was mostly focussed on understanding the potential role for agent-based modelling for understanding behavioural aspects that shape transport demand, especially as related to increased adoption of low carbon transport modes. While it is recognised that there is significant merit in more traditional approaches to transport demand modelling that are focussed on identifying the most efficient mode on the basis of ‘rational behaviour’ theory, these models may not reflect that a traveller’s behaviour is shaped by experiences and attitudes, and therefore there may be a role for a model that simulates the impacts of these factors on mode shift behaviour.

![Figure 8.6: Schematic of ABM-TMC](image)

The key elements of the modelling tool include:

- travel survey used to segment the travelling population and identify key attributes in choice modelling. The survey also provides a baseline of travel behaviour specific to the case study
- scenario development based on discussions with key planning stakeholders within the case study precinct, and a review of existing strategies
- decision-making profiles where the processes within ABM-TMC apply the ‘Consumat Approach’, a model of human behaviour based on consumer behaviour (Janssen and Viek 2001). It is based on concepts and theories from psychology, economics and computer science (Janssen and Jager 2002). The ABM is
developed within NetLogo, a software platform for creating ABMs, which is a free, open-source software (Tissue and Wilensky 2004)

- spatial network analysis of accessibility by modes, undertaken within a GIS environment, used to highlight origins and destinations of trips to work on a daily timeframe. The accessibility index applies concepts from Curtis and Scheurer (2015) SNAMUTS (described in the following section), and is based on travel impedance (travel time) between activity nodes and node attractiveness (number of jobs and residents relative to metropolitan area), where accessibility is defined as 30 minute travel time isochrones. The transport demand modelling has been undertaken at the macro-level, which considers impedance of movement between different origins and destinations, and changes in the resident population and employment density of different nodes within the region
- scenario outputs visualising changes in mode share over time, highlighting the adoption of active and transit. The net reduction in CO₂ emissions from increased adoption of low carbon transport modes is calculated based on the GHG intensities of different modes.

8.7.3 Scope of application
ABM-TMC has been designed to address the following key urban planning and design questions related to increased adoption of sustainable transport modes within precincts:

- behavioural drivers that are likely to impede or encourage mode shift following investment in improving accessibility by low carbon transport modes
- analysis of different interventions in increasing share of trips undertaken by low carbon transport modes, and resulting impacts on GHGE.

8.7.4 Input data and sources

<table>
<thead>
<tr>
<th>Data type</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveller survey</td>
<td>Traveller decision-making profiles</td>
<td>Online precinct survey</td>
</tr>
<tr>
<td>Residential population</td>
<td>Change in residential population in local govt areas</td>
<td>Victoria In Future</td>
</tr>
<tr>
<td>Employment projections</td>
<td>Changes in employment (attraction) in planning zones</td>
<td>Vic Planning Authority</td>
</tr>
<tr>
<td>ABS Census data</td>
<td>Trip production and attraction by zone</td>
<td>ABS</td>
</tr>
<tr>
<td>Primary land use</td>
<td>Used to assign residential and employment population to zones in LGA</td>
<td>ABS Mesh Blocks</td>
</tr>
<tr>
<td>Transport network</td>
<td>Configuration of transport network servicing the case study area precinct</td>
<td>Victorian Government Data Portal</td>
</tr>
</tbody>
</table>

8.7.5 Key outputs and performance measures/indicators

<table>
<thead>
<tr>
<th>Key Outputs</th>
<th>Performance measure</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in share of trips by low carbon modes</td>
<td>Increase in share of trips by active and public transit.</td>
<td>% of trips by each mode</td>
</tr>
<tr>
<td>GHGE generated from work trips</td>
<td>Net reduction in CO₂-e emissions</td>
<td>T CO₂-e</td>
</tr>
</tbody>
</table>
8.8 Accessibility tool for public transport planning

Visualisations of the impact of possible planning interventions are an important tool in planning processes, particularly for engagement with decision makers and the wider public. This research tested the use of maps and other visualisations produced with SNAMUTS, a supply-side public transport accessibility model (Curtis & Scheurer, 2016), to explore the changes required in land-use and public transport supply to achieve significant shift to ‘low carbon’ modes for travel.

8.8.1 Objectives and description of use of the tool

In public transport planning for Australian cities, evaluation, if undertaken at all, is often limited to use of tools such as the 4-step model, which are designed for planning processes. More appropriate tools have been developed. SNAMUTS is a sophisticated example of these new tools because of the ways in which it combines understandings of the interplay between land-use and networked public transport supply (Mees, 2010). However, there is a gap between academic knowledge of its benefits and its use in practice (Silva, 2017).

This research tests the use of the SNAMUTS accessibility model for public transport supply by:

- analysing outputs of existing planning processes with a case study for the Monash National Employment and Innovation Cluster (NEIC). NEICs are areas of Melbourne designated by the State Government as locations for future investment to support growth in jobs and services.
- identifying scenarios for possible planning interventions to achieve a shift to low-carbon modes (this includes changes in demographics, land-use and supply of opportunities for lower-carbon travel)
- producing maps and other visualisations to illustrate changes in accessibility
- using these visualisations in workshops led by developers of the model to address the objectives listed above
- evaluating the usefulness of the tool to support and improve planning practice.

8.8.2 Scope of application

This tool is useful at the precinct or metropolitan scale, and was applied at the precinct level in Melbourne’s south-east. It can be used either as a means to evaluate accessibility changes from current proposals, or as a method of testing what types of change in transport supply and land-use are required to achieve a desired level of accessibility for a precinct such as the Monash NEIC.

8.8.3 Input data and sources

Data requirements include:

- projections for changes in residential population and employment at ABS SA2 level
- GIS data for routes and timetables for existing and proposed public transport services.

8.8.4 Key outputs and performance measures/indicators

The SNAMUTS tool provides indicators of:

1. relative ease of movement to and from a node in the public transport network (speed and frequency of service)
2. average minimum numbers of transfers required to reach all other nodes in the network
3. “movement energy”, that is, the number of transit journeys passing through each node
4. jobs and residents within 30-minute travel time by any combination of public transport modes (expressed as a percentage of the metropolitan total accessible from each node)

5. potential for transit-oriented development (‘connectivity’ measured by the number of lines and services at each node)

6. latent demand – potential mismatch between actual service levels and number of lines passing through a node

7. efficiency change – geographical distribution of changes in accessibility resulting from any proposed changes in public transport provision

8. a legible composite index of public transport performance.

These outputs are designed to be used as discursive tools. Comparisons of the potential impacts of different proposals for change to the public transport network can be clearly demonstrated to planners and the public and allow for informed debate on the relative merits of different investments (as shown in Figure 8.7).

Figure 8.7: (SNAMUTS) Accessibility tool for public transport planning

References


Duncan, G. (2010) From microsimulation to nanosimulation: visualizing person trips over multiple modes of transport, Transportation Research Board, 2175(15), 130–137


Taylor, M.A.P. (2014) Presentation to the Low Carbon Mobility Workshop on Greening Suburban Travel, Swinburne University of Technology, 11 Nov, 2014

8A. Modelling Public Transport Service Standards for Low-Carbon Transport in Middle and Outer Suburbs of Australian Cities

Jana Perkovic, John Stone, University of Melbourne, and Carey Curtis, Curtin University

8A.1 Outline and Rationale

This case study explored the changes to public transport services required to shift a significant number of trips to a major suburban employment and education precinct to lower carbon travel modes.

It used the SNAMUTS public transport and land-use accessibility model as a discursive tool for planners working to improve low-carbon transport for the Monash National NEIC in Southeast Melbourne. The study engaged with planners from state and local government, major employers in the precinct including Monash University and CSIRO, and private consultants working for stakeholders in the NEIC.

The case study explored the relationship between technical-rational planning practice (exemplified by the SNAMUTS model), and current opaque and politicised planning practice in Victoria.

8A.2 Data and Inputs

The Monash NEIC is one of seven sites identified in Plan Melbourne 2017-2050 as “a focus for jobs growth and strategic infrastructure investment”. It is located in Clayton, 20km from the CBD. Its core area covers approximately 6 km² with about 75,000 knowledge sector jobs, a university with 30,000 students, and a major suburban hospital. This core is surrounded by dispersed locations for “supporting employment” and zoning for future high-density housing. It is expected to grow significantly (perhaps by 100%) by 2050.

The Monash NEIC does not have a direct connection to the suburban rail system. The principal link to the CBD is via a frequent shuttle bus from Huntingdale Station (3km to the centre of the NEIC). Other public transport is provided by buses on major arterials at low frequencies of service.

8A.3 Outputs, Findings and Implications

Modelling the existing public transport network shows the difficulty of attracting employees of the Monash NEIC to public transport. The SNAMUTS indicator for ‘connected nodes’ scored only 4 for Monash University (only 24 identified nodes in Melbourne have worse connectivity). The second Monash campus at Caulfield scored 295. The mean score for Melbourne is 84. (See Figure 8.8, Figure 8.9 and www.snamuts.com/melbourne-2014.html)
SNAMUTS modelling was used to compare the changes in connectivity at the centre of the Monash NEIC, achieved through two scenarios for public transport improvement:

- upgrading bus services linking the NEIC to multiple stations on the Dandenong, Glen Waverley and Ringwood lines in a grid-pattern at 10-min frequencies
- a new light-rail from Caulfield to Nunawading (on the Ringwood line via Chadstone Shopping Centre and the Monash NEIC).
The analysis showed that, under the bus option, the centre of the NEIC scored 96 (just above the mean for Melbourne). The light-rail option achieved a connectivity score of only 42.

SNAMUTS is a supply-side model and so does not estimate the ridership of a re-structured network. However, a shift of 20% of car travel to the Monash NEIC to public transport powered by renewably-generated electricity would avoid about 0.32 MT CO$_2$-e per annum in 2027 on conservative projections for growth of the NEIC.

Planners found the SNAMUTS modelling of various scenarios useful. They believed the visual representations of the network impacts of various scenarios for new bus and light-rail services into the NEIC would be valuable for communication with politicians and the public. These scenarios were suggested by the project team and by representatives of major employers in the NEIC but, as discussed below, were not included as options in the formal planning processes.

A strong limiting factor in the planning process for improved public transport to the Monash NEIC was revealed in interviews with participants. These planners revealed that politicians do not allow transit proposals to be considered even in semi-public planning processes such as those conducted for the NEIC. This is to avoid any community ‘expectations’ that investment will take place. The result is that planning processes cannot properly investigate the potential for enhancing public transport to meet desired objectives.
8B. Modelling the Impacts of Autonomous Mobility on Demand Services

Hussein Dia and Farid Javanshour, Swinburne University of Technology

8B.1 Outline and Rationale

Innovations in the transport sector continue to introduce new low-carbon mobility opportunities. New business models that offer a range of new mobility services (ride-hailing, car-sharing, bike-sharing and vehicle subscription models) are also helping to provide flexible options to meet the demands for travel. In particular, in recent years self-driving vehicle technologies have captured people's imaginations and inspired visions of a different future, as well as a great deal of hype. Considerable research is needed to distinguish between hype and reality, and any impacts on urban mobility.

One of the future business models being promoted is Autonomous Mobility-on-Demand (AMoD). These have been advocated as holding great promise for addressing urban mobility challenges in cities, particularly for meeting the first and last-kilometre travel requirements. The key concept behind these systems is that they use fleets of shared, electric, self-driving vehicles to respond to customer demand in real-time, making them a lower carbon solution in addition to being a more cost-effective alternative to privately owned vehicles. Because of the reduced cost of operating these fleets, which do not need a human driver, they are also seen as an alternative mode of public transport, potentially cutting the number of vehicles on the road.

The following questions remain:

- Will they reduce or increase congestion?
- Will they induce more demand for travel?
- Will they increase or decrease urban sprawl?
- What impact will they have on parking?
- Will they reduce or increase emissions?
- How will they impact car ownership?

The work reported in this case study is part of a research agenda to study the impacts of AMoD systems in our cities. This study aimed to demonstrate the feasibility of using agent-based models to understand the impacts of low-carbon mobility solutions under scenarios of AMoD services. The work included the development of a simulation model that was used to evaluate such impacts in the context of suburban travel in Melbourne.

8B.2 Data and Inputs

The study area for the pilot was located in the City of Stonnington in Melbourne, and covered an area of approximately 6 km² (Figure 8.10). Travel demand was obtained from the Victorian Integrated Survey of Travel Activity (VISTA) and was aggregated into nine distinct areas representing the Origin-Destinations for travellers. The study period was the AM-Peak (7am-9am) and examined only the 2,136 trips from VISTA that were undertaken using single-occupant privately owned vehicles considered as first candidates for AMoD. The development of the simulation model also required access to road network layouts, signalised and un-
signalised intersection information, lane geometry and other information necessary for development of simulation models. This data was obtained from VicRoads databases and other publicly available information.

Figure 8.10: Pilot study area in Melbourne

8B.3 Outputs, Findings and Implications

The results showed that AMoD systems result in a significant reduction in both the number of vehicles required to meet the transport needs of the community (reductions up to 88% depending on scenarios being modelled), and the required on-street parking space (reduction up to 83%).

Such impacts have a clear influence on urban form in our cities and could free up substantial amounts of land that can be used for other purposes. However, the results also showed that AMoD systems would increase the total vehicle kilometres travelled due to empty vehicle running and repositioning (increase up to 29%).

As the environmental impacts are related to fleet size and per-kilometre emissions, the carbon performance will depend on the extent to which the self-driving fleets are shared and the degree to which they employ more fuel-efficient and less polluting technologies. The modelling results for various scenarios of sharing were investigated. It was found that net carbon emissions would be reduced by up to 19% for scenarios in which 78% of the self-driving fleet was shared.

The benefits are expected to increase with wider adoption of autonomous shared electric vehicles in the future, particularly when the energy supply will be from renewable sources. The results also showed that proper planning for their deployment should include their promotion for use as first and last-kilometre travel solutions especially in outer suburban areas that are not well-served by other forms of public transport.

This work provided valuable policy insights including:

• key challenge to public policy is to promote and support the shared use of vehicles
• future urban mobility should include high capacity mass transit complemented by AMoD for first and last-kilometre of travel
• freed up space must be proactively managed. New opportunities to integrate transport and land-use planning must be explored.
• high capacity rail investments will remain critical in future mobility scenarios
• environmental benefits will depend on vehicle technology and the public’s perception of acceptable levels of service (which have been found to impact vehicle-kilometre travelled per capita). If travellers are willing to accept slightly longer waiting times and are willing to share rides, the emissions reductions would be higher.

• AMoD systems present a real threat to suburban bus transit lines. The lines will increasingly become blurred between traditional timetable bus services and new business models such as on-demand shared ride services including future AMoD systems.

References


Dia, H. and Javanshour, F. (2016) Modelling the impacts of autonomous shared mobility systems, ITS World Congress, 10-14 Oct, Melbourne, Australia

Javanshour, F., Dia, H. and Duncan, G. (2018) Exploring the relationship between fleet size and vehicle-kilometres travelled in autonomous mobility on-demand systems for various travel demand patterns, from the 16th ITS Asia Pacific Forum, 8-10 May, Fukuoka, Japan
8C. Using the Precinct Shared Use Mobility Calculator in the City of Port Phillip

Damian Moffatt and Hussein Dia, Swinburne University of Technology

8C.1 Outline and Rationale

The Precinct Shared Use Mobility Calculator (PSUMC) is designed to act as a tool of change by providing municipal decision makers with a quantitative assessment of the impacts of low carbon transport interventions in terms of reductions in emissions. This calculator has an explicit transport focus and consideration of network constraints, and behavioural patterns of travellers within the precinct being assessed.

This case study has been prepared to demonstrate the feasibility of the methodology of the calculator. Port Phillip City is the subject of the assessment and was chosen because of its proximity to the Melbourne CBD, and its diverse use of travel modes, which provide a good test of the tool. Through the ongoing development of this tool the Port Phillip Council was consulted to ensure that the tool and the outputs would be useable and would address their strategic planning requirements.

8C.2 Data and Inputs

The PSUMC is scalable and can cater for a variety of precinct sizes. Required input data is described in Table 8.6. The City of Port Phillip occupies an area of 20.7 km² and has a population of about 100,000 people. For this case study, only the AM peak period (7am to 9am on weekdays) was considered.

Table 8.6: Data inputs and sources

<table>
<thead>
<tr>
<th>Data Inputs</th>
<th>Case Study Source</th>
<th>Possible Alternative Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population and Demographics</td>
<td>Australian Census 2016</td>
<td>• Census Data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Surveys</td>
</tr>
<tr>
<td>Origin-Destination Trip Data</td>
<td>Victorian Integrated Survey of Travel and Activity 2017</td>
<td>• Origin Destination Surveys</td>
</tr>
<tr>
<td>Carbon emission intensity values</td>
<td>Various Australian and Melbourne based studies</td>
<td>• Previous studies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In-field testing</td>
</tr>
<tr>
<td>Mode Preference</td>
<td>Mode Preference Survey</td>
<td>• Existing mode preference studies</td>
</tr>
</tbody>
</table>

This calculator focuses on transport network capacity and the behaviour of travellers. As traveller behaviour varies by locality and the availability and/or attractiveness of transport infrastructure varies within each precinct, it is critically important that a mode preference survey is undertaken, or relevant data is sourced for the tool.

When developing the survey, the objective was to create a straightforward questionnaire for residents where results could be used to calculate a redistribution of modes. Commonly travel preference surveys focus on deriving the overall preference using a variety of techniques such as comparing mobility scenarios. This survey collected data on the existing modes used by travellers, and what were the most likely modes they would switch to if required. This allows for development of a redistribution matrix (i.e. the likelihood of a traveller on
mode A changing to mode B). The responses collected provide an understanding of the likely redistribution, and instances when travellers cannot or are unwilling to change mode.

While the results of the survey and its application within PSUMC are adequate to calculate the traffic impacts relatively quickly, a traffic simulation model would need to be completed to accompany PSUMC calculations and further refine the outputs. This would allow for greater control and simulation of the transport network capacity, notably future scenarios where there may be major infrastructure changes such as new train or tram lines or arterial roads. This study does not include the traffic model as it was intended to demonstrate how this calculator can be adopted by councils for quick assessments, before investing more time into developing a traffic model and completing more comprehensive analysis.

8C.3 Outputs, Findings and Implications

Survey Findings

The survey was developed to provide a greater level of detail when interrogating the mode preferences. A small extract from the data collected is represented in Figure 8.11 and Figure 8.12. The former figure shows the survey results for what mode drivers of private cars would change to if they could not use their current preference of a private car. No reason for change is stated as part of the survey. Figure 8.12 illustrates the current mode share and the proposed mode share based on adopting a maximum reduction of private cars and redistributing those trips according to the redistribution matrix developed from the travel preference survey results. Both figures also identify the portion of travellers that are unable (or unwilling) to change modes, which limits the absolute minimum number of trips each mode can be reduced to in the calculator. For this analysis, 19% of the current car trips cannot be removed and thus private car usage can only drop from a mode share of 31% to 6% (an approx. 80% reduction in private car trips).

![Figure 8.11: The Proposed Redistribution of Private Cars as sourced from the outcomes of the Travel Preference Survey](image-url)
Unsurprisingly, train has a high level of appeal to commuters as a second option to driving. Further research could be conducted in this area to see how to translate the appeal into a reduction of private car trips. Similarly, Carpooling evoked a high level of appeal, likely due to the similar levels of comfort and practicality of private car trips.

**Calculator Findings**

**Scenario 1:** Based on the calculator findings there is a current annual level of greenhouse gas emissions within the City of Port Phillip of 63.6 MT CO₂e or 560 kg CO₂e per person. For a nominal reduction of greenhouse gas emissions of 5% (3.2MT CO₂e per year) an annual reduction of 7.5% of private vehicle trips is a possible solution. The shift away from private trips will see a marginal increase in personal trip distance (approximately 1km) given that shared modes do not travel directly between two destinations, but the mode shift will result in less distance travelled by private cars.

**Scenario 2:** This scenario builds upon the results from Scenario 1 and analyses how the population growth of the City of Port Phillip affects the long-term greenhouse gases reduction strategy. Figure 8.13 illustrates the calculated greenhouse gas levels for 2018, 2023, and 2028 dependent on the reduction of private vehicle trips. To maintain the current level of emissions in the context of projected population growth to 2028 would require a private vehicle trip reduction of 25%, which is possible.
Figure 8.13: The levels of Greenhouse Gas Emission for 2018, 2023, and 2028 given a Specified Reduction in Private Vehicle Trips

References

Co-Benefits Calculator for Health and Wellbeing

Jason Thompson and Mark Stevenson, University of Melbourne
9. Co-Benefits Calculator for Health and Wellbeing

9.1 Introduction

The urban age is upon us: it is estimated that by 2050, 70% of the world’s population will be living in cities (Dobbs, 2010; World Bank, 2012). Unless we begin to devise and adopt more effective urban policies that can achieve multiple goals, namely, economic efficiencies, environmental sustainability and population health, we are destined to expose increasingly large urban populations to greater economic, environmental, injury and health-related risks. The prosperity of modern Australian cities relies on balancing the desire for growth alongside new, efficient, sustainable, and healthy urban regeneration, regeneration that does not continue to support sprawling, inefficient, obesogenic and injurious urban form.

With 1.5 million deaths and almost 80 million healthy years of life lost due to road trauma each year and a further 184,000 deaths due to motor vehicle-related air pollution, the global health loss associated with urban areas is considerable (Bhalla et al., 2014). Of significant concern is the fact that the global health burden due to motor vehicles is increasing, with deaths due to road injury and air pollution increasing by 46% and 11% over the past two decades, respectively (Bhalla et al., 2014). Further, the cost associated with managing road trauma across the road network, is estimated to be the equivalent of between 1.7% and 3.0% of a country’s GDP. (Jacobs, Aeron-Thomas, & Astrop, 2000; Risbey, Cregan, & De Silva, 2010). In Australia alone, personal compulsory third-party personal injury insurance schemes collect and pay out over $5 billion in emergency, hospital, and rehabilitation costs for the nearly 1300 people who are killed and 50,000 people who are injured on our roads (BITRE, 2017; Motor Accident Commission, 2015; Motor Accident Insurance Commission, 2016; Motor Accidents Authority, 2015; Northern Territory Motor Accidents Compensation Commission, 2015; Victorian Transport Accident Commission, 2016; World Health Organization, 2016).

Recent analysis has highlighted the health gains that can be achieved by implementing strategies that focus on the design of a city and that implement sustainable transport and urban policies (Giles-Corti et al., 2016; Stevenson et al, 2016). For example, cities that facilitate greater uptake of safe, active (walking and cycling) transport, cities that provide reduced distances to access public transport, and cities with greater mixed land-use and population densities are capable of delivering significant reductions in chronic disease and injury (Stevenson et al, 2016).

9.2 Objectives

The objective of the Low-Carbon Living Co-Benefits Calculator project (LCL-CBC) was to develop a tool that urban planners and property developers could access to explore the potential to promote/implement designs that would enhance economic and health-related co-benefits associated with regenerative low-carbon urban precincts.

The tool is not a guideline for low-carbon design, rather it is an interactive tool that accesses government and publically available data including data collected from samples of the general population (for example, the Victorian Government’s health survey) with available sources of data related to land use and urban design. The tool describes the observed (and predicted) associations between a city’s urban form and:

Health:
- perceptions of individual citizens’ general health status
- perceptions of general physical health status
• perceptions of general mental health status
• health behaviour, including incidental exercise and food consumption
• overweight and obesity
• social capital, connection and cohesion.

Transport:
• uptake of active transport, including frequency and intensity of walking and cycling
• access to public transport
• road safety, including road injury associated with car, pedestrian and cycling
• risk of road crash
• traffic congestion, productivity and time lost in unproductive transport.

Pollution:
• exposure to air pollution
• exposure to noise pollution.

By combining a variety of tools and techniques from public health, transport studies, road safety, and geographic information sciences into a single interface, the LCL-CBC aims to provide potential users with a host of alternative avenues for examining and promoting the benefits of low-carbon precinct design beyond carbon reductions, themselves. This may be particularly useful when deciding between various precinct design scenarios, locations, or plans involving decisions to regenerate a precinct. The LCL-CBC enables the user to compare both the absolute and relative benefit that may be expected to be produced by alternative development scenarios.

The interactive nature of the interface is also a purposeful departure from previous guidelines that have adopted a more manual and static ‘tick-box’ style. In this way, the tool attempts a human-centred approach that balances the need to be valid, acceptable, and viable (Rouse, 2015). By ‘valid’, we intend the tool to accurately reflect and provide solutions for the purpose it was intended. By ‘acceptable’, we mean that it solves these problems in a manner that users easily understand and embrace. By ‘viable’, we intend the costs of learning and using the tool to be low, therefore facilitating its uptake.

9.3 Schematic Representation and Description of the Tool

The LCL-CBC tool was based on a linear model established from a health impact assessment framework developed to explore the relationship between land-use transport and the health of city residents (Stevenson et al., 2016). The basic premise of the model is that population health and well-being is influenced by the urban environment in which people reside and interact. The proximity of individuals to urban design features such as public transport, roadways, recreational facilities, schools, shops, workplaces and other services exerts an influence on a person’s day-to-day behaviour and hence exposure to risk and consequent illness.

These factors and characteristics of the urban environment may be represented by land-use elements such as 1) density, 2) distance to amenity, and 3) diversity of land-use (see Figure 9.1). Density refers to the population and/or dwelling density of a given area, which tend to be highly correlated but can, on occasion, diverge when household sizes vary. Distance refers to the proximity of dwellings or precincts from other services or features of the urban environment (e.g. schools, shops, transport stops) as described above.
Finally, diversity relates to the number of land-uses that a given area is used for. An area with low levels of diversity may be one that is ‘only’ used for residential housing or ‘only’ used as an industrial site. High levels of diversity reflect areas of mixed use where housing, commercial buildings, industry and community facilities are integrated. There are certainly overlapping relationships between the land-use elements. For example, areas of high land-use diversity are also likely to have smaller distances between households and essential services. Areas of high density may also be able to incorporate more types of land-use within a more compact area.

Figure 9.1: Basic depiction of the LCL-CBC structure, which analyses precinct-level land-use characteristics and translates what the effect of these may be on population-level health, wellbeing, and productivity.

The land-use elements are directly related to the transport modes available to city residents (second column Figure 9.1). Higher density land-use, which supports shorter distances between households and services, as well as greater land-use diversity, reduces the requirement for private vehicle transport. When travel distances are reduced people are more likely and able to walk, cycle, or take public transport to reach their desired destinations.

Similarly, proximity to train stations enables people who need to travel longer distances to do so via rail rather than by private motor vehicle. The way land is allocated and used, therefore, greatly affects the way in which people travel around the city (Currie & Senbergs, 2007). This influence on movement patterns has implications for risk exposures (e.g. road trauma and pollution), as well as individual transport costs, and the productivity and efficiency of the entire transport system.
9.4 Analytical approach

Figure 9.2 illustrates how the LCL-CBC captures the variation in land-use across metropolitan areas (such as Melbourne, which forms the urban test-bed of the tool). To assess the variation in land-use, 800m radii around the centroid of 1.2 million individual land parcels were drawn in order to capture land use and other related data within the catchment of the identified land parcel. Captured counts of features drawn from the PSMA database were then associated with the land parcel, describing its characteristics across:

- population density
- household density
- public transport stops (trains, trams and bus-stops)
- educational facilities
- community health facilities
- sporting and recreational grounds
- commercial premises
- industrial premises
- intersections
- government and public service buildings
- community care facilities
- hospitals
- cultural facilities, and
- number of different land-uses in catchment.

These variables formed a set of independent variables (land-use features) associated with health and productivity outcomes that could then be associated with health and productivity outcomes through a series of linear regression equations adjusted for educational attainment and household income (see below).

![Figure 9.2: Depiction of the parcel-level approach undertaken, which captures land-use data within a radius surrounding parcel centroids](image-url)
9.5 Identifiable land-use clusters

The collection of features in each location revealed patterns of land-use across Melbourne’s metropolitan area. These ‘similar-to-one-another’ areas were then defined through performing a cluster analysis. The cluster analysis simplified the complexity of potential city feature combinations, identifying areas across Melbourne that a) shared common features and b) potentially shared common outcomes.

The results of the cluster analysis revealed five main land-use typologies (see Figure 9.3):

1. High Density Inner City (green)
2. Inner Urban (blue)
3. Connected Pockets (orange)
4. Middle Suburbia (red)
5. Urban Fringe (pink)

Figure 9.3: Spatial depiction of the five identified land-use clusters across the Melbourne metropolitan region shown at macro (top) and medium (bottom) scale
The characteristics representative of each of the clusters highlighted in Figure 9.3 reflect a unique spatial distribution. Figure 9.4, below, shows the relative differences between each of these cluster groups as they relate to land-use characteristics.

The High Density Inner City cluster shows the highest density of dwellings and population, alongside the highest number of commercial premises, educational facilities, health care settings, public transport stops, and public buildings. This equates to High Density Inner City areas having the highest levels of land-use diversity. At the other extreme, the locations in the Urban Fringe (Cluster 5) show very low levels of land-use diversity and have the lowest levels of population and housing density, alongside the lowest levels of access to commercial and public facilities. The remainder of clusters predictably vary between these two extremes in a generally radial pattern. An exception, however, is Cluster 3, Connected Pockets.

Connected Pockets are distinct areas that tend to exist wholly within otherwise Inner (Cluster 2) or Middle Suburban (Cluster 3) areas and, unlike remaining clusters, are not connected to one another. Their distinctive feature is that, similar to High Density Inner City locations (Cluster 1), they are very well serviced by sporting facilities and train stations, which translates into higher levels of land-use diversity (see Figure 9.4). This accessibility to public transport provides residents of these areas with transport options beyond private motor vehicles that are less available to their surrounding suburban counterparts.

![Figure 9.4: Land-use characteristics associated with each of the identified five land-use clusters](image)

### 9.6 Population health and productivity measures

Precinct health and productivity outcomes potentially associated with the observed land-use variables (columns 3 and 4 in Figure 9.1) were assessed using data from the Victorian Department of Health and Human Services, Victorian Public Health Survey. This survey of over 30,000 Victorians provided information related to individual health and health behaviours across items of relevance including:

- height
- weight
- body mass index (BMI)
- smoking status
- transport behaviours (public transport, driving, walking, cycling)
- social capital
- self-rated physical health
- psychological health
• perceptions of trust and social cohesion (e.g. perceptions of multiculturalism)
• general life satisfaction
• feeling safe after dark
• education and income status.

Linking both the land-use characteristics and health characteristics, while controlling for demographic characteristics such as education and income, enabled isolation of risk exposure and health factors that were associated with the location in which individuals lived. From here, a set of regression equations were developed that could be used to estimate the health and wellbeing of all measured land-parcels across Melbourne.

These differences in precinct performance as they relate to each the five land-use clusters described above are illustrated in Figure 9.5. An individual example of how BMI is estimated to differ across the Melbourne metropolitan region is shown in Figure 9.6 (note the relationship between public transport corridors and estimated lower BMI).

**Figure 9.5:** Output from the web interface showing the mean performance of each identified land-use cluster across health, wellbeing, and productivity variables

**Figure 9.6:** A representation of estimated BMI across the Melbourne metropolitan area with lighter colours representative of lower estimated BMI
Armed with this information and set of equations, the LCL-CBC tool can then be used by planners and developers to assess and compare either existing or proposed urban developments to estimate their potential impact on health, wellbeing and productivity.

Planners and developers can use the simple web interface, below ([thud.msd.unimelb.edu.au/tools-and-models/co-benefits-calculator](http://thud.msd.unimelb.edu.au/tools-and-models/co-benefits-calculator)), or access the custom built interface where precinct area shapefiles can be drawn or imported and the results downloaded automatically by the user ([crcprecintanalyser.com.au](http://crcprecintanalyser.com.au)). The precinct analyser will continue to be updated and maintained through the University of Melbourne’s Transport, Health and Urban Design Research Hub.

### 9.7 Scope of Application

The following questions that the LCL-CBC can address relate to comparable health and productivity benefits associated with candidate precinct development decisions:

- where should a precinct regeneration project be located?
- proximity to which features will influence or promote positive behaviour and health?
- development or inclusion of which features will generally be beneficial to the community that resides there?
- what is the health and productivity performance of a given area likely to be?
- how does the performance of a proposed development precinct compare with another?

The spatial scale at which the tool is most useful is at the precinct level (viz. at least 30 households). It is not suitable for smaller areas because individual behaviour is still subject to far too much variability (i.e. someone may live next to a train station but still choose to drive) to model at this scale. On average, however, we may expect behaviour of groups of individuals to follow patterns consistent with previous data and reflected in the model regression estimates.

Figure 9.7 illustrates the scale of analysis of the Lochiel Park Living Laboratory precinct in Adelaide. Observable in the figure is that analysis not only considers the 15ha area containing the precinct’s approximately 100 residences but also an 800-metre buffer zone around the precinct. This buffer area is recognition that the characteristics and quality of areas surrounding a precinct development are also influential in relation to health, behavioural and productivity outcomes.

![Figure 9.7: The information and data collection area for model inputs expands in an 800m buffer beyond the edge of the precinct under analysis](image-url)
9.8 Input Data and Sources

As described above, the type of data required to create the LCL-CBC is a combination of parcel-level, geo-coded land-use data, combined with an overlay of health and wellbeing data. It is the combination of these two data sets that enables the creation of regression equations that can proceed to estimate the association of precinct design on health, or health-related behaviour, of a given population or community contained within that precinct.

Land-use data in Victoria was gathered through the Australian Urban Research & Infrastructure Network AURIN (www.aurin.org.au). AURIN collected and analysed data from PSMA (https://www.psma.com.au/), collating fine-grained land-use classifications into broader, intelligible categories for analysis.

Health and wellbeing data was primarily collected from the Victorian Department of Health and Human Services’ (www.dhhs.vic.gov.au) Victorian population health survey. This was supplemented by geo-coded road crash and infrastructure data gathered from VicRoads (www.vicroads.vic.gov.au). Again, it is the combination of these datasets, rather than their use in isolation, that has enabled this analysis to successfully occur.

Melbourne was selected as the test-bed for the pilot calculator as both comprehensive land-use and health data existed for this location. Outside Victoria, the datasets are not as readily available. This means that broad-scale analysis of entire metropolitan regions is more difficult. Instead, individual locations must rely on a combination of datasets that are available (i.e. much of the transportation infrastructure information is available across states), as well as either input gathered on the ground, or through alternative open-source information (e.g. Google Maps).

For example, to estimate the relative performance of areas in Adelaide (Tonsley, Bowden, Lochiel Park – see Figure 9.8) and Fremantle (White Gum Valley), the project team was required to undertake intensive on-the-ground data collection, walking over 120km within the buffer zones of each district and manually inputting precinct information into a purpose-built GIS application (also available from the research team on request). Initial results from this analysis indicate that, comparing the three Adelaide locations, Bowden is likely to be associated with the greatest health benefits and highest levels of productivity. This is primarily because of Bowden’s close location to facilities associated with the Adelaide CBD, which reduces the amount of time spent in private motor vehicles, and increases the likelihood and frequency of active transport such as walking.
Figure 9.8: Comparative performance of Adelaide-based living laboratories across selected health and productivity performance indicators.

For other areas where GIS data is not available and can be estimated, model input data can also be entered into the calculator and downloaded from the web interface as shown in Figure 9.9. The user’s own data will be represented by the black line.

Figure 9.9: Manual interface of the LCL-CBC where users can input land-use data relevant to their chosen precinct (represented by the black line) as well as download results in .csv format for further analysis and comparison.
9.9 Key Outputs and Performance Measures/Indicators

Table 9.1 is an overview of the observed relationships that link performance indicators and outcomes as estimated by the LCL-CBC. All outcome measures are estimated on either a per-capita (in the case of estimated health status) or per-capita per time-unit (in the case of activities). The number of inputs and outputs available to the platform will continue to expand over time as new data becomes available and new analyses are completed. For example, particulate pollution and noise pollution are not currently available for assessment in the co-benefits calculator. However, analysis is currently being conducted to ensure its inclusion in future iterations of the tool.

Table 9.1: Key inputs and outputs of the LCL-CBC

<table>
<thead>
<tr>
<th>Land-use variables (inputs)</th>
<th>Health and productivity outcomes (outcomes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population density</td>
<td>Belief that multiculturalism is positive (rating scale)</td>
</tr>
<tr>
<td>Density of dwellings</td>
<td>Belief that people can be trusted (rating scale)</td>
</tr>
<tr>
<td>Land-use diversity</td>
<td>Body mass index (BMI)</td>
</tr>
<tr>
<td>Number of bus stops</td>
<td>Mental health self-rating (Kessler 10)</td>
</tr>
<tr>
<td>Number of community facilities</td>
<td>Noise exposure (tbd)</td>
</tr>
<tr>
<td>Number of cultural facilities</td>
<td>Number of people spoken to yesterday (count)</td>
</tr>
<tr>
<td>Number of educational facilities</td>
<td>Number of take-away meals per week (count)</td>
</tr>
<tr>
<td>Number of industrial premises</td>
<td>Number of times walked &gt; 10 minutes per week (count/week)</td>
</tr>
<tr>
<td>Number of intersections</td>
<td>Perceived social capital (rating scale)</td>
</tr>
<tr>
<td>Number of public buildings</td>
<td>Perceptions of feeling safe after dark (rating scale)</td>
</tr>
<tr>
<td>Number of sporting facilities</td>
<td>Perceptions of general health (rating scale)</td>
</tr>
<tr>
<td>Number of train stops</td>
<td>Pollution exposure (tbd)</td>
</tr>
<tr>
<td>Number of tram stops</td>
<td>Rating of overall life satisfaction (rating scale)</td>
</tr>
<tr>
<td></td>
<td>Time spent in car per day (mins/day)</td>
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<tr>
<td></td>
<td>Time spent on public transport per day (mins/day)</td>
</tr>
<tr>
<td></td>
<td>Time spent sitting per day (mins/day)</td>
</tr>
<tr>
<td></td>
<td>Time spent walking per day (mins/day)</td>
</tr>
<tr>
<td></td>
<td>Vegetable serves per day (count/day)</td>
</tr>
</tbody>
</table>

References


9A. Urban Form and Fabric and Population Health: City Scale Co-Benefit Analysis

Jason Thompson and Mark Stevenson, University of Melbourne

9A.1 Outline and Rationale

This use case of Melbourne demonstrates distinct land-use typologies that exist across the region, and how these are associated with differences in population health and well-being. Broadly, five distinct urban typologies were identified in this analysis and these typologies can be used by planners and developers to understand the connections between urban form and health.

The premise underlying this LCL-CBC is that population health and productivity is influenced by where people live and the quality and characteristics of the built environment that surrounds them. The contribution of this case study is to demonstrate that practical changes to urban form and fabric can assist whole communities move toward healthier, more sustainable, and more productive lives. Importantly, the project isolates various parameters from those driven by demographic characteristics commonly associated with health, including education and household income.

Presented here are health and wellbeing outcomes that could be obtained from a broad-scale urban intervention if existing middle and outer suburban areas could be transformed to more closely resemble those of inner-urban areas.

9A.2 Data and Inputs

The inputs for this use case are the selection and comparison of two common urban typologies identified through the LCL-CBC: Inner Urban and Middle Suburbia. Inner Urban land-use parcels make up 9% of total land-use parcels analysed, while Middle Suburbia represents the largest group of individual land parcels at about 45%. The land area covered by these parcels, however, is not proportionate to their total count given differences in dwelling density and the compact nature of inner urban areas (Stevenson et al., 2016). When total land-area is considered, inner urban areas account for just 3% of the total land area analysed, while middle-suburban areas comprise 27%.

As shown in Figure 9.10, below, the inner urban land use area (blue) and the middle suburban (red) land use areas of Melbourne are distributed radially from Melbourne’s CBD. However, these boundary distinctions are not simply concentric circles. Inner urban land-use areas are also found beyond the CBD and encapsulated within areas of middle suburbia. Despite often being located within otherwise suburban areas, inner urban (blue) land use areas show features of a more compact nature associated with:

- higher land-use diversity (count of land-use types in an 800m, or approximately 10-minute walking distance at 5km/h)
- more cultural premises (count in 800m radius)
- more commercial premises (count in 800m radius)
- higher density population and density of dwellings (counts in 800m radius)
- higher numbers of educational facilities (count in 800m radius)
- more public buildings (count in 800m radius)
- more public transport options, including train and tram stops (count in 800m radius).
9A.3 Outputs, Findings and Implications

Outputs from the calculator analysis of local area attributes listed below are estimated upon data derived from the 2015 Department of Health and Human Services’ Victorian Population Health Survey. Controlling for levels of education and household income, it shows (see Figure 9.11) there may be co-benefits associated with encouraging land-use change in middle suburban land-use areas (depicted by the red line) to more closely resemble characteristics of inner urban land use areas (blue line) – see use case on Greyfield Precinct Design Assessment.

These include:

- reducing mean BMI of residents from a mean of 27.6 (overweight) to a mean of 24.3 (normal weight), thereby reducing risk of developing Type 2 Diabetes and cardiovascular disease
- increasing people’s self-reported general health status
- increasing perceptions of safety after dark
- increasing self-reported levels of life satisfaction
- increasing self-reported levels of mental health
- increasing the average amount of time people spend walking by about 50 minutes per person, per week
- increasing the reported frequency that people report walking more than 10 minutes by about four occasions per week
- reducing the number of take-away meals people consumed per week by about one meal per fortnight
- reducing the number of minutes of reported weekday driving from a mean of 45 minutes per person per day to under 10 minutes per person per day. Such a change would significantly reduce congestion, reduces risks associated with particulate (e.g. pm2.5, pm10), NOx, and carbon pollution, and reduce risk of road trauma
- increasing the number of reported servings of vegetables people consume per day from one to 1.4
- increasing perceptions of the benefits of multiculturalism.
However, there may also be some disadvantages associated with a movement towards more compact, inner urban land-use configurations. These include:

- reduced perceived social capital
- an increase in the number of minutes of estimated sitting per weekday and weekend day of about 50 to 60 minutes per day, respectively (potentially associated with more desk-based employment among people living near/commuting to the CBD)
- reduced reported vegetable consumption.

Figure 9.11: Output chart from the LCL-CBC demonstrating differences in estimated health and wellbeing outcomes associated with inner urban (blue) and middle suburban (red) areas of Melbourne

This analysis demonstrates that, controlling for household income and levels of education, compact urban form may have co-benefits across many self-reported physical and psychological health measures. Further, it demonstrates that alternative urban forms that can potentially achieve such changes are not outside the realms of possibility; these areas already exist. Planners and developers can take clear cues from the characteristics of high-performing areas across health and productivity criteria, promoting these same characteristics in greenfield or regenerative infill projects.

References

9B. Precinct Scale Health and Well-Being Benefits Linked to Built Form

Jason Thompson and Mark Stevenson, University of Melbourne

9B.1 Outline and Rationale

The small-scale case study described here demonstrates how the LCL-CBC can be used to identify relative advantages (as well as challenges to be redressed) associated with specific small-scale precinct selection for redevelopment. The objective of this example is to show how the locational targeting of renewal precincts may be associated with likely development outcomes and how this may consequently influence the choice of location and the scope of development envisaged for urban planning and design interventions.

9B.2 Data and Inputs

The LCL-CBC tool has been designed to enable planners and property developers to input their own precinct design and development project data through a GIS interface that can accept polygons, point locations, corridors, or uploaded pre-configured shape-files.

In this example, we examine the difference in expected co-benefits of proposed small-scale redevelopments of approximately 4000m² identified for locations equidistant from the central business district (~13 km) but located on either side of a major Melbourne arterial road, the Monash Freeway. In doing so, we demonstrate that small distances between locations of proposed re-development precincts can have potentially large impacts on the way people live and interact in the precinct. The two areas to be compared are highlighted in Figure 9.12.
Figure 9.12: Comparative analysis of health and productivity performance of urban precincts

These aerial views appear to be very similar. They are both the same distance from the CBD, have medium density housing, are similar distances to the freeway, and are characterised by grid-based roads. At first glance, the health and productivity differences between choosing to invest in regenerating one area in favour of the other would seem minimal.
9B.3 Outputs, Findings and Implications

Despite the ostensible similarities between Areas 1 and 2, the small-scale precinct analyser shows that the land-use characteristics of these areas are very different (see Figure 9.13). Most of Area 1 falls into a Connected pockets, or Inner Urban cluster (see previous metropolitan case study). Even before an attempt at area regeneration, Area 2 demonstrates better access to public transport, commercial buildings, public facilities, educational facilities, and other local services that are not in Area 1. Therefore, the comparative performance of these areas across a range of health and productivity measures is also likely to differ.

![Figure 9.13: Differences in access to public transport depicted across the selected areas of analysis](image)

The small-scale precinct analysis enables planners and developers to assess the associations between urban form clusters and potential co-benefits shown from the metropolitan scale analysis. Also, this comparative analysis suggests that Area 1 is a better candidate for higher density residential redevelopment given its higher amenity in relation to public transport access.

Furthermore, it enables further insights in relation to redevelopment by assessing individual land-parcels contained within the proposed precinct boundary and their redevelopment potential [see ENVISION use case]. The translation of these differences provides health and productivity insights. For example, in comparison to residents of Area 2, residents of a regenerated Area 1 are likely to:

- drive an average of about 12 minutes less per person per day, improving productivity, and reducing vehicle pollution, and potentially reducing requirement for car-parking
- walk for an average of 80 minutes per person per week more than residents in Area 2
- walk for more than 10 minutes at a time on three or more occasions per week
- spend about 20 minutes less time sitting per person per day

Therefore, while improvements could be made to the urban form of Area 2, a redevelopment site selected in Area 1 already has features that promote health and low-carbon living for existing as well as additional new residents that need to be attracted to medium-density infill housing in established suburbs – a major challenge for Plan Melbourne 2017-2050 (Newton, Meyer, & Glackin, 2017).

References

Mitigating Urban Heat
Lan Ding and William Craft, University of New South Wales
10. Mitigating Urban Heat

10.1 Introduction

Precinct development in greenfields, brownfields and greyfields must consider the impact of extreme heat now and into the future as it can have significant influence on the liveability of a precinct and the health of its inhabitants. There are a number of analytical models and experimental evidence related to urban heat island (UHI) effects, especially within the CRCs for Water Sensitive Cities and Low Carbon Living. However, most of the UHI analysis has been conducted using GIS and remote sensing technologies on a large-scale.

There is a lack of integrated UHI analysis across precinct and building scales to support precinct development assessment by local governments and urban planners and designers. So, it has been difficult for government and urban development decision-makers who do not possess the required technical knowledge to use current analytical models and algorithms, or to select the proper combination of mitigation techniques to examine urban heat implications of development proposals at increasingly higher-built density.

The CRCLCL funded a research project (RP2023) to address the gap between urban microclimate research and its practical application. The project aims to develop a robust and tangible urban heat island mitigation tool to support well-informed decisions about urban heat mitigation in a local context, that is accessible to government, developers and planners. The challenge is real. For example, differences in temperature across Sydney can be as much as six to 10 degrees centigrade between the Eastern and Western suburbs, and heat-related deaths in the Western Suburbs can be up to three times higher than in the Eastern Suburbs during extreme heat waves (Santamouris et al., 2017b).

The project adopts urban development approaches to mitigate urban heat and answers the following research questions:

- can innovative urban development approaches reduce the heat island effects and minimise the impact of increasing temperature extremes on outdoor thermal comfort, human health and energy consumption?
- to what extent do particular aspects of urban form, parks, greenery, waterways, building elements (e.g. facades, roofs) and urban heat mitigation techniques (e.g. evaporative techniques, reflective materials) help reduce urban heat island effects?

10.2 Objectives

The research project has the following objectives:

1. develop a systematic urban scenario analysis tool to inform development assessment, planning practices and urban policy related to potential building and urban interventions capable of urban cooling. The scenario analysis can be used to cool streetscapes and cities, reduce energy consumption, protect the health of the vulnerable, and improve thermal comfort
2. perform an urban heat island mitigation analysis across building, precinct and city scales
3. develop an Urban Heat Mitigation Performance Index to support government in establishing performance targets for their planning controls at municipal and metropolitan levels. This index will be linked to A Heat Vulnerability Index for Metropolitan Sydney developed by UNSW (Bodilis et al., 2017).
10.3 Schematic Representation and Description of Tool

The microclimate and urban heat island decision-support tool (UHI-DS) provides scenario analysis of precinct development options and possible cooling interventions, and estimates urban heat mitigation outcomes to inform urban policy and development assessment (Figure 10.1).

The outcomes are achieved by adopting computational simulation and artificial neural network methods as well as scientific models such as prediction of reduction of peak electricity demand (Santamouris et al., 2017a) and assessment of the thermal performance of green infrastructure (Koc et al. 2018). Four representative urban precincts were selected to demonstrate the methods and utility of the UHI-DS tool (Table 10.1).

<table>
<thead>
<tr>
<th>CBD Redevelopment</th>
<th>Parramatta Civic Link</th>
<th>Parramatta Council</th>
<th>Western Sydney</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Square Town Centre</td>
<td>Landcom, City of Sydney</td>
<td>City of Sydney</td>
<td></td>
</tr>
<tr>
<td>Greenfield Development</td>
<td>Leppington</td>
<td>Stockland, Campbelltown Council</td>
<td>Western Sydney</td>
</tr>
<tr>
<td>Macarthur Heights</td>
<td>Landcom, Campbelltown Council</td>
<td>Western Sydney</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10.1: UHI-DS Tool Framework
10.4 Characterising the Microclimate of a Precinct

Characterising the microclimate of a precinct in relation to heat extremes is the first step in the analysis. It will identify urban heat challenges in a precinct and assist in validation of UHI mitigation prediction models. Microclimate characteristics at a precinct scale comprise key variables such as air temperature and humidity, surface temperature, wind speed and direction. Figure 10.2 illustrates thermal environments of the four exemplar precincts collected over Sydney’s 2017/18 summer, where different surface temperatures are represented in different colours.

Figure 10.2: Thermal environments of the four exemplar precincts
10.5 Identifying Precinct Development Characteristics

Precinct development characteristics provide a local context for urban heat mitigation analysis. There are different urban characteristics in CBD redevelopments compared to greenfield developments, such as urban form, population, density, building type, public and private space and vegetation. It is critical to identify precinct development characteristics because they provide insight into the specific urban heat challenges of a precinct. Figure 10.3 and Figure 10.4 illustrate key development characteristics of CBD and greenfield environments using Parramatta and Macarthur Heights as examples.

<table>
<thead>
<tr>
<th>CBD Redevelopment (Parramatta)</th>
<th>Precinct Development Characteristics</th>
</tr>
</thead>
</table>
| Image: Parramatta City Council | • **Location:** Project is bounded by Parramatta river to the north, Parramatta train station to the south, Marsden St to the west, Smith St to the east  
• **Municipality:** Parramatta City Council  
• **Zones:** Includes both B3 Business Core and B4 Mixed-Use Zones  
• **Land-use:** Mixed-use area with heritage buildings, public spaces and plans for significant redevelopment of multiple sites  
• **Proposed development:** Two proposed pedestrian links for the future – Civic link and along Church St  
• Includes the Parramatta Light Rail corridor along Macquarie St and Church St  
• **Population:** Residential population expected to grow to 34,600 by 2036; working population expected to grow to 83,000 by 2041 |

Figure 10.3: Examples of key development characteristics of CBD: Parramatta, Western Sydney

<table>
<thead>
<tr>
<th>Greenfield Development (Macarthur Heights)</th>
<th>Precinct Development Characteristics</th>
</tr>
</thead>
</table>
| Image: UNSW | • Project area: 122ha  
• Location: The project is located alongside the Western Sydney University (WSU) campus at Campbelltown, bounded by Narellan Rd, the Hume Highway and the main southern railway line  
• **Municipality:** Campbelltown City Council  
• **Delivery timing:** 2014–2019  
• **Proposed residential lots:** 966 lots  
• **New residents:** 2,460  
• **Zones:** R3 – Medium Density Residential Zoning  
• **Stage 5 construction (future key development area for UHI-DS scenario analysis):** Starting mid-2018 |

Figure 10.4: Example of key greenfield development characteristics: Macarthur Heights, Western Sydney
10.6 Identifying Precinct Development Challenges

Precinct development challenges vary depending on urban heat issues and precinct characteristics. For example, lack of urban vegetation, need for increased density to match the population growth, and poor outdoor thermal comfort during extreme heat days are the major challenges for CBD redevelopments. The main challenges for greenfield developments are increasing private open (green) space, introducing lighter roof colours and materials, and decreasing reliance on air conditioning. Reduced private open (green) space, introducing lighter roof colours and materials, and increased reliance on air conditioning are main challenges for greenfield developments (Table 10.2). These challenges can be addressed through scenario analysis provided by the UHI-DS tool.

Table 10.2: Examples of main challenges for CBD and greenfield developments

<table>
<thead>
<tr>
<th>Main challenges For cbd redevelopments</th>
<th>Main challenges For greenfield developments</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Poor outdoor thermal comfort during extreme heat days:</td>
<td>• Reduced private open space:</td>
</tr>
<tr>
<td>• Reduced economic performance for street level retail and increased health risk for the vulnerable (elderly, children &amp; disabled)</td>
<td>• Reduced private open space due to high concentrations of large detached dwellings on smaller lot sizes</td>
</tr>
<tr>
<td>• Lack of urban vegetation:</td>
<td>• Dark roof materials:</td>
</tr>
<tr>
<td>• Less urban vegetation and green infrastructure due to urban form and change of land use, e.g. Parramatta CBD has a canopy coverage of 9% whereas best practice target is about 15% (Civic Link Framework, 2017); Green Square was previously an industrial precinct with minimal vegetation</td>
<td>• Detached dwellings often have predominantly darker roof materials. There is a need for local governments and developers to endorse high performing cool roof materials through development guidelines and planning control</td>
</tr>
<tr>
<td>• Need for increased density to match residential and working population growth:</td>
<td>• Increased reliance on air conditioning:</td>
</tr>
<tr>
<td>• To accommodate population growth and reduce urban sprawl, CBD precincts require significant increases in density, e.g. Parramatta CBD’s residential population is forecast to be 34,600 by 2036 and its working population to be 83,000 by 2041 (City of Parramatta, 2017).</td>
<td>• Limited places of relief from extreme heat for those without air conditioning and/or a swimming pool.</td>
</tr>
</tbody>
</table>
10.7 Providing Scenario Analysis of Mitigation Options

The UHI-DS tool provides scenario analysis of mitigation options to address precinct development challenges. It provides an interactive 3D visualisation platform capable of testing various urban heat mitigation scenarios to support precinct development assessment and decision-making. The scenario analysis of mitigation options falls into two major categories – built form and public realm – to support urban heat mitigation decision-making based on specific precinct development characteristics. Table 10.3 shows examples of scenario analysis options provided by the UHI-DS tool for CBD redevelopments.

Table 10.3: Examples of scenario analysis of urban heat mitigation options for CBD redevelopments

<table>
<thead>
<tr>
<th>Example Scenarios for CBD Redevelopments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BUILT FORM</strong></td>
</tr>
<tr>
<td>• Building Height</td>
</tr>
<tr>
<td>• <strong>Parramatta Case:</strong> Impact of existing and proposed building heights surrounding public spaces and along proposed pedestrian links</td>
</tr>
<tr>
<td>• Building Footprint</td>
</tr>
<tr>
<td>• <strong>Parramatta Case:</strong> Impact of building setbacks and footprints of future buildings along proposed pedestrian links</td>
</tr>
<tr>
<td>• Façade Materials</td>
</tr>
<tr>
<td>• <strong>Green Square Case:</strong> Impact of façade materials (high albedo, high emittance and green walls) for all proposed buildings over six storeys</td>
</tr>
<tr>
<td>• Roof Materials</td>
</tr>
<tr>
<td>• <strong>Green Square Case:</strong> Impact of roof materials (high albedo, high emittance and green roofs) based on Green Star Communities Urban Heat Credit requirements</td>
</tr>
<tr>
<td>• Awnings</td>
</tr>
<tr>
<td>• <strong>Parramatta Case:</strong> Impact of building awnings (3m width and 4.5m vertical clearance) along proposed pedestrian links.</td>
</tr>
<tr>
<td><strong>PUBLIC REALM</strong></td>
</tr>
<tr>
<td>• Hard-Scape Surface Materials</td>
</tr>
<tr>
<td>• <strong>Parramatta and Green Square Cases:</strong> Impact of cool, permeable, high albedo, vegetated or light-coloured pavements within proposed public spaces and pedestrian links</td>
</tr>
<tr>
<td>• Water</td>
</tr>
<tr>
<td>• <strong>Parramatta and Green Square Case:</strong> Impact of the Parramatta River on the northern boundary of the CBD and impact of water misting within proposed public spaces and pedestrian links</td>
</tr>
<tr>
<td>• Vegetation</td>
</tr>
<tr>
<td>• <strong>Green Square Case:</strong> Impact of vegetation, trees, and landscaping design within the proposed public parks, plazas and streets</td>
</tr>
<tr>
<td>• External Shading Structures</td>
</tr>
<tr>
<td>• <strong>Parramatta and Green Square Cases:</strong> Impact of external shading structures within the proposed public parks and plazas.</td>
</tr>
</tbody>
</table>
10.8 Integration of BIM and GIS

PIMs are developed to link BIM and GIS to provide an integrated smart information environment to support urban heat mitigation analysis across building and precinct scales. GIS provides spatial data of a precinct including land uses, street networks, green infrastructure, etc. BIM models contain rich semantic information of buildings, including not only building geometry but also building components and their properties, such as facade and roof materials, awnings, etc. Precinct information models created here are based on CityGML (an open standardised data model) to store 3D precinct information that links to GIS and BIM. The integrated digital information environment enables the UHI-DS tool to provide an interactive urban heat mitigation analysis and decision-support across building and precinct scales.

10.9 3D Visualisation of Outcomes

The UHI-DS tool provides 3D visualisation for current precinct conditions and proposed precinct developments, as well as their impacts on urban heat intensification and mitigation. Furthermore, the tool provides opportunities to make changes to development options and mitigation strategies on the 3D visualisation platform, and then view the impact of those changes in real-time. Figure 10.5 shows an example of 3D visualisation of part of proposed Green Square redevelopments (City of Sydney, 2018) and an overlay of potential ground cover temperature distribution from the UHI-DS tool.
10.10 UHI Mitigation Index (Linking to Urban Heat Vulnerability Index)

The Urban Heat Mitigation Performance Index (UHMPI) is hosted on an online interactive portal that provides additional support to local governments, developers and urban planners to mitigate extreme heat in addition to the UHI-DS tool. The UHIMPI provides mitigation strategies and alternatives to support building planning, public realm and community program planning decisions (Figure 10.6).

Furthermore, it is linked to the Urban Heat Vulnerability Index (UHVI) (Bodilis et al., 2017) to allow users to query vulnerability information of a population to support UHI mitigation decision-making. The UHVI was developed using the Intergovernmental Panel on Climate Change (IPCC) methods (IPCC, 2007) comprising of three sub-indexes: Exposure, Sensitivity and Adaptive Capacity (refer to Use Study). Both UHIMPI and UHVI are linked with the UHI-DS tool to provide complementary analysis.

10.11 Scope of Application

The UHI-DS tool is developed to support urban development assessment and enable local governments, developers and urban planners to make informed decisions about mitigating urban heat island effects. The UHI-DS tool is a web-based application and free to use under an open source license. The use of the tool is demonstrated with four representative precincts in Greater Sydney, however, it can be tailored to other urban contexts as well.
Figure 10.6: UHI Mitigation Performance Index Structure
### 10.12 Input Data and Sources

The input data required for the UHI-DS tool is outlined in Table 10.4. The UHI-DS tool represents precincts in an online 3D visualisation platform and explores alternative mitigation strategies based on its specific microclimatic conditions.

#### Table 10.4: Input data and sources

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Source / Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured microclimate conditions</td>
<td>Air temperature</td>
<td>Bureau of Meteorology (BOM), drone with a thermal camera, weather station (EnergyBus, ground measurements)</td>
</tr>
<tr>
<td></td>
<td>Air humidity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface temperature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind speed</td>
<td></td>
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<tr>
<td></td>
<td>Wind direction</td>
<td></td>
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<tr>
<td></td>
<td>Barometric pressure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solar radiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface radiation balance</td>
<td></td>
</tr>
<tr>
<td>Current urban conditions and future development plans</td>
<td><strong>Built form</strong></td>
<td>GIS Data, BIM, CAD Drawings, SketchUp models, 3D models in PDF, masterplans, development applications (DAs)</td>
</tr>
<tr>
<td></td>
<td>• 3D building models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Building roof materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Building façade materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Awnings</td>
<td></td>
</tr>
<tr>
<td>Public realm</td>
<td>• 3D city models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Vegetation and trees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Roads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Urban surface materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Public space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• External shading structure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water body, misting, etc.</td>
<td></td>
</tr>
<tr>
<td>Government planning controls</td>
<td>• Development control plans (DCP)</td>
<td>Local governments</td>
</tr>
<tr>
<td></td>
<td>• Local environmental plans (LEP)</td>
<td></td>
</tr>
<tr>
<td>Design guidelines by developers</td>
<td>• Design guidelines</td>
<td>Developers</td>
</tr>
</tbody>
</table>
It is crucial for the 3D visualisation platform to present both current urban conditions and future development plans of precincts. The data requirements for this include spatial data (GIS), development masterplans, and building scale information provided through BIM, CAD drawings, DAs and so on. Local council development control plans (DCP), local environmental plans (LEP) and developers’ design guidelines are needed to inform any future development within precincts. Each precinct’s development priorities are extracted from these data sources to ensure mitigation scenario options are consistent with future development directions.

On-site microclimate measurements are essential and are drawn from weather stations, ground level measurements and drones. The weather stations record wind speed and direction, air temperature, barometric pressure and dew point. Pyranometers and pyrgeometers are used for ground level measurements to derive net radiation, albedo and sky and surface temperatures. A drone equipped with a thermal camera is used to determine the surface temperatures of different urban fabrics within the precinct.

### 10.13 Key Outputs and Performance Indicators

Key outputs of the UHI-DS tool are the assessment outcomes from the mitigation scenarios generated using computational modelling, neural network analysis and scientific assessment models. Computational modelling methods are employed to estimate surface and air temperature distributions in the precinct, which can be validated through on-site measurements. Scientific assessment models are employed to predict the peak electricity demand during a summer period. A neural network approach is developed to provide scenario analysis of mitigation options for decision-makers.

The assessment results from mitigation scenario analysis fall into four categories: Predicted Surface and Air Temperature Distributions, Outdoor Thermal Comfort Index, Annual Cooling Load Savings and Reduction of Peak Electricity Demand, which are measured through a set of key performance indicators (Table 10.5). Predicted Surface and Air Temperature Distributions can be visualised on the 3D visualisation platform.

A comparative analysis between the existing precinct and proposed precinct developments with mitigation options is supported by the UHI-DS tool. Outdoor Thermal Comfort is measured through Universal Thermal Climate Index (UTCI), which is derived from air temperature, humidity, radiation and wind speed of precincts. Annual Cooling Load Savings are based on the reduction of annual cooling degree days (CDD), which is influenced by the outdoor air temperature during a year. Reduction of Peak Electricity Demand is predicted based on the data from Australian Energy Market Operator and temperature profiles over a summer period using statistical methods (Santamouris, 2017a).

Table 10.5: Assessment results and key performance indicators from the UHI-DS tool

<table>
<thead>
<tr>
<th>Assessment Results</th>
<th>Key Performance Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface and Air Temperature Distributions</td>
<td>Air temperature</td>
<td>Street level air temperature</td>
</tr>
<tr>
<td></td>
<td>Surface temperature</td>
<td>Ground cover surface temperature</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>Solar radiation</td>
</tr>
<tr>
<td></td>
<td>Humidity</td>
<td>Air humidity</td>
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<tr>
<td></td>
<td>Wind speed</td>
<td>Wind speed</td>
</tr>
<tr>
<td></td>
<td>Wind direction</td>
<td>Wind direction</td>
</tr>
<tr>
<td>Assessment Results</td>
<td>Key Performance Indicator</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>---------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Outdoor Thermal Comfort Index</td>
<td>UTCI</td>
<td>The air temperature of the reference environment, which produces an equivalent dynamic physiological response according to a human thermoregulation model (Bröde, P, et al., 2011). Factors that influence UTCI are air temperature, humidity, radiation and wind speed</td>
</tr>
<tr>
<td>Annual Cooling Load Savings</td>
<td>Reduction of CDD</td>
<td>CDD is a measurement to quantify the demand for energy needed to cool a building in a particular location over a year</td>
</tr>
<tr>
<td>Reduction of Peak Electricity Demand</td>
<td>Peak demand during the summer period</td>
<td>It refers to the electricity power required in a certain period that is significantly higher than average supply levels. A key factor that influences peak electricity demand is the temperature profiles throughout this period.</td>
</tr>
</tbody>
</table>

References


City of Sydney, (2018) Green Square redevelopment plans and models, Working Documents,


Santamouris, M. (2017a) Cooling Western Sydney – A Strategic Study on the Role of Water in Mitigating Urban Heat in Western Sydney, presentation slides

10A. Urban Heat Vulnerability Index for Greater Sydney

Carole Bodilis, University of New South Wales and University of Aveiro, Aveiro, Portugal, Komali Yenneti and Scott Hawken, University of New South Wales

10A.1 Outline and Rationale

Sydney regularly scores highly in city liveability rankings. However, these rankings mask vulnerable populations and the city’s risk to extreme heat conditions in the face of climate change. Managing and mitigating urban heat requires a good understanding of urban vulnerabilities and how this occurs throughout cities. The UHVI developed by UNSW researchers allows governments, developers and urban planners to identify the most vulnerable populations geographically throughout the Greater Sydney area. It provides visualisation of spatio-temporal patterns of population vulnerability across a city at the Statistical Area 2 (SA2) level. The UHVI is linked to the UHI-DS tool to support comprehensive UHI mitigation analysis.

The UHVI comprises socio-economic, meteorological, built-environment and governance indicators that influence the vulnerability of populations to extreme heat conditions. This can involve a combination of one or more of the following:

- socio-economic conditions (poverty, inequality, access to education, etc.)
- hard and soft built environment surfaces (roads, vegetation, buildings, etc.)
- local climate conditions (extreme heat days)
- water bodies
- housing types
- demographic characteristics (population density, women, elderly population, indigenous population, children, etc.)
10A.2 Data and Inputs

The UHVI for Greater Sydney is built on the existing literature on heat vulnerability (Loughnan et al., 2012) but uses the IPCC’s methodology on vulnerability to climate change (IPCC, 2007). It is a function of three sub-indices: exposure, sensitivity and adaptive capacity (Figure 10.7). An increase in exposure and sensitivity results in an increase in vulnerability, while an increase in adaptive capacity results in a diminution of the overall vulnerability.

Figure 10.7: Impact of sub-indices on the final vulnerability index

The following list outlines the input data for the UHVI to assess urban heat vulnerability for Greater Sydney (Figure 10.8).

Figure 10.8: Vulnerability index, Sub-indices and Input data
10A.3 Outputs, Findings and Implications

The UHVI is an indicator-based web application which provides users with a range of information on vulnerability through dynamic visualisations. The outputs can show spatio-temporal patterns of vulnerability, three sub-indices and 18 sub-indicators at the smallest area level as defined by the ABS for the years 2011 and 2016.

Overall Vulnerability Outputs: The results show that hotspots of heat vulnerability in Sydney are located along the highly urbanised Inner West and near the CBD, combined with socio-economically marginalised areas (from Parramatta to Penrith and from Liverpool to Campbelltown). Average levels of vulnerability are identified in less urbanised suburbs in the North West and South West, while areas near national parks have the lowest levels of vulnerability (Figure 10.9).

![Figure 10.9: Outputs of UHVI Vulnerability Analysis in Greater Sydney](image)

Findings from the three sub-indices are presented below.

**Exposure:** Socio-economic indicators combined with meteorological conditions – number of extreme heat days (>38°C), population density, road density, poverty and inequality. *Analysis Outcome:* High exposure levels are observed in concentrated poverty and inequality areas around Fairfield, high population and dense hard surface CBD (Surry Hills, Redfern) and a hotspot (>38°C) around Penrith (outer western suburbs).

**Sensitivity:** Population characteristics-based indicators comprising elderly population (>65yrs), young children (<4yrs), women, people living alone and needing care, indigenous people, and housing (multi-dwellings). *Analysis Outcome:* Sensitivity factors exacerbate exposure and vulnerability of a population, and therefore the sensitivity outcomes are directly proportional to that of exposure. Hotspots of high sensitivity are around Penrith, Lethbridge Park, Liverpool, and CBD.

**Adaptive Capacity:** Heat mitigation and risk coping-based indicators – access to internet, tree canopy and parklands, water bodies, education and local government expenditure. *Analysis Outcome:* Hotspots with low levels of adaptive capacity are around less green Waterloo, and socially disadvantaged areas around Fairfield and Liverpool.
The results show the spatial patterns of vulnerability in areas with less green space, greater urban density and higher socio-economically marginalised populations. The UHVI provides an invaluable interactive information resource to help governments, developers and designers more clearly identify and address urban heat challenges in order to create more resilient and liveable cities and communities.

When linked with the UHI-DS tool, the UHVI can support well-informed decision-making for urban heat island mitigation, in particular the effective mitigation strategies for vulnerable populations and neighbourhoods.

References


Bodilis, C., Yenneti, K. and Hawken, S., UHVI: https://arcg.is/0quK4H
10B. Mitigating Urban Heat for the Green Square Town Centre Redevelopment

William Craft, Henry Petersen, Shamila Haddad, Lan Ding and Mat Santamouris, University of New South Wales

10B.1 Outline and Rationale

Green Square is one of Sydney’s many inner-city redevelopment areas. Between 2011 to 2016, the Green Square area almost doubled in population density and the number of days above 38°C rose to four in 2016 (Bodilis et al., 2017). This poses increased heat stress risk for its inhabitants.

The UHI-DS has been applied to the Green Square Town Centre (GSTC) redevelopment to assist City of Sydney Council and developers to effectively mitigate these extreme heat conditions. To support City of Sydney’s aspiration for a world-class resilient community in the heart of Sydney, the UHI-DS tool provides decision-support for assessing the urban heat implications of development proposals. The objective is to enable decision makers to determine what the most effective urban design interventions are in reducing air temperature in the GSTC redevelopment precinct during extreme heat conditions.

10B.2 Data and Inputs

GSTC is an inner-city redevelopment area of Sydney that is being transformed from an industrial precinct into a thriving residential community. The planned Town Centre is a 14 ha urban renewal project within the larger redevelopment of Green Square (278 ha), which is expected to provide over 30,000 new residential dwellings by 2030. The Town Centre is currently under development and upon completion it will house a wide range of residential, mixed-use and community facilities, including a new aquatic centre and library.

The following list outlines the input data for assessing urban heat mitigation strategies in GSTC:

- Urban heat characteristics of existing GSTC (Figure 10.10):
  - air temperature and humidity
  - surface temperature
  - wind speed and direction
  - barometric pressure
  - solar radiation
  - surface radiation balance
- Current and future development plans (Figure 10.11), City of Sydney and Landcom:
  - 3D building and city object models
  - building material properties
  - vegetation and trees
  - street network
  - surface materials
  - public space
- Government planning controls:
  - Green Square Town Centre Development Control Plan 2012
Figure 10.10: Urban heat characteristics of GSTC precinct

Figure 10.11: Future GSTC development plans (Landcom, 2017)
10B.3 Outputs, Findings and Implications

The UHI-DS tool is a performance-based decision-support platform which enables users to quickly and easily trial alternative mitigation measures to assess their impact in real-time. Initial results from applying the UHI-DS tool to the GSTC redevelopment show the impact of the proposed redevelopment and the potential of alternative design interventions and mitigation strategies to reduce air temperature in the precinct during extreme heat conditions.

The scenario analysis was conducted for GSTC using the heat wave conditions experienced in Sydney over the summer of 2017-2018 as the microclimate context (using the air temperature at 2pm on a heat wave day in February 2018). The results of the mitigation potential of several planning scenarios for GSTC are presented in Figure 10.12 and Table 10.6.

**Proposed GSTC Redevelopment:** Comprises a number of planned buildings, new street networks and public open spaces. *Analysis Outcome:* Hot spots identified through modelling included the Library Plaza (38°C), the Drying Green (37.5°C) and an open area to the east of the Aquatic Centre (36°C). These were likely due to the relative lack of outdoor shade and tree canopy cover.

**A Plan of Trees and Vegetation:** Planned tree canopy cover of the GSTC redevelopment, which includes street tree planting along new street networks and in the new public parks (City of Sydney, 2018). *Analysis Outcome:* GSTC Precinct reduction in average air temperature of 0.6°C, and maximum reduction in local air temperature of 2.4°C.

**Compliance with Green Star Communities Urban Heat Island Credit Requirements:** Increased cool pavements, roads and roofs to meet minimum Green Star Communities Urban Heat Island Credit requirements (Green Building Council of Australia, 2016). *Analysis Outcome:* GSTC Precinct reduction in average air temperature of 0.7°C, and maximum reduction in local air temperature of 2.5°C. Cool pavements and roads were effective at reducing air temperature.

**Combination of Mitigation Options:** Cool and green roofs on most buildings where feasible, cool surfaces for pavements and roads, water evaporative systems such as misting cooling systems in the Library Plaza area and a plan for a small water body. *Analysis Outcome:* GSTC Precinct reduction in average air temperature of 1.3°C, and maximum reduction in local air temperature of 6°C by water evaporative systems. The large reduction in local air temperature is due to the localised impact of the water evaporative systems in the Library Plaza area.
The urban heat scenario analysis of GSTC using the UHI-DS tool can identify hot spots in the precinct and examine the effectiveness of current and alternative planning decisions to mitigate extreme heat conditions. Due to the limitation for urban greenery within GSTC, alternative mitigation strategies are required to effectively reduce air temperature and to meet Green Star Communities requirements. Analysis results from the UHI-DS tool suggest that alternative mitigation strategies for GSTC can be focused on the large open spaces within the public realm and combined mitigation options including cool pavements, evaporative systems, etc. Water evaporative systems are a highly effective strategy to reduce localised air temperature in those areas.

The benefit of the UHI-DS tool is that it allows users to explore these different mitigation strategies in a specific urban development context and see their localised and precinct-wide impact in real-time (Figure 10.13). The UHI-DS tool therefore offers an effective means of scenario-based planning and decision making for governments, developers and planners seeking to reduce urban heat within their precincts.
Figure 10.13: Example of part of planned buildings in GSTC and overlay of potential ground cover surface temperature distribution from the UHI-DS tool

References


Section 11

Integrated Precinct Assessment

Peter W. Newton, Swinburne University of Technology
11. Integrated Precinct Assessment

11.1 Introduction

The design of a precinct in any of the greenfield, brownfield or greyfield areas represents an opportunity to pursue multiple urban objectives aligned to the Council of Australian Government’s vision for the performance of Australia’s cities (Department of Infrastructure and Transport, 2011): competitive, productive, liveable, environmentally sustainable and socially inclusive; and more recently, resilient to climate change (Department of Environment, 2015).

Realising this vision, however, involves engagement with the mix of challenges and opportunities afforded by a particular site, its wider spatial and functional context, and the range of governance and market processes surrounding its development. It is a complex, multi-factor process.

Brownfield sites present significant opportunities for regenerative urban development, given that they are frequently strategically located in central city locations and are of a size that permits a range of design and technology responses to be explored. The challenge is to provide a process that will enable multiple stakeholders and enablers to engage in early concept visioning and sketch designing in an open, transparent and timely manner; and to have a range of innovative development scenarios assessed as rapidly as possible to determine performance against objectives, value propositions etc. (refer Chapter 3). Design charrettes as originally conceived can perform a number of important functions, such as concept generation and possible design strategies, but typically lacked a facility for rapidly assessing alternative development scenarios with the result that innovative ideas tended to be ignored and abandoned in favour of more concrete, tested, business-as-usual solutions (Willis, 2010).

There are many examples of such outcomes in Australian urban renewal projects (e.g. the failure of Melbourne’s Docklands redevelopment to incorporate any new precinct-scale energy, water or waste technologies; Newton and Thomson, 2017).

The concepts of Integrated Assessment and Research Synthesis were first applied by the CRC for Water Sensitive Cities (https://watersensitivecities.org.au/solutions/research-synthesis/) as a process for generating new ideas and applying and testing research in real-world situations. They provide an environment where domain experts and their specialist building and precinct assessment tools (often advanced research-based prototypes) can be brought to bear on challenging urban development projects.

11.2 Case Study

11.2.1 Objectives

A project undertaken jointly by the CRCWSC and the CRCLCL (2015) on a 258ha brownfield urban redevelopment project in inner Melbourne (Fishermans Bend, see Figure 11.1) was designed to identify precinct urban design concepts capable of accommodating a future (2055) resident population of 80,000 to 120,000 that were:

- water sensitive – minimising the import of potable water into the precinct; exporting wastewater; mitigating flood hazards and avoiding stormwater pollution of urban waterways
- carbon negative – generating electricity from renewable energy that is surplus to the requirements of buildings and occupants
- biophylic – optimising the exposure of the community to natural elements e.g. green space and vegetation, water features, natural ventilation and light.
Providing options to integrate in-building and in-precinct water and energy management therefore became an essential urban design consideration from the earliest phases in the precinct planning process. The public realm also needed to respond to the soil contamination of the site attributed to past industrial land uses and the historical vulnerability of the site to flooding.

Given this context, the CRC Research Synthesis project sought to identify regenerative redevelopment options capable of application to Fishermans Bend that would significantly and materially reduce demands and reliance on currently stressed centralised energy, water and sewerage infrastructure systems using decentralised water and sewerage systems plus distributed renewable energy technologies.

Source: CRCWSC and CRCLCL (2015)
Figure 11.1: Location of Fishermans Bend
11.2.2 Method

Research Synthesis projects provide a mechanism for integrating diverse objectives and urban design responses into site-based development scenarios/solutions (Figure 11.2). Three research synthesis workshops were held between October 2014 and February 2015 to scope the ideas for Fishermans Bend.

These workshops were attended by a large number of researchers from the two CRCs as well as representatives of CRCWSC participant organisations: Department of Environment, Land, Water and Planning, Melbourne Water, South East Water, City of Melbourne, City of Port Phillip, City West Water, Yarra Valley Water, Department of Health, Environment Protection Authority Victoria, and GHD. Representatives from the Metropolitan [now Victorian] Planning Authority also took part in the workshops.

The sequential meetings involved:

- Workshop 1: the focus was on understanding precinct development objectives from state and local government perspectives as well as hearing from CRC researchers outlining frontiers in energy and water research relevant to the precinct and the types of tools capable of being employed in design assessment
- Workshop 2: CRC domain experts and leading practitioners outlined a number of design options that had undergone preliminary performance assessment to gauge level of acceptance and seek input into a further round of scenario assessments
- Workshop 3: provided a final set of precinct design concepts that are outlined in Ideas for Fishermans Bend (CRCWSC and CRCLCL, 2015; https://watersensitivecities.org.au/content/ideas-for-fishermans-bend/).
Figure 11.2: Summary of key ideas for buildings and precincts in Fishermans Bend

**FISHERMANS BEND**
- Central green spine(s)
- Grey water to potable reuse
- Third pipe as a collector system
- No regrets local waste water treatment plant design
- Liveability contribution
- Coordinating body
- Policy evaluation

**PRECINCT SCALE**
- Green corridors
- Blue corridors
- Pressure sewer

**BUILDING SCALE**
- Harness the design podium design
- Intelligent systems
- Alternative water harvesting
- World leadership building ratings

- Manage water on the surface
- Maximise microclimate benefits
- Harness potential energy associated with elevated podium design
- Design landscape(s) that tolerate temporary flooding

- Buildings that actively manage stormwater & microclimate
- Maximise reuse opportunities
- Minimise energy footprint at building scale

- Coordinate critical infrastructure from day one
- Staging of development using ‘no regrets’ solutions
- Scale provides water-energy nexus opportunities
- Reduce peaks in water services

- Flood risk reduced
- Microclimate enhanced Active transport enabled
- Water & energy efficient buildings
- Land take for raingardens minimised

- Reduced water & sewer load on central systems
- Liveability for CBD
- Flood risk reduced
- Microclimate enhanced Active transport enabled
- Water & energy efficient buildings
- Land take for raingardens minimised

Source: CRCWSC and CRCLCL (2015)
Figure 11.2: Summary of key ideas for buildings and precincts in Fishermans Bend
11.2.3 Key Results

The water sensitive and low carbon strategy to emerge for Fishermans Bend was based on the application of four key principles:

1. adopting a definition of water security that includes flood resilience, environmental performance and liveability as essential elements of security for a city
2. consideration of the water-energy nexus to maintain a balanced approach to sustainability
3. using water services or assets to enhance liveability by maintaining community health and wellbeing, creating a sense of place and ultimately drawing people into Fishermans Bend as a destination in its own right
4. harnessing urban design as a platform to integrate these ideas.

As a result of these site conditions there was a preference to minimise buried services or assets and to use raised podium developments (Figure 11.3). Podium development should be the norm at Fishermans Bend for flood resilience and as an enabler of green infrastructure solutions.

Source: CRCWSC and CRCLCL (2015)
Figure 11.3: Podium development for Fisherman’s Bend

From a catchment perspective, the Fisherman’s Bend site can also be re-shaped to accommodate:

- retreat: making room for temporary flooding in designated open spaces and green corridors
- adaptation: creating source control for stormwater by incorporating natural filtration processes into the urban landscape as well as draining directly to the Bay
- defence: reconfiguring the elevations of the relatively flat topography to create protected spaces that provide areas that offer protection from stormwater and flood water.

In this way, the catchment can be layered to provide a lower stormwater/flood zone where water is conveyed on the surface; and a network of raised podiums and corridors (inspired by New York’s Highline) that create a new, liveable landscape above the flood inundation zone.

To minimise the reliance on central potable water supplies, greywater will be harvested, treated and used as a potable source. Greywater is chosen as the preferred source to minimise the policy, risk management and perception implications often associated with the potable reuse of sewage.
This idea has the additional benefit of concentrating the sewerage waste stream discharged to a centralised wastewater treatment plant or a dedicated local resource recovery plant. This decreases the load on the sewerage system while also aiding resource recovery opportunities.

All buildings are required by the Strategic Framework to provide a third pipe connection to a reticulated system. Transforming the third pipe network from a supply system into a collection system will facilitate the potable reuse scheme. To operate the greywater recycling it is proposed that this network be configured within buildings as a collection system for greywater.

The district system will be connected as an input rather than an output to the proposed local wastewater treatment plant.

The benefits to accrue to this water sensitive precinct design include a 60% reduction in demand for imported potable water due to greywater harvesting and local treatment using 3rd pipe as a collection system; an approximately 70% reduction in discharge to centralised treatment plant; and ~ 2°C mitigation of urban heat island stress through irrigated green space and shaded urban environment.

Given targets for future population and jobs and the proximity to Melbourne’s CBD, high-rise and mid-rise apartments represented the primary dwelling typologies for development and modelling. Building energy modelling using the MUtopia model (Newton et al., 2017) identified opportunities for 70% reduction in operating energy demand compared to BAU practices and regulations by employing 10 star NatHERS, energy efficient built-in and plug-in appliances, and rooftop solar PV.

Innovative building design is a necessary but not sufficient step in maximising carbon mitigation. Distributed solutions will also be required across the four precincts, with rooftop photovoltaic and rooftop solar thermal likely to be the most cost effective options at this scale. To install further distributed renewable energy systems in medium to high-rise developments would mean moving towards vertical facade mounted photovoltaic systems. As the cost of photovoltaic technology decreases, vertical facades become increasingly technically and economically possible. These integrated systems add value by incorporating multiple functions (weather proofing, electricity, heat, cooling, daylighting and insulation) compared with current products. Other precinct-based energy options include cogeneration and trigeneration using natural gas or biogas derived from renewable sources.

In addition, the ideas assembled for Research Synthesis deliver a number of non-market benefits that are a key to achieving the vision for Fishermans Bend. These benefits include a healthier Port Phillip Bay by reducing the harmful discharge of urban stormwater and treated sewerage, and enhanced amenity and health benefits through the creation of an irrigated, green and shady urban environment that also provides connectivity throughout precincts to encourage active transport. The improvements to urban heat mitigation are a further benefit that will contribute to the reduction in hospital admissions for heat stress in this high-density community.

References

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Section 12

Precinct Information Modelling: An Emerging Platform for Integrated Precinct Scale Modelling

Jim Plume, University of New South Wales, David Marchant, Woods Bagot and John Mitchell, University of New South Wales
12. Precinct Information Modelling: An Emerging Platform for Integrated Precinct Scale Modelling

12.1 Introduction

The term “precinct” can be used interchangeably with neighbourhood, district and community. With the increasing adoption of digital city models, it is appropriate to define precincts in terms of how they might be digitally represented. A precinct represents an urban locality of variable size that is considered holistically as a single entity in the context of broader urban planning processes. It typically comprises multiple land parcels occupied by constructed facilities (generally buildings or major infrastructures) or open space. For planning and analysis purposes, these precinct objects are clustered into urban zones that share some common characteristics and are supported by infrastructure services to manage energy, water, waste, communication and transport, as well as a range of social infrastructures related to health care, education, safety, retailing and entertainment.

PIM describes the process of creating a 3D digital model at the scale of any project-defined precinct. As such, it describes an activity where all the information pertinent to that precinct is held in a digital form, defined in a way that supports the processes that are critical to that practical purpose. PIM is therefore a process that can be used by a broad range of industry practitioners who are responsible for the planning, design, delivery and operational management of the built environment. The same information can then become a resource for the community who use and interact with the built environment, lending critical support for the smart cities and communities that are emerging as a partial solution to the challenges of rapid urbanisation across the globe.

PIM takes an object-based view of the built environment, focusing on the things that we wish to talk about (at various levels of granularity) in any discourse about the physical environment we inhabit, generally within the context of a professional activity related to the management of the built environment at some stage during its life cycle. Figure 12.1 illustrates some examples of those entities.
In information modelling terms, it is not just the objects and their properties that are important, but the relationships between those objects that help us understand the built environment. Those relationships are explicitly represented within the models and may define concepts such as containment, adjacency, interdependence, connection and assemblage.

In a PIM, objects may be represented as geometric forms that are spatially located, so it is often thought of as a 3D model (with the associated ability to visualise it). But that is only a small part of the story.

The implementation of PIM is really an extension of the familiar BIM concept, a digital modelling process that is used widely within the building design, construction and facility management professions. There are few practitioners now who would consider undertaking any serious planning and design activity without first creating a 3D digital prototype using commercial BIM software applications.

Notably, it is not the 3D model itself that is important, but the processes that surround that way of working and the opportunity to use the model in a collaborative way among the many professional participants involved, based on shared information about the project held within the precinct model. The acronym PIM can be used to refer to the precinct information model itself, but it is more commonly used to refer to the process of precinct information modelling as illustrated in Figure 12.2.
This more effective way of collaborative working has been the driver for the infrastructure sector to become interested in the adoption of BIM over recent years, and this adoption has been a key component of the transition from single building BIM to all urban built assets PIM. Increasingly, both in Australia and across the world, the planning and design of linear transport infrastructure (roads, railways, bridges and tunnels) is recognised as a strategic application of BIM, not to mention the delivery of wet/dry, above/below ground utilities, urban space and even ports and harbours (Plume, et al., 2015).

Digital modelling or prototyping relies on commercial software applications to support the creation and editing of the models by a range of professional disciplines (with specialised modelling requirements) as well as other software applications to manipulate and analyse those models to enable effective, collaborative work practices and decision-making. It is therefore critical that the PIM data can be freely shared between those commercial software tools. This leads to the need for agreed information modelling standards to support interoperability between commercial software systems. The key to such a standard is to define an agreed common data model (or schema) that enables the representation of all the objects ("things") that constitute the precinct model, along with their defined properties and relationships.

There is an existing international standard (Industry Foundation Classes, or IFC) for exchanging BIM data developed by an industry group known as buildingSMART International (bSI) and adopted as ISO standard ISO 16739 (IFC4, 2013). PIM is an extension of IFC. This approach is the scope of infrastructure and built environment extensions being adopted by bSI as its highest priority and supported by global national support for incorporation in its international standards.

The PIM platform is designed to support the sharing of precinct information independently of any proprietary software application. It is not a software tool and therefore, by its nature as an open, public information modelling standard, it cannot be commercialised. Any research project or other activity that deals with precinct information can make use of the open PIM platform as a means of storing and sharing relevant information in a collaborative way. This can potentially lead to efficiencies in the way precinct information is
handled as well as the opportunity to develop integrated solutions to complex issues such as built environmental carbon assessment and management.

Because the PIM work has focused on an urban precinct scale, it has inevitably intersected with the many geographic-scale modelling technologies (often collectively described as GIS tools) that seek to represent and understand the physical world at a larger and less granular scale. The concept of a precinct very neatly describes that common space or overlap between information modelling at a detailed building scale and that undertaken at a larger geographic scale (see Figure 12.3).

Rather than duplicate standards, the work towards a PIM standard has investigated and identified strategies that bring these two domains together while respecting the essential integrity of both approaches to the challenge of modelling the built and natural environments. This integration is illustrated in Figure 12.4, that brings together the top-down and bottom-up viewpoints of the Open Geospatial Consortium (OGC) and bSI.
Figure 12.4: Cycle of information flows across the building and geospatial domains, showing the domain of PIM in that context

Since the PIM standard includes additional entities beyond those that existing software “understands”, a generic PIM Viewer software (Marchant, 2016c) has been developed (Figure 12.5). This was used to view and interrogate the models that are described in the following section.
12.2 Prototype applications of PIM

This section is a summary of collaborations with other CRCLCL research projects outlined in previous sections of this guide that demonstrate the flexibility and capability of the proposed PIM standard.

12.2.1 Energy, Transport, Water and Waste (ETWW) – a testbed for data representation

As a first step in collaboration between the PIM and ETWW projects, the PIM team reproduced the ETWW input and output data in PIM format, implementing a demonstrator model of the Tonsley brownfield precinct in Adelaide. The model includes 3D representations of the exemplar residential units to be developed on the site (shown to the rear in Figure 12.5). Each of the Tonsley scenarios is a separate PIM model, held on the PIM model server.

The Tonsley demonstrator model includes the original master plan for the site, as well as the demand forecasting analysis undertaken as part of the CRCLCL project ETWW. In addition, the proposed roadworks for the Residential Zone have been modelled in detail with road elements as an example of the PIM extension for Road, a subclass of the generic Built Facility entity.

The ETWW research project addresses residential precincts in terms of the characteristics of household types. These household types are derived from Mosaic demographic data. Development assumptions in the ETWW Scenarios have been modelled with representative apartment types to assess the actual capacity of the sites and the urban environment impacts.

The Multi-purpose Adaptive Building (MAB) in the centre of the site is a detailed model of an existing building, while the other development zones are either modelled as development type zonal polygons, or as 3D block models to reflect a more detailed volume for planning or building consent assessment. This is illustrated in Figure 12.6.

![Figure 12.6: Precinct model of the ETWW scenario A for Tonsley](image)
ETWW data containing both inputs and output results for ETWW is held in a spreadsheet file. For the PIM model, the spreadsheet data (Figure 12.7) has been transformed into PIM objects that are defined by property sets exactly replicating the ETWW detailed data.

This is a demonstration of how all the ETWW analysis requirements can be stored in a PIM repository, with the additional capability to visualise and interrogate that data via an integrated 3D model.

12.2.2 The Broadway precinct - a testbed for precinct concepts

To date, the precinct model developed initially for the Empowering Broadway project (Figure 12.8) has supported a number of key investigations and findings:

- creation of a large data set of buildings (over 400 in the immediate precinct of interest in Broadway, Sydney, and a further 200 in the Ultimo extension) derived from the City of Sydney’s Floor Space and Employment Survey data. The council’s data was converted into PIM format using bespoke software developed by the MUtopia group at the University of Melbourne. The Broadway precinct model is essentially an aggregation of 3D space representations, organised into buildings and storeys across the precinct, with simple external wall and slab objects to enclose each building. The precinct model is shown in Figure 12.8 and comprises 379 sites (lots) 440 buildings and 16,000 rooms.

- understanding in detail how Development Planning works under the NSW Local Environment Planning legislation (LEP) using the concepts of Land Use Zones (for example, General Residential and Mixed Use) and Development Types (for example, Dwelling House and Educational Establishment)

- understanding the role of cadastre – legal land ownership – in current surveying systems and the context for map-referencing and the global navigation satellite system (GNSS) in precinct scale developments

- understanding how local governments (in this case, the City of Sydney) classify building assets (e.g. by usage of each space within a building) and the organisations that use these assets to understand changes in development activity within an LGA
• identifying the properties of precinct objects (at their differing levels of typology or detail) to capture environmental impacts for comprehensive sustainability performance recording
• a platform for testing the requirements for an extended urban context to include built facility types other than buildings, such as roads, bridges, utilities, civic space, and landscaping.

Figure 12.8: Broadway precinct model

The objective of the Broadway project was to understand both the governance and technological challenges associated with retrofitting a CBD precinct with distributed low carbon energy and water infrastructures. More specifically, it aimed to “to identify and understand the economic, stakeholder, regulatory and technical barriers to transitioning existing communities to low carbon energy and water solutions...” (Swinbourne et. al., 2016).

A key element of the project was “to empower stakeholders within communities to drive transitions to low carbon energy and water use, by providing them with the data and processes they need for change”. The Federal Government’s recent decision to expand the NCOS to buildings, precincts and cities gives added impetus to precinct modelling such as this (Department of the Environment and Energy, 2017).

A challenge that the research found in establishing precinct models is the difficulty of obtaining consistent, up-to-date data. There is an absolute paucity of base data for both the urban context of precincts – roads, pavements, utilities, civic space, etc. – and the owners’ assets in terms of facilities, equipment, operations, maintenance, performance, energy and water consumption, and patterns of usage.

12.2.3 Integrated carbon metrics – a testbed for the carbon-related attributes of objects

The Integrated Carbon Metrics (ICM) research project has taken a top-down approach to determining embodied carbon metrics based on national sector-based (input-output) economic data.

The challenges encountered in deriving such data to precinct-level objects are: the comprehensiveness of the data (i.e. is there sufficient coverage of metrics for building materials or elements of the built environment to allow for the calculation of a meaningful profile of the embodied carbon of a precinct); and, the level of detail at which the metrics are available (i.e. can the metrics be applied at an aggregated level in the same way that building costs can be applied per square metre of functional area).
Since ICM provides per dollar carbon metrics, for a precinct model it is first necessary to calculate the cost of each component of that precinct (entity or material of which it is composed) then multiply by the embodied carbon measure. For a precinct designer, for example, this requires the integration of the two sources of reference data (costs and embodied carbon) as shown in Figure 12.9, where the ICM globally unique identifiers (GUID) and Cost GUID labels in the diagram refer to GUIDs that allow particular entries in the respective databases to be unambiguously accessed.

**Figure 12.9: Calculating embodied carbon using ICM metrics**

To date, the ICM project has developed metrics for some (but not all) materials and elements used in construction. The PIM team have created a prototype web service to house ICM data, allowing access through the web, but have not populated that repository with the latest ICM dataset. This approach is a simulation of the linked data methodology (semantic web) that is being adopted by governments around the world as a means of publishing their data in an open, software-accessible form.

Several areas of work are required to aggregate ICM data to make it applicable to actual precinct information models. For example, typical housing types (either as a whole, or on some measurement basis such as per bedroom, or per number of occupants) per kilometre of typical roadway types, or per hectare of open space (parkland etc.).
12.2.4 Urban heat island modelling

The Microclimate and Urban Heat Island Decision-Support Tool (MUHIDST) project aims to develop a microclimate and urban heat island mitigation decision-support tool to evaluate urban redevelopment proposals that increase density (and potentially temperatures) in built-up areas of Australian cities. The project framework is described in Figure 12.10.

As Figure 12.10 shows, the MUHIDST project is using GIS-based technology as its data repository. Therefore, the following are suggestions only on how PIM could be used:

- As an object-based model repository for exemplar precincts used to implement and test both the scenario analysis and the assessment of the predicted UHI mitigation outcomes. Importantly, these precinct models would be based on an open standard format (the PIM schema) so that the information can be shared with other precinct analysis tools. The PIM project could provide an on-line portal that allows researchers and other stakeholders to access the precincts database remotely.

- As support within the PIM concept model for the specific precinct entities (at appropriate levels of granularity) that are used to represent the physical environment for UHI analysis. The key variables identified as part of the project would be expressed as properties of those precinct entities, forming the basis for determining the UHI mitigation index. These entities fall broadly into two categories: built form and vegetation features that provide shading and localised microclimatic effects (air movement and humidity); and, the surfaces that radiate, absorb or disperse heat within the built environment.

- As a repository for reference data that holds the relevant attribute values for precinct entity types. This would be accessed by the decision-support tool when performing the analysis.
A determinant of urban microclimate is the form, position and orientation of the urban fabric. This can be modelled at different levels of granularity. PIM would allow accurate representation of all the individual features that may have some impact on microclimate, including building form, street layout, vegetation (ranging from ground cover, shrubs and small trees to big trees) water bodies, street furniture and other urban structures. This would allow for fine-grained analysis of localised conditions.

At a coarser level of granularity, urban precincts could be organised into spatial zones that have particular characteristics, such as open parkland, sparse bushland, dense canopied bushland, low-rise, sparse residential areas, compact low-rise residential, high-rise commercial, etc. Such zones would be classified and could be treated as precinct objects for analysis purposes.

A key aspect of the UHI project work is to provide support for testing different scenarios. These can be handled by a PIM database as versions of the full model, or implemented as versions of each individual entity. This work provides an excellent basis for a collaborative project to develop a precinct assessment tool that analyses a precinct in terms of its ability to respond to microclimatic impacts of urbanisation (e.g. urban heat island effect) and to show an exemplar of a standardized modelling approach for precinct information.

12.2.5 Advantages of the PIM methodology for integrated precinct assessment

In summary, PIM is an enabling technology that provides the following benefits:

- an open, non-proprietary standard to model all relevant built environment entities, their properties, and inter-relationships up to, and including, precinct level granularity. The entity definitions correlate not only to real-world physical objects, but also to processes and the actors involved in those processes. “Open” is important because it enables many software applications to work with the same precinct model data in an agreed format rather than being non-compatible with others.
- the means to model the characteristics of entities both geometrically and non-geometrically, allowing for a multi-dimensional appreciation of the modelled precinct.
- a standard that is integrated across multiple built environment disciplines. This allows for a precinct model to be comprehensive while retaining the ability to check-in and check-out purpose-specific views of that model.
- the proposed PIM extensions fit seamlessly into the existing IFC standard, so can be adopted as a new version of the existing standard, which means that all existing software that relies on that standard can be relatively simply modified to embrace the additional functionality. In addition, the proposed PIM extensions have been defined so that they correlate to equivalent concepts in other geospatial standards such as CityGML, which will allow for the further harmonisation of geospatial and detailed built form standards into the future.
The methodologies for implementing PIM are described in much more detail in the various PIM-related CRCLCL publications listed in the references section below. In the context of Australia’s current national focus on city infrastructure, and the emerging awareness of the value of Internet of Things (IoT) applications, the role of PIM becomes even more relevant (Figure 12.11).

Figure 12.11: Example of tracking in a hospital precinct, using a PIM repository and IoT. Source: St. Olavs Hospital, Central Norway Regional Health Authority, Norway

PIM in this context provides an integration capability with the physical objects in the city; it is the natural complement for creating data ecosystems and, by the use of large data analytics, can identify the performance of systems used by local government and large institutional owners.

IoT, set in the context of the digital PIM, provides a continuous monitoring/tracking of fixed and mobile data sources, a solution enabling a big data ecosystem, gathering a history and detailed performance data. From this data analytics can reveal and inspire new insights and genuine innovation at the precinct scale.

In summary, we can observe two major digital modelling breakthroughs – the first is the comprehensive articulation of a built environment model; the second breakthrough is the behaviour and performance modelling facilitated by IoT.

The adoption of both of these approaches is the core of precinct modelling. So a final question is posed: how and by whom is a PIM used?

As we move roles from designer to builder to operator, we note a new focus on clients and users. The related organisations are private and institutional owners, and all levels in government. A PIM provides the means for more efficient procurement and development, but more importantly much enhanced operations and management based on the integrated data gathered over the procurement and acquisition processes and fed by continuous data collection in operation. PIM provides a precise data framework linking objects to performance.
This transition will not be rapid or easy. Large infrastructure digital modelling is just beginning. IoT applications are also in their first stages of implementation. So, precinct modelling will be conditional on exemplar efforts by these two communities of interest. We think the best results will be obtained by targeted problem solving based on both a representative digital built environment model with monitoring of its components (for example, a new urban centre with local government energy modelling of street lighting) or projects derived from Australia’s ambitious infrastructure and Smart Cities initiatives.

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Section 13

Performance Indicators

Michael A. P. Taylor, University of South Australia
13. Performance Indicators

Quantification of performance is a basic requirement in the assessment of precinct designs. This provides a basis for comparing the performance of existing precincts, examining alternative scenario developments for a precinct, or evaluating alternative designs and technologies.

Performance indicators are required for this purpose, on a common basis to enable valid comparisons between alternative designs. Different sets of indicators may be appropriate in different circumstances, but the indicators need to be defined in a consistent manner. They need to be set against critical objectives that align with sustainable urban development targets, such as regeneration, low carbon and resilient built environments.

For this guide, the goals and indicators are aligned with those linked to the Extended Urban Metabolism framework developed for Australia’s State of Environment (Human Settlements /Built Environment) Reporting, as outlined in Chapter 2. The performance indicators associated with the CRCLCL precinct tools can also be aligned with several of the UN’s 17 Sustainable Development Goals for the 2030 Agenda for Sustainable Development. These were agreed by 193 member states (including Australia) at the UN Sustainable Development Summit in September 2015. Voluntary National Reviews are required from signatory countries (https://sustainabledevelopment.un.org/vnrs/) and a national website has been established (https://sdgs.org.au/about-us/resources/) where projects such as this involving indicator development can be listed (Table 13.1).

13.1 Performance Indicator Characteristics

A performance indicator provides a quantitative measure that reflects some aspect of performance of a system, enterprise or operation. A set of performance indicators may be constructed to help ascertain the extent to which a system in its current state is meeting its strategies, goals and objectives (e.g. ‘as conceived’ versus ‘as designed’). Performance indicators may also be used for monitoring and as diagnostic instruments to determine areas within a system where performance can be improved – if sufficient, reliable and accurate data are available (e.g. ‘as designed’ versus ‘as built’ versus ‘as operated’). The indicators may also be used for benchmarking and comparisons between systems and between alternative scenarios for a system – if defined appropriately to allow for comparisons.

In general, performance indicators relate to (1) efficiency (the relation between resource inputs and service outputs) and (2) effectiveness (the ability to meet the prescribed objectives). There is also scope for indicators on appropriateness – the relevance of the objectives to overall goals.

Performance indicators can be established at multiple levels. High level indicators focus on the overall performance of the system, while lower level indicators may focus on different subsystems or components within the system. The higher level indicators are generally obtained by aggregating upwards from the lower levels.

Indicators used for purposes of comparison – between systems, or between component subsystems, or between alternative development scenarios for the system – generally need to be expressed as rates per unit of (consistent, measurable) activity for the comparisons to be meaningful.
Table 13.1: UN Sustainable Development Goals Indicators linked to CRCLCL precinct assessment tools, with assessment of current Australian national performance

<table>
<thead>
<tr>
<th>UNSDG (1)</th>
<th>Indicator (1)</th>
<th>Tool</th>
<th>Australian performance assessment (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Good health and well being</td>
<td>3.6.1 Road traffic injuries and deaths</td>
<td>CBC</td>
<td>On track</td>
</tr>
<tr>
<td></td>
<td>3.9.1 Indoor and ambient air pollution</td>
<td>CBC</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>3.8.1 Health worker density and distribution</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>6 Clean water and sanitation</td>
<td>6.5.1 ALT Extent of integrated water resources management</td>
<td>ESP</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>6.3.1 ALT Extent of wastewater treatment</td>
<td>FB/WSC</td>
<td>On track</td>
</tr>
<tr>
<td></td>
<td>6.6.1 Change in extent of water-related ecosystems</td>
<td>FB/WSC</td>
<td>Off track</td>
</tr>
<tr>
<td>7 Affordable and clean energy</td>
<td>7.2.1 Extent of renewable energy in total final energy consumption</td>
<td>ETWW</td>
<td>Breakthrough needed</td>
</tr>
<tr>
<td></td>
<td>7.3.1 Energy intensity of economy</td>
<td>ECE</td>
<td>Needs improvement</td>
</tr>
<tr>
<td></td>
<td>7.3.2 Energy efficiency</td>
<td>ESP</td>
<td>Needs improvement</td>
</tr>
<tr>
<td>9 Industry, innovation and infrastructure</td>
<td>9.4.1 CO2 emissions</td>
<td>ABM-TMC, ECE, ENVISION, ETWW, PCA, PSUMC</td>
<td>Needs improvement</td>
</tr>
<tr>
<td>11 Sustainable cities and communities</td>
<td>11.2.1 Convenient access to public transport</td>
<td>CBC</td>
<td>Needs improvement</td>
</tr>
<tr>
<td></td>
<td>11.3.1 Ratio land consumption/population growth [sprawl]</td>
<td>ENVISION</td>
<td>–</td>
</tr>
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<td></td>
<td>11.3.2 Public participation in urban planning and management</td>
<td>iHUB</td>
<td>–</td>
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<tr>
<td></td>
<td>11.5.2 Economic and human loss from extreme events</td>
<td>UHI</td>
<td>On track</td>
</tr>
<tr>
<td></td>
<td>11.6.1 Waste generation and rate of disposal to landfill</td>
<td>ETWW</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>11.6.2 Air pollution (small particles)</td>
<td>CBC</td>
<td>On track</td>
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<tr>
<td></td>
<td>11.7.1 ALT Amount of public open space</td>
<td>UHI</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>11.a.1 Implementation of urban and regional development plans</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>12 Responsible consumption and production</td>
<td>12.2.2 Material footprints (per capita, per GDP)</td>
<td>ICM</td>
<td>Needs improvement</td>
</tr>
<tr>
<td></td>
<td>12.3.1 Food waste</td>
<td>ETWW</td>
<td>Breakthrough needed</td>
</tr>
<tr>
<td></td>
<td>12.5.1 ALT Recycling rate</td>
<td>ETWW</td>
<td>On track</td>
</tr>
<tr>
<td>13 Climate action</td>
<td>13.1.3 Capability to adapt to the adverse impacts of climate change</td>
<td>UHI</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>13.2.1 NEWC Foster low GHG emissions development</td>
<td>ECE, ENVISION, ETWW, PCA</td>
<td>Off track</td>
</tr>
<tr>
<td>16 Peace, justice and institutions</td>
<td>16.1.4 ALT Safety of walking alone</td>
<td>CBC</td>
<td>Needs improvement</td>
</tr>
<tr>
<td></td>
<td>16.6.2 Satisfaction with public services</td>
<td>–</td>
<td>Breakthrough needed</td>
</tr>
</tbody>
</table>

13.2 Performance Indicators in Low Carbon Precinct Assessment

For precinct assessment, the system is the precinct itself. Its subsystems or components include the land uses, services and infrastructure objects and systems in the precinct or used by the precinct and its occupants. A 'precinct' in this Guide can be characterised or defined as any area ranging in size from several contiguous land parcels within a greyfield suburb to a much larger brownfield or greenfield site, that is, large enough to accommodate a significant urban development project. The flexibility of contemporary spatial information systems requires no necessary *a priori* definition or delineation; although an evaluation of the appropriateness of a particular distributed utility system for a precinct will be scale-sensitive (e.g. area, population served).

The primary indicator of interest in this guide is the carbon emission 'signature' of the precinct, and this needs to be attributed to the domain sources of the emissions (e.g. sector; whether embodied or operating emissions).

There are also other considerations of precinct performance that may need estimation in an assessment. The economic cost of the precinct development would be one, and others could include economic benefits (including health, liveability and productivity co-benefits) from low carbon initiatives, the contribution of the development to the attainment of specific planning objectives (e.g. climate change mitigation and adaptation) or contribution to the fulfilment of urban policies. For precinct assessment in the context of the current guide these would be seen as complementary indicators.

Figure 13.1 provides a schematic view of the precinct and its components. The top level in the figure is the precinct itself. Below this is the set of land uses and activities contained within the precinct. Each of these may in turn comprise subcategories of land use/activity, for instance the residential land use may comprise housing of different types (e.g. low density single dwelling units, medium density townhouses, high density apartments, etc.). The carbon emissions, costs etc. of each component will be related to the emissions sources (domains) used by each component, including both the technologies employed and the methods and behaviours adopted in that utilisation.

![Figure 13.1: Hierarchical schematic view of a precinct, its components and carbon emissions sources](image)

In terms of the emissions (or other performance outputs) of the precinct, it is necessary to aggregate these from the elemental components within each land use/activity present in the precinct. Figure 13.2 provides an illustration of this process, for a residential land use.
Figure 13.2 indicates the potential source contributions of carbon emissions for one residential housing type relating to the infrastructure/service domains of energy, transport, water and waste. For instance, energy is used within the dwelling for purposes such as cooking, heating and cooling, lighting and hot water. The extent to which each of these activities is undertaken by a household will determine the amount of energy consumed. The level of carbon emissions associated with the activity depends on the sources of that energy (e.g. type of fossil fuel or renewable). There is the potential for interaction between the domains and consequently on the carbon emission of the household and precinct. For instance, ‘hot water’ is a common factor under energy and water supply in the figure. The quantity of hot water consumed and the temperature to which that water is raised will affect the emissions, as will the source of the heating energy (e.g. solar or gas). Likewise, substitution of electric vehicles for petroleum fuelled vehicles will lead to differences in emissions. These differences reflect differences in the technologies used and the behaviours adopted by households.

The domain sources of the emissions thus need careful consideration, including the interactions between domains and the potential trade-offs that may occur, when reducing carbon emission from one domain may increase emissions from another. Even if the overall outcome is positive, the trade-off needs to be recognised. The use of electric vehicles instead of petroleum-fuelled vehicles for mobility would be one good example.

Comparisons between precincts and perhaps between different scenarios for a given precinct will need to be based on emission rates, i.e. the identification of a suitable unit of activity to represent the emissions source. This provides a common datum for comparisons between precincts of different scales and land uses. In addition, a time period for the emissions will need to be specified.

A useful way to approach the development of specific performance indicators is to follow the following steps. For a given precinct/development plan:

1. identify the set of emissions sources
2. quantify the level of activity of each source (in a relevant physical unit)
3. use a unit intensity of emission for the activity to estimate its carbon emission performance
4. aggregate the emissions from each source to give an overall level of emission. This may be expressed as a rate for the basic unit of size for the precinct (e.g. per household or per dwelling in a residential precinct) or as a total emission of the precinct.
These steps also apply to other measures of precinct performance, such as the economic cost (for which the unit intensity in Step 3 would be replaced by the unit cost).

The steps may also be summarised by the following mathematical relation:

\[ E = P \times T \times B \] (13.1)

In this relation:
- \( E \) is the emission or impact
- \( P \) represents population (scale, size) of the precinct/alternative
- \( T \) represents the technology (infrastructure domain or service type) under consideration, and would be described by the emissions intensity for that domain
- \( B \) represents the behaviour/consumption of the population, associated with the usage of the domain, per unit of scale, by user type, per unit time

The principal domains for consideration in a precinct plan are outlined in Figure 13.2 and would generally include the following: energy; housing/building; water; mobility (transport); waste, and landscape/built environment. Other domains may also be present in specific instances. The domains represent the sources of carbon emissions. Within any domain there may be sub-domains, for instance in energy there are generally two basic sources (electricity, gas) and within these sources there will be service alternatives (e.g. the method of generation of the electricity) with different emissions intensities and different unit costs of service provision. Table 13.2 outlines some key sub-domains and service alternatives.

The level of activity for a given domain is best represented as a rate per unit of the activity. For residential precincts/land uses appropriate units would be per person or per household. For other activities and land uses the unit of activity might be per enterprise, per m² of gross floor area (GFA), per hectare, or per $ spent.

The time period relating to the activity is also of importance. The common time periods might be per hour, per day, per week or per month for the activity, expanded to per annum for the resulting carbon emissions for reporting purposes (although for developing infrastructure supply options for certain domains – such as energy - estimating demand on an hourly basis, or finer, to assess demand peaks would be required). Seasonal and climatic factors may also influence the consumption, e.g. for energy (heating/cooling) and water use, in particular.

The definition and development of performance indicators (e.g. carbon emissions) per unit of activity per unit time provides a rational basis for the monitoring of precinct performance over time, making comparisons between different precincts, and comparisons between different development scenarios for a given precinct. This provides the basis for informed decision making.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Sub-domain</th>
<th>Service alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Electricity</td>
<td>Coal-fired</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gas turbine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renewables</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery storage</td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td>Natural gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LPG</td>
</tr>
<tr>
<td>Domain</td>
<td>Sub-domain</td>
<td>Service alternative</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Housing/building</td>
<td>Residential</td>
<td>Low density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High density</td>
</tr>
<tr>
<td></td>
<td>Retail</td>
<td>Corner store</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strip shopping centre</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shopping mall</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td>Low density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High density</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Education</td>
<td>Primary school</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary school</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tertiary institution</td>
</tr>
<tr>
<td>Water</td>
<td>Indoor cold water use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outdoor water use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hot water demand</td>
<td>Energy source</td>
</tr>
<tr>
<td></td>
<td>Rainwater yield</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Walking</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cycling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Public transport</td>
<td>Heavy rail</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light rail</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Express bus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local bus</td>
</tr>
<tr>
<td></td>
<td>Ride sharing</td>
<td>Petrol car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diesel car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td>Private car</td>
<td>Petrol car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diesel car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td>Car sharing</td>
<td>Petrol car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diesel car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
<tr>
<td>Domain</td>
<td>Sub-domain</td>
<td>Service alternative</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>Waste</td>
<td>Landfill</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recyclables</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green waste</td>
<td></td>
</tr>
<tr>
<td>Landscape/built environment</td>
<td>Paved space</td>
<td>Space devoted to transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pedestrian space</td>
</tr>
<tr>
<td></td>
<td>Green space</td>
<td>Passive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Active</td>
</tr>
</tbody>
</table>

Note: This table is neither complete nor exhaustive. It is for illustrative purposes only.

Following on from relation (13.1) above, the derivation of primary performance indices from elemental indices is illustrated in Figure 13.3 and Figure 13.4. The figures take, respectively, the energy and transport components in Figure 13.2. Figure 13.3 considers the computation of carbon emissions from household energy use, in which the activities are taken as cooking, heating and cooling, lighting, hot water and other (e.g. plug-in appliances).

Two main sources of household energy are typically available: electricity and gas. Each of these sources has carbon emission rates (per unit of consumption). These rates represent the energy technologies employed and the sources of energy. Estimation of the daily energy usage from each energy source by each household activity combined with the given emission rates provides the total carbon emissions per household per day.

Figure 13.4 considers the carbon emissions from transport activities undertaken by precinct households. Travel activity is divided into two parts: travel within the precinct and travel by precinct residents outside the precinct. Travel activity is represented in terms of person-km of travel (PKT), spread among the different travel modes available to residents. The division between intra-precinct travel and external travel allows for assessment of the potential impacts of mixed land uses within the precinct, whereby some travel demand may be satisfied within the precinct itself (encouraging the greater use of active travel, walking and cycling). Mode-specific carbon emission rates (per unit distance of travel) may then be applied to estimate the household carbon emissions per day.

These two figures illustrate how higher level performance indicators may be developed from lower level data on activity and available technologies.
Figure 13.3: Derivation of carbon emissions performance indicator for household energy consumption, based on in-house activities and energy technologies

Figure 13.4: Derivation of carbon emissions performance indicator for household travel, based on travel activity, available transport modes, and transport technologies
13.3 Precinct Performance Indicators

The assessment tools developed in the CRC’s low carbon precincts program provide a broad set of precinct performance indicators that follow the indicator characteristics described above. The set of indicators extracted from the tools in the guide is listed in Table 13.3. The indicator set covers the following domains:

- built environment
- energy
- environment
- health
- housing
- thermal comfort
- transport/mobility
- water
- waste, and
- carbon emissions.

The table indicates the base units for each indicator. It also identifies the tools that provide data and information for specific indicators.

In terms of built environment, Table 13.3 lists a number of indicators concerned with the size of the precinct and the allocation of space within it to different land uses and infrastructure. The main indicators are population density and dwelling density. There is also an indicator for accessibility, expressed as the number of jobs accessible within 30 minutes’ travel time by public transport from the precinct. Housing indicators include dwelling type (and dwelling quality and age), household size and socio-demographic characteristics of households.

Energy is a primary determinant of precinct performance and carbon emissions. Embodied and operational energy for building and facilities in the precinct are covered. A range of indicators for energy supply and use are available, including household energy consumption, potential reductions in peak period energy consumption, and energy costs under different supply scenarios (including PV, renewables and co-generation). Temporal variations in demand, from hours of the day to months of the year, may also be considered.

The main transport/mobility indicators provided are for travel activity, including person-km of travel (PKT), person-hours of travel (PHT) and vehicle-km of travel (VKT). These indicators can be disaggregated by travel mode, and there is a focus on changes in travel activity in favour of increased usage of low carbon transport (walking, cycling and public transport). The indicators also relate to those in other domains, such as accessibility for the built environment and walking activity for health.

The water-related indicators focus on household water consumption, including total water demand and demand for hot water. Stormwater runoff and rainfall water retention and storage are also included. Seasonality in water demands may also be captured as the indicators for water consumption include month-by-month profiles.

Indicators for waste production by households are also available, with separate measures for landfill, recyclables and green/food wastes.
Indicators for public exposure to vehicle-based air pollutant emissions and noise are available as considerations in environmental impacts, along with a set of indicators relating to public health. The latter includes an indicator on sedentary behaviour (time spent sitting). The health indicators also relate to transport/mobility indicators linked with active travel. A pair of indicators relating to urban microclimates and thermal comfort – the Universal Thermal Climate Index (UTCI) and annual Cooling Degree Days (CCD) – are also available.

The primary performance indicators for low carbon precinct assessment necessarily relate to the carbon emissions of the precinct. As discussed previously, carbon emissions are generally estimated on the basis of rates of activity in the precinct and the carbon intensities of those activities. There is a substantial set of carbon intensities provided for building and facility materials and systems operations all relating to precincts, as identified in the ICM-ECE tool (see Table 13.3 for details). Total CO₂ equivalents are available, in toto and for both embodied carbon and operational carbon. Disaggregation of carbon emissions by infrastructure domain (and, for residential precincts, for different household types) is possible. A specific indicator for carbon emissions from public transport is also provided.

The combined set of performance indicators summarised by Table 13.3 provides a firm basis for the assessment of the carbon performance of precincts under a wide range of precinct types, land use mixes, environmental and operating conditions, and design alternatives. They also provide an indication of the potential for integrated modelling and integrated precinct assessment.
<table>
<thead>
<tr>
<th>Domain</th>
<th>Performance indicator</th>
<th>Base unit</th>
<th>Rates</th>
<th>Tool*</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built environment</td>
<td>property redevelopment potential</td>
<td>Land value, total property value</td>
<td>$</td>
<td>ENVISION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accessibility</td>
<td>Employment (no of jobs)</td>
<td></td>
<td>SNAMUTS</td>
<td>Number of jobs within 30 min travel time by public transport from node</td>
</tr>
<tr>
<td></td>
<td>Population</td>
<td>Persons</td>
<td></td>
<td>ESP</td>
<td>Population of precinct</td>
</tr>
<tr>
<td></td>
<td>Population density</td>
<td>Persons</td>
<td>Persons/ha</td>
<td>ESP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Employment</td>
<td>Jobs</td>
<td></td>
<td>ESP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dwelling density</td>
<td>Dwellings</td>
<td>Dwellings/ha</td>
<td>ESP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Area</td>
<td>ha</td>
<td></td>
<td>ESP</td>
<td>Total area of precinct</td>
</tr>
<tr>
<td></td>
<td>Building area</td>
<td>ha</td>
<td></td>
<td>ESP</td>
<td>Area of precinct occupied by built structures</td>
</tr>
<tr>
<td></td>
<td>Open space</td>
<td>ha</td>
<td></td>
<td>ESP</td>
<td>Area of precinct as open space</td>
</tr>
<tr>
<td></td>
<td>Commercial space</td>
<td>ha</td>
<td></td>
<td>ESP</td>
<td>Area of precinct used by commercial activities</td>
</tr>
<tr>
<td></td>
<td>Institutional space</td>
<td>ha</td>
<td></td>
<td>ESP</td>
<td>Area of precinct used by institutions</td>
</tr>
<tr>
<td></td>
<td>Parking</td>
<td>ha</td>
<td></td>
<td>ESP</td>
<td>Area of precinct for vehicle parking</td>
</tr>
<tr>
<td></td>
<td>Pathway length</td>
<td>km</td>
<td></td>
<td>ESP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trees</td>
<td></td>
<td></td>
<td>ESP</td>
<td></td>
</tr>
<tr>
<td>Carbon emissions</td>
<td>Total CO$_2$ equivalents</td>
<td>kg CO$_2$-e</td>
<td>kg CO$_2$-e/hhld/day, kg CO$_2$-e/person/day</td>
<td>ETWW</td>
<td>Breakdown by household type and infrastructure domain</td>
</tr>
<tr>
<td></td>
<td>Total CO$_2$ equivalents</td>
<td>t CO$_2$-e</td>
<td>t CO$_2$-e/year</td>
<td>ECE, PCA</td>
<td>Breakdown by GHG components (CO$_2$, CH$_4$, NO$_x$ etc.) also available</td>
</tr>
<tr>
<td></td>
<td>CO$_2$ equivalents from transport</td>
<td>t CO$_2$-e</td>
<td>t CO$_2$-e/year</td>
<td>ABM-TMC, ETWW</td>
<td>Net reduction in carbon emissions from work trips</td>
</tr>
<tr>
<td></td>
<td>Carbon intensity</td>
<td>$</td>
<td>$/t CO$_2$-e</td>
<td>ECE</td>
<td>Available for wide range of materials and systems</td>
</tr>
<tr>
<td>Domain</td>
<td>Performance indicator</td>
<td>Base unit</td>
<td>Rates</td>
<td>Tool*</td>
<td>Remarks</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------</td>
<td>-----------</td>
<td>--------------------------------</td>
<td>----------------</td>
<td>--------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Carbon emissions density (from transport)</td>
<td>t CO₂-e</td>
<td>t CO₂-e/km²</td>
<td>PSUMC</td>
<td>Typical values: 1-2 Very Good (e.g. London), 4-8 Very Bad (e.g. Shanghai) (all t CO₂-e/km²)</td>
</tr>
<tr>
<td></td>
<td>Carbon emissions on public transport</td>
<td>g CO₂-e</td>
<td>g CO₂-e/km/person</td>
<td>PSUMC</td>
<td>Typical values: 300 large passenger car, 180 suburban bus, 50 suburban train (all g CO₂-e/km/person)</td>
</tr>
<tr>
<td></td>
<td>Total embodied CO₂ equivalents</td>
<td>t CO₂-e</td>
<td></td>
<td>ECE, ENVISION</td>
<td>Breakdown by surface type, materials and parking</td>
</tr>
<tr>
<td></td>
<td>Total CO₂ sequestration</td>
<td>t CO₂-e</td>
<td></td>
<td>ENVISION</td>
<td>Breakdown by surface type, materials and parking</td>
</tr>
<tr>
<td>Energy</td>
<td>Embodied energy</td>
<td>MJ</td>
<td></td>
<td>PCA</td>
<td>Embodied energy in buildings</td>
</tr>
<tr>
<td></td>
<td>Operational energy</td>
<td>MJ</td>
<td></td>
<td>PCA</td>
<td>Operational energy in buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Operational energy in infrastructure and service facilities, including energy supply, transport and water supply Also use of renewables</td>
</tr>
<tr>
<td></td>
<td>Energy consumption</td>
<td>kWh</td>
<td>kWh/hhld/day, kWh/person/day</td>
<td>ETWW</td>
<td>Can include the source of electrical energy (renewables, PV, etc.)</td>
</tr>
<tr>
<td></td>
<td>Grid exported solar energy</td>
<td>kWh or $</td>
<td>kWh/dwelling</td>
<td>ETWW</td>
<td>This is the export solar energy that occurs when local generation exceeds demand. It can be expressed in dollars if revenue is generated from the grid export energy</td>
</tr>
<tr>
<td></td>
<td>Cost of energy</td>
<td>$/kWh or $/hhld</td>
<td>$/kWh/hhld/day, $/kWh/person/day</td>
<td>ETWW</td>
<td>This is the cost of grid-used energy</td>
</tr>
<tr>
<td></td>
<td>Cost of solar and battery</td>
<td>$</td>
<td>$/hhld</td>
<td>ETWW</td>
<td>The cost saving from solar and battery systems comes from avoiding the use of grid-import energy. The amount of money saved is directly related to the tariff, solar resource and the time of the day that energy is used</td>
</tr>
<tr>
<td></td>
<td>Cost saving from solar and battery system</td>
<td>$</td>
<td>$/year</td>
<td>ETWW</td>
<td></td>
</tr>
<tr>
<td>Domain</td>
<td>Performance indicator</td>
<td>Base unit</td>
<td>Rates</td>
<td>Tool*</td>
<td>Remarks</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------</td>
<td>-----------</td>
<td>-------</td>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td>Red. of peak elect. demand</td>
<td>kWh (or TWh, for UHI-DS)</td>
<td>ETWW, UHI-DS</td>
<td>Peak demand during the summer period. Refers to the electricity power required in a certain period that is significantly higher than average supply levels. A key factor that influences peak electricity demand is the temperature profiles throughout this period.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health</td>
<td>Time spent sitting</td>
<td>h</td>
<td>h/person/day</td>
<td>CBC</td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>Dwelling type</td>
<td>ESP</td>
<td>Detached single unit house, semi-detached house, town house, unit, apartment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dwelling size</td>
<td>Floor area (m²)</td>
<td>ESP</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dwelling quality</td>
<td>ESP</td>
<td>Design principles (e.g. passive solar), insulation, double glazing, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household size</td>
<td>No of persons</td>
<td>Persons/hhld</td>
<td>ETWW</td>
<td>Also by household type</td>
</tr>
<tr>
<td>Socio-economic characteristics of household</td>
<td>Various</td>
<td>ETWW</td>
<td>Includes household composition, income, educational attainment, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal comfort</td>
<td>Outdoor Thermal Comfort Index</td>
<td>Universal Thermal Climate Index (UTCI)</td>
<td>UHI-DS</td>
<td>The air temperature of the reference environment, which produces an equivalent dynamic physiological response according to a human thermoregulation model (Brode et al., 2011). Factors that influence UTCI are air temperature, humidity, radiation and wind speed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Annual Cooling Load Savings</td>
<td>Annual Cooling Degree Days (CDD)</td>
<td>UHI-DS</td>
<td>CDD is a measurement to quantify the demand for energy needed to cool a building in a particular location over a year. A key factor that influences CDD is the outdoor annual temperature. The savings refer to reductions in CDD</td>
<td></td>
</tr>
<tr>
<td>Domain</td>
<td>Performance indicator</td>
<td>Base unit</td>
<td>Rates</td>
<td>Tool*</td>
<td>Remarks</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------</td>
<td>--------------</td>
<td>------------------------------</td>
<td>-------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Person-km of travel (PKT)</td>
<td>Person-km</td>
<td>PKT/hhld/day, PKT/person/day</td>
<td>ETWW</td>
<td>For each travel mode (e.g. car driver, car passenger, public transport, bicycle, pedestrian), further disaggregated by household type</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Person-hour of travel (PHT)</td>
<td>Person-h</td>
<td>PHT/day</td>
<td>CBC</td>
<td>On public transport, and in car</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Vehicle-km of travel (VKT)</td>
<td>Vehicle-km</td>
<td>VKT/day</td>
<td>AMoD</td>
<td>Total VKT in network, including ‘empty’ VKT</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Vehicle-km of travel (VKT)</td>
<td>Vehicle-km</td>
<td>VKT/person/day</td>
<td>PSUMC</td>
<td>Reduction in daily VKT</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Vehicle-km of travel (VKT)</td>
<td>Vehicle-km</td>
<td>VKT/day</td>
<td>ETWW</td>
<td>For car travel by precinct residents</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Vehicle-km of travel (VKT) by waste collection trucks</td>
<td>Vehicle-km</td>
<td>VKT/day</td>
<td>ETWW</td>
<td>Removal of solid wastes (landfill, mixed recyclable and green waste) from precinct. Fuel usage (L/day) and carbon emissions (CO₂-e (kg/day) are also available for the waste collection</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Total fuel use for cars and electricity use for EVs</td>
<td>kL/kWh</td>
<td>kL/day/hhld/kWh/day/hhld</td>
<td>ETWW</td>
<td></td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Trip demand</td>
<td>Person-trip</td>
<td>Trips/hhld/day/Trips/person/day</td>
<td>ETWW</td>
<td>Available for each origin-destination pair</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Percentage of trips by low carbon modes</td>
<td>%</td>
<td>%</td>
<td>ABM-TMC</td>
<td>Increase in number of trips by low carbon modes (walking, cycling, public transport)</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Walking distance</td>
<td>Trip</td>
<td>Trips/week</td>
<td>CBC</td>
<td>For walking trips &gt; 10 min duration</td>
</tr>
<tr>
<td>Transport (/mobility)</td>
<td>Time spent walking</td>
<td>Person-h</td>
<td>PHT/week</td>
<td>CBC</td>
<td>Total walking activity</td>
</tr>
<tr>
<td>Domain</td>
<td>Performance indicator</td>
<td>Base unit</td>
<td>Rates</td>
<td>Tool*</td>
<td>Remarks</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------</td>
<td>-----------</td>
<td>--------------------------------------</td>
<td>-------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Water</td>
<td>Total water demand</td>
<td>kL</td>
<td>kL/hhld/day, kL/person/day</td>
<td>ETWW</td>
<td>Includes monthly profile</td>
</tr>
<tr>
<td></td>
<td>Hot water demand</td>
<td>kL</td>
<td>kL/hhld/day, kL/person/day</td>
<td>ETWW</td>
<td>Includes monthly profile. Note that the parameters 'monthly cold water temperatures (CWT)' and 'target hot water temperature' are important factors associated with the energy required for water heating</td>
</tr>
<tr>
<td></td>
<td>Rainfall (water tank) yield</td>
<td>kL</td>
<td>kL/hhld/day, kL/person/day</td>
<td>ETWW</td>
<td>Includes monthly profile</td>
</tr>
<tr>
<td></td>
<td>Stormwater runoff</td>
<td>kL</td>
<td>kL/h</td>
<td>ESP</td>
<td></td>
</tr>
<tr>
<td>Waste</td>
<td>Landfill waste</td>
<td>kg</td>
<td>kg/hhld/week, kg/person/week</td>
<td>ETWW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mixed recyclable waste</td>
<td>kg</td>
<td>kg/hhld/week, kg/person/week</td>
<td>ETWW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green waste</td>
<td>kg</td>
<td>kg/hhld/week, kg/person/week</td>
<td>ETWW</td>
<td></td>
</tr>
</tbody>
</table>

* Key to tools:
ETWW, research project RP2002: Integrated energy transport waste and water demand forecasting and scenario planning for precincts,  
ECET, PCAT, research project RP2007: Integrated carbon metrics – (1) Embodied carbon explorer tool (ECET) and (2) Precinct carbon assessment tool (PCAT)
PSUMC, AMoD, ABM-TMC, SNAMUTS, research project RP2021: Greening urban and suburban travel: tools for modelling the impacts of low carbon mobility solutions. PSUMC, AMoD and ABM-TMC developed in project. For SNAMUTS, see Curtis and Schreurer (2016).
UHI-DS, research project RP2023: Microclimate and urban heat island mitigation decision-support tool (UHI-DS)
LCL-CBC, research project RP2028: A low carbon living co-benefits calculator
ENVISION, ESP, research project RP3034: Community co-design of low carbon precincts for urban regeneration in established suburbs
The above discussion has been concerned with the identification of relevant performance parameters for a given precinct design plan or for a set of scenarios for development of a precinct. This would enable the planner to identify the scenario with lowest carbon impact from the available set of alternatives, and so determine a preferred option. This is the use of performance indicators in a local, relative sense. The developer or planner may well have an interest in the comparative performance of the precinct design in a broader context, in terms of the achievement of specific goals and targets (e.g. for carbon emissions) or as a comparison against ‘best practice’ precinct designs and implementations. To do so requires the consideration of goals and targets and performance benchmarking.

13.4 Targets and Benchmarking

Design of a ‘low carbon precinct’ implies that the carbon emissions of the precinct will be lower than those from conventional or historical precinct designs. The extent of reductions in carbon emissions needs to be measured through estimation of emissions performance of a given design and through monitoring of the actual emissions of a precinct. There may be emissions targets set for precinct performance, either aspirational or operational. For instance, the Adelaide City Council has an aspirational plan ‘to make Adelaide the world’s first carbon neutral city, by building community partnerships and focusing on five pathways to carbon neutrality’ (ACC 2016). ‘Carbon neutrality’ is planned to be achieved through a combination of measuring and reducing greenhouse gas emissions and then purchasing carbon offsets to yield net zero carbon emissions for the municipality. This is a pragmatic approach to realising the aspiration of carbon neutrality. It is a typical, practical approach to the target. A similar approach is identified by Waverley Council (2017) in its Master Plan for Bondi Junction, where the emphasis is on showcasing Bondi Junction as a sustainable precinct, which includes improving energy and water efficiency in building and ensuring future development is economically and environmentally sustainable and of a high design quality, highlighting reduced carbon emissions.

In urban planning and design, carbon neutrality (or ‘zero emissions’) means buildings and facilities that use renewable energy on site (e.g. solar PV) to generate the energy for their operation, so that over an extended period (e.g. a year) the net amount of energy generated in the precinct equals the net amount of energy required by the precinct (and the activities associated with it). As indicated above, a precinct that is unable to generate that amount of energy may seek to obtain carbon offsets to reach neutrality. Minimising the need for carbon offsets to achieve carbon neutrality is an important design goal.

Carbon neutrality implies that the net carbon emissions of a given entity, including any carbon offsets associated with it, are zero. The next stage is carbon negative, in which the entity’s carbon footprint is reduced to less than neutral – the entity then has a net effect of removing carbon dioxide. Beyond carbon negative is carbon positive, under which regime fossil fuels are removed from the operations of the entity.

Carbon neutrality is seen in many circles as present day ‘best practice’. According to Pipkorn and Reardon (2013) however, future planning goals will seek carbon positive development in which the building or precinct will produce surplus energy that can be exported to the grid.

The degree of attainment of a target carbon emissions state for an actual precinct can only be ascertained through measurement and monitoring of its carbon emissions. Evaluation of precinct designs on the basis of comparisons between estimated performance of the design against in-service actual performance should be an inherent part of the planning and design process. Performance evaluation also requires the consideration of benchmarks.
Benchmarking is the process of comparing the performance of one system (e.g. a precinct) against the performance of other, similar systems which are designated ‘best practice’ in a particular field – and for which established metrics of performance are available. Key performance indicators of the types described in this chapter would be used to establish such metrics for precinct carbon performance. While there are existing benchmarks for buildings, especially commercial and residential properties, there are few established benchmarks for precincts at present.

The ‘Green Star’ rating system used by the Green Building Council of Australia includes a ‘Green Star – Communities rating tool (GBCA 2018) for assessing the planning, design and construction of large-scale development projects at precinct, neighbourhood and community scales. The rating tool uses five dimensions: governance, liveability, economic prosperity, environment and innovation, of which the last two would be directly relevant to low carbon investigations.

At a broader urban scale, at the level of the municipality or beyond, there are carbon emissions rating systems that may be used for benchmarking purposes. One such tool is the Siemens ‘CyPT’ City Performance Tool (Siemens 2018), which has been applied in many cities around the world (e.g. Adelaide, see ACC (2016)). This tool contains an innovative benchmarking option which compares carbon emission performance of a number of (precinct-relevant) technologies, e.g. LED street lighting, electric cars, home energy monitoring, solar PV panels, etc., to the known performance of a specific technology (e.g. wall insulation) in terms of carbon emissions and cost effectiveness of those emissions (kg CO₂-e per unit cost). See Siemens (2018) for more information on the tool and its applications. CyPT has the potential to be applied at the precinct scale.

Benchmarking using performance indicators of the types discussed in this chapter will become an important consideration in the future planning and design of low carbon precincts once better and more comprehensive data on precinct performance becomes available. This is a significant area for future research.

References


Section 14

Accessing the CRCLCL Tools

Stewart Wallace, University of New South Wales, and Christian Urich, Monash University
14. Accessing the CRCLCL Tools

The tools described in the chapters above continue to be hosted by partner institutions of the CRCLCL. The information below gives guidance on where the tools are hosted and who to contact if you want access or more information. Some tools are open access, but others require the creation of a user account and assistance from the developers. In some cases, a funded project may need to be initiated to enable effective use of a tool. Most of the tools can also be accessed from the CRCLCL’s Knowledge Hub at builtbetter.org/lowcarbontools

14.1 RP2007 - Integrated carbon metrics (ICM]

Table 14.1: ICM-ECE - Embodied Carbon Explorer

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>UNSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td><a href="https://ielab-aus.info/">https://ielab-aus.info/</a></td>
</tr>
<tr>
<td>Main contact</td>
<td>A/Prof Thomas Wiedmann - <a href="mailto:t.wiedmann@unsw.edu.au">t.wiedmann@unsw.edu.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Soo Huey Teh <a href="mailto:soohuey.teh@unsw.edu.au">soohuey.teh@unsw.edu.au</a> and Dan Micevski <a href="mailto:d.micevski@unsw.edu.au">d.micevski@unsw.edu.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>None required, online</td>
</tr>
<tr>
<td>Permission and access</td>
<td>Contact team to setup login to IE-lab</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>See links in IE-Lab</td>
</tr>
<tr>
<td>Open-source</td>
<td>NA</td>
</tr>
<tr>
<td>Data</td>
<td>The underlying data are based on open-source data (i.e. national input-output tables by ABS and greenhouse gas data by AGEIS). Data are updated and managed by support team</td>
</tr>
</tbody>
</table>

Table 14.2: ICM-PCA – Precinct Carbon Assessment

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>UNSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>The full version in Matlab is accessible through remote desktop - contact the team. There is also a packaged runtime Matlab version. The ‘Light’ online version is at <a href="http://precinculators.info">http:// precinculators.info</a></td>
</tr>
<tr>
<td>Main contact</td>
<td>Dr. Ke Xing - <a href="mailto:Ke.Xing@unisa.edu.au">Ke.Xing@unisa.edu.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Dr. Bin Huang - <a href="mailto:Bin.Huang@unisa.edu.au">Bin.Huang@unisa.edu.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>None required, online or remote desktop access</td>
</tr>
<tr>
<td>Permission and Access</td>
<td>Contact team to setup login to online version</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>Contact team</td>
</tr>
<tr>
<td>Open-source</td>
<td>NA</td>
</tr>
<tr>
<td>Data</td>
<td>From IELab</td>
</tr>
</tbody>
</table>
14.2 RP3034 - Community co-design of low carbon precincts for urban regeneration.

Note: ENVISION and ESP were deployed for the CRCLCL project RP3034 but were largely developed by the CRCSI, now FrontierSI.

Table 14.3: ENVISION

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>FrontierSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main contact</td>
<td>Phil Delaney, Manager, Partner services, Frontier SI. <a href="mailto:pdelaney@frontiersi.com.au">pdelaney@frontiersi.com.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Alex Leith - <a href="mailto:aleith@frontiersi.com.au">aleith@frontiersi.com.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>Online</td>
</tr>
<tr>
<td>Permission and Access</td>
<td>Login required, online registration available at <a href="http://www.greyfieldplanning.com.au/">http://www.greyfieldplanning.com.au/</a> or contact support</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>Online with each application. A training module is also available. Contact support.</td>
</tr>
<tr>
<td>Data</td>
<td>Not available</td>
</tr>
</tbody>
</table>

Table 14.4: ESP - ENVISION Scenario Planner

Note: The output data from ENVISION provide the required input data for ESP

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>FrontierSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main contact</td>
<td>Phil Delaney, Manager, Partner services, Frontier SI. <a href="mailto:pdelaney@frontiersi.com.au">pdelaney@frontiersi.com.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Alex Leith - <a href="mailto:aleith@frontiersi.com.au">aleith@frontiersi.com.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>Online</td>
</tr>
<tr>
<td>Permission and access</td>
<td>Login required, online registration available at <a href="http://www.greyfieldplanning.com.au/">http://www.greyfieldplanning.com.au/</a> or contact support</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>Online with each application. A training module is also available. Contact support.</td>
</tr>
<tr>
<td>Data</td>
<td>Not available</td>
</tr>
</tbody>
</table>
14.3 RP2002 - Integrated energy, transport, waste and water demand forecasting and scenario planning for precincts.

Table 14.5: ETWW

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>Flinders University</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Local install</td>
</tr>
</tbody>
</table>
| Main contact        | Prof. Michael Taylor - Michael.Taylor@unisa.edu.au  
                      Dr. Nicholas Holyoak - nicholas.holyoak@flinders.edu.au |
| Support contact     | Dr. Nicholas Holyoak - nicholas.holyoak@flinders.edu.au |
| Installation        | The tool is an Excel spreadsheet with attached software modules. The modules will require assistance from the team:  
                      - **ETWW-en** separate module for energy demand  
                      - **ETWW-h2o** separate module for water demand  
                      - Optionally, a link to an external Strategic Transport Model (STM) for the city containing the study precinct. Every major city in Australia has an STM, access to which is available through the relevant state transport agency e.g. the NSW Bureau of Transport Statistics (for Sydney, Newcastle and Wollongong). |
| Permission and access | No login required |
| Help and manuals    | Contact team       |
| Open-source         | Excel is part of Microsoft Office Systems. Attached modules are executables that are not accessible. Modification is not recommended. Contact support |
| Data                | The tool makes some use of Mosaic data on household characteristics and behaviour, which is available from Experian Pty Ltd. The existing data set obtained from Experian is built in to the ETWW tool under the CRC’s licence agreement. Should a user seek or require new or additional Mosaic data, this would need to be negotiated with Experian. |

14.4 RP2021 - Greening urban and suburban travel: tools for modelling the impacts of low carbon mobility solutions.

Table 14.6: PSUMC – Precinct Shared Use Mobility Calculator

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>Local install</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Excel spreadsheet</td>
</tr>
<tr>
<td>Main contact</td>
<td>Damian Moffatt - <a href="mailto:dmoffatt@swin.edu.au">dmoffatt@swin.edu.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>A/Prof Hussein Dia - <a href="mailto:HDia@swin.edu.au">HDia@swin.edu.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>Excel only</td>
</tr>
<tr>
<td>Permission and access</td>
<td>No login required</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>In spreadsheet</td>
</tr>
<tr>
<td>Open-source</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The key data is from ABS and VISTA (Victorian Travel Data). Ideally, a travel preference survey will need to be completed. An example set of data that was collected is included and can be used to approximate the results for other users. Depending on the scenario being modelled, a traffic model may also need to be developed to generate travel preference data for the calculator.

Table 14.7: AMoD – Autonomous Mobility On-Demand tool

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>Local install</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>ABM based on the Commuter nanoscopic traffic simulator. Now part of the Infraworks 360 Autodesk. <a href="https://www.aimsun.com/">https://www.aimsun.com/</a></td>
</tr>
<tr>
<td>Main contact</td>
<td>A/Prof Hussein Dia - <a href="mailto:HDia@swin.edu.au">HDia@swin.edu.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Saeed Bagloee - <a href="mailto:sasadibagloee@swin.edu.au">sasadibagloee@swin.edu.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>Local install - may require video card Infraworks install</td>
</tr>
<tr>
<td>Permission and access</td>
<td>Software licences required but no login</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>See package manuals</td>
</tr>
<tr>
<td>Open-source</td>
<td>NA</td>
</tr>
<tr>
<td>Data</td>
<td>From state transport agencies</td>
</tr>
</tbody>
</table>

Table 14.8: ABM-TMC – Agent-based Model of Transport Mode Choice

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>CSIRO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main contact</td>
<td>Dr. Magnus Moglia - <a href="mailto:Magnus.moglia@csiro.au">Magnus.moglia@csiro.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Stephen Cook - <a href="mailto:Stephen.cook@csiro.au">Stephen.cook@csiro.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>Full version runs on NetLogo available at <a href="https://ccl.northwestern.edu/netlogo/download.shtml">https://ccl.northwestern.edu/netlogo/download.shtml</a></td>
</tr>
<tr>
<td>Permission and access</td>
<td>Software licences required but no login</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>See package manuals</td>
</tr>
<tr>
<td>Open-source</td>
<td>NetLogo code is open-source</td>
</tr>
<tr>
<td>Data</td>
<td>Model uses some secondary data that inherits licence conditions, summary of primary survey data collected as part of the project will be available from <a href="http://www.ned-abm.com.au/">www.ned-abm.com.au/</a></td>
</tr>
</tbody>
</table>
Table 14.9: SNAMUTS – Spatial Network Analysis for Multi-modal Urban Transport Systems

*Note:* SNAMUTS was used in the Use Study for this project (see Curtis, C. and Schreurer, J. (2016) Planning for Public Transport Accessibility – An International Sourcebook (Routledge, London and NY)

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>Curtin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td><a href="http://www.snamuts.com">http://www.snamuts.com</a></td>
</tr>
<tr>
<td>Main contact</td>
<td>Prof. Carey Curtins - <a href="mailto:C.Curtis@exchange.curtin.edu.au">C.Curtis@exchange.curtin.edu.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td>Contact the SNAMUTS team at <a href="http://www.snamuts.com">http://www.snamuts.com</a></td>
</tr>
</tbody>
</table>

14.5 **RP2028 - A low carbon living co-benefits calculator**

Table 14.10: CBC - Co-Benefits Calculator

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>University of Melbourne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main contact</td>
<td>Prof. Mark Stevenson - <a href="mailto:mark.stevenson@unimelb.edu.au">mark.stevenson@unimelb.edu.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Prof. Mark Stevenson - <a href="mailto:mark.stevenson@unimelb.edu.au">mark.stevenson@unimelb.edu.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>Online</td>
</tr>
<tr>
<td>Permission and access</td>
<td>No login required</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>See website</td>
</tr>
<tr>
<td>Open-source</td>
<td>NA</td>
</tr>
<tr>
<td>Data</td>
<td>Partly AURIN, DHHS</td>
</tr>
</tbody>
</table>

14.6 **RP2023 - Microclimate and urban heat mitigation decision-support tools**

Table 14.11: UHI-DS – Urban Heat Island Decision Support tool

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>UNSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td><a href="http://uhimitigationindex.be.unsw.edu.au/uhitool/login.html">http://uhimitigationindex.be.unsw.edu.au/uhitool/login.html</a></td>
</tr>
<tr>
<td>Main contact</td>
<td>Dr. Henry Petersen - <a href="mailto:h.petersen@unsw.edu.au">h.petersen@unsw.edu.au</a></td>
</tr>
<tr>
<td>Support contact</td>
<td>Dr. Henry Petersen - <a href="mailto:h.petersen@unsw.edu.au">h.petersen@unsw.edu.au</a></td>
</tr>
<tr>
<td>Installation</td>
<td>Online</td>
</tr>
<tr>
<td>Permission and access</td>
<td>Contact support</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>Contact support</td>
</tr>
<tr>
<td>Open-source</td>
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### Table 14.12: UHVI – Urban Heat Vulnerability Index

<table>
<thead>
<tr>
<th>Hosting institution</th>
<th>UNSW</th>
</tr>
</thead>
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<tr>
<td>Location</td>
<td>Access through - <a href="http://uhimitigationindex.be.unsw.edu.au">http://uhimitigationindex.be.unsw.edu.au</a></td>
</tr>
<tr>
<td>Main contact</td>
<td>Dr. Henry Petersen - <a href="mailto:h.petersen@unsw.edu.au">h.petersen@unsw.edu.au</a>  &lt;br&gt; A/Prof Lan Ding - <a href="mailto:lan.ding@unsw.edu.au">lan.ding@unsw.edu.au</a></td>
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<tr>
<td>Support contact</td>
<td>Dr. Henry Petersen - <a href="mailto:h.petersen@unsw.edu.au">h.petersen@unsw.edu.au</a>  &lt;br&gt; A/Prof Lan Ding - <a href="mailto:lan.ding@unsw.edu.au">lan.ding@unsw.edu.au</a></td>
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<tr>
<td>Installation</td>
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<td>Permission and access</td>
<td>No login required</td>
</tr>
<tr>
<td>Help and manuals</td>
<td>See website</td>
</tr>
<tr>
<td>Open-source</td>
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### Table 14.13: UHI Mitigation Index

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</tr>
<tr>
<td>Main contact</td>
<td>Dr. Henry Petersen - <a href="mailto:h.petersen@unsw.edu.au">h.petersen@unsw.edu.au</a>  &lt;br&gt; A/Prof Lan Ding - <a href="mailto:lan.ding@unsw.edu.au">lan.ding@unsw.edu.au</a></td>
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<td>Support contact</td>
<td>Dr. Henry Petersen - <a href="mailto:h.petersen@unsw.edu.au">h.petersen@unsw.edu.au</a>  &lt;br&gt; A/Prof Lan Ding - <a href="mailto:lan.ding@unsw.edu.au">lan.ding@unsw.edu.au</a></td>
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<td>Installation</td>
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<td>Help and manuals</td>
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<tr>
<td>Open-source</td>
<td>No</td>
</tr>
<tr>
<td>Data</td>
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</tr>
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## 14.7 Integrated access to tools

The tools described in this guide will be accessible through the CRCLCL’s Knowledge Hub at [http://builtbetter.org/](http://builtbetter.org/). They will also be available and more closely integrated in the iHUB network that is being established from 2019 ARC funding (see also Chapter 15). The iHUB will also include a number of tools developed in the CRCWSC (CRCWSC). Table 14.1 provides a brief description of the CRCWSC tools.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
<th>Reference</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRCWSC Transition Platform</td>
<td>The Water Sensitive Cities Transition Platform guides cities and city councils in how to steer the transition to more water sensitive practices and outcomes through targeted strategic interventions. Accessed through a web platform, cities benchmark the current urban water system set targets, model the impact of potential management responses, track progress over time, and collaborate more effectively with other industry organisations to manage water in ways that helps create more liveable, productive, resilient, and sustainable urban environments.</td>
<td>Chesterfield et. al. (2016) ‘A Water Sensitive Cities Index to support transitions to more liveable, sustainable, resilient and productive cities’ Proceedings for Singapore International Water Week, Singapore 2016 Tool website <a href="https://watersensitivecities.org.au/solutions/wsc-index/">https://watersensitivecities.org.au/solutions/wsc-index/</a></td>
<td>Briony Rogers <a href="mailto:briony.rogers@monash.edu">briony.rogers@monash.edu</a></td>
</tr>
<tr>
<td>CRCWSC Scenario Platform</td>
<td>Accessed through a web interface, the Scenario Platform assists planners, designers and engineers in assessing the multiple benefits of green infrastructure solutions in terms of their biophysical and ecological impacts, and combined with an economic evaluation framework to provide the basis for robust water sensitive business cases at a precinct to catchment scale.</td>
<td>Dotto et. al., (2014), ‘Towards Water Sensitive Urban Precincts: Modelling Stormwater Management Opportunities’, 13th International Conference on Urban Drainage, 6-12 September, Sarawak, Malaysia. Under development</td>
<td>Christian Urich <a href="mailto:christian.urich@monash.edu">christian.urich@monash.edu</a></td>
</tr>
<tr>
<td>Tool</td>
<td>Description</td>
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<td>Contact</td>
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<tr>
<td><strong>Non-Market Value Tool</strong></td>
<td>A non market value tool consisting of a comprehensive database of existing non-market values of water sensitive systems and practices that will be used to underpin various benefit-transfer methods. A set of guidelines have been developed to assist the user.</td>
<td>Tool website <a href="https://watersensitivecities.org.au/research/our-research-focus-2016-2021/integrated-research/irp2-wp2/">https://watersensitivecities.org.au/research/our-research-focus-2016-2021/integrated-research/irp2-wp2/</a></td>
<td>Dr Md. Sayed Iftekhar <a href="mailto:mdsayed.iftekhar@uwa.edu.au">mdsayed.iftekhar@uwa.edu.au</a></td>
</tr>
<tr>
<td><strong>Water Sensitive Cities Index</strong></td>
<td>The WSC Index is a tool designed to benchmark a city’s current performance against seven goals of a water sensitive city. These goals include both biophysical and socio-institutional goals, which organised 34 corresponding indicators.</td>
<td>Chesterfield et. al. (2016) ‘A Water Sensitive Cities Index to support transitions to more liveable, sustainable, resilient and productive cities’ Proceedings for Singapore International Water Week, Singapore 2016 Tool website <a href="https://watersensitivecities.org.au/solutions/wsc-index/">https://watersensitivecities.org.au/solutions/wsc-index/</a></td>
<td>Briony Rogers <a href="mailto:briony.rogers@monash.edu">briony.rogers@monash.edu</a></td>
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<td>Tool</td>
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<tr>
<td><strong>DAnCE4Water</strong></td>
<td>Modelling tool to inform planning and decision-making about water management and adaptation strategies. It simulates technical, social and economic dimensions of a city’s integrated urban water system as it changes over time in response to water management strategies and drivers such as climate change, societal shifts and population growth.</td>
<td>Rauch, W. et al., (2017) ‘Modelling transitions in urban water systems’, Water Research. Elsevier Ltd, 126, pp. 501–514. doi: 10.1016/j.watres.2017.09.039. Available through the CRCWSC Design/Scenario Platform</td>
<td>Christian Urich <a href="mailto:christian.urich@monash.edu">christian.urich@monash.edu</a></td>
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<tr>
<td><strong>Stream health</strong></td>
<td></td>
<td>Walnut et al., Cities as water supply catchments – Stream ecology (Project B2.1) Accessible through the WSC Toolkit</td>
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<tr>
<td>hydrology and water quality</td>
<td>From urbanised towards natural streams</td>
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<tr>
<td>(modified EB index)</td>
<td>Frequency of runoff days</td>
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<td></td>
<td>Proportion of total volume reduction</td>
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<tr>
<td></td>
<td>Proportion of filtered flows</td>
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<td><strong>Stream Erosion Index - SEI</strong></td>
<td>Geomorphic stability</td>
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<td><strong>Microclimate</strong></td>
<td>Land surface temperature benefits</td>
<td>Tapper et al., Cities as Water Supply Catchments: Green cities and microclimate (Project B3.1) Accessible through the WSC Toolkit</td>
<td>Nigel Tapper <a href="mailto:Nigel.Tapper@monash.edu">Nigel.Tapper@monash.edu</a></td>
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<tr>
<td>Tool</td>
<td>Description</td>
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<td>-----------------------------------------------------------------------------</td>
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</table>
| TARGET                       | Air temperature and thermal comfort for precincts                            | An urban micro-climate model for assessing impacts of Water Sensitive Urban Design  
K.A. Nice, N. Tapper, J. Beringer, A. Coutts, S. Krayenhoff  
Development 5 (4), 919-940  
Accessible through the WSC Toolkit | Nigel Tapper  
Nigel.Tapper@monash.edu |
Accessible through DAnCE4Water | Christian Urich  
Christian.urich@monash.edu |
karn@env.dtu.dk |
Available as excel spreadsheet | Steven Kenway  
s.kenway@uq.edu.au |
Section 15

Future Directions
Peter W. Newton, Swinburne University of Technology
15. Future Directions

In pursuit of sustainable urban development in the 21st century, smart strategies are needed to radically shrink the ecological footprints of the built environments of Australian cities. The two principal targets are: resource use and GHG mitigation. Reduction in resource use calls for regenerative, eco-positive urban development. Rapid decarbonisation is needed to avoid global warming and climate change on a scale foreshadowed in the most recent IPCC report (IPCC 2018). Precautionary principles also require more attention be given to planning for more adaptive and resilient cities with the prospect of temperatures that are 1.5°C above 20th century levels by 2050 (Newton et al., 2018).

Innovations in technology and urban design can combine to deliver significant transformation of built environment performance – the context in which all human activity and consumption takes place. Behaviour change holds the prospect of delivering the most rapid reduction in ecological footprint if appropriate triggers for change can be found (Newton and Bai, 2018) and they are coupled with appropriate technological developments. The potential for transition across all three domains is clear, if accelerated and scaled up (Newton et al., 2019).

Realising such a transition, however, requires identifying, addressing and overcoming a number of deficits. This guide is focussed on overcoming a deficit in precinct design performance assessment. Precincts are acknowledged as the building blocks of our cities, and collectively contribute to a city’s performance in relation to productivity, sustainability, liveability, health, resilience and social inclusion, among a long list of indicators. Precincts also represent the places in which people live and work in cities (Matan and Newman 2016). They need to become the major focus for urban planning and urban design, which is especially challenging in an era when regenerative urban re-development is becoming the pre-eminent focus.

There are multiple objectives associated with precinct performance, listed in detail in Chapter 2 (Table 2.1). How to assess that performance is challenging – even when the focus is primarily on environmental performance. We are currently at a similar stage of applied research activity for precincts as we were for buildings at the end of the 20th century, due to the relative complexity of the topic. Digitalisation proved to be the principal driver of innovation in combined building performance design and assessment, with BIM capability meshing with increased knowledge about the environmental performance of building objects and spaces (Newton et al., 2009).

A similar transition is required for PIM as a new digital platform capable of supporting integrated assessment and integrated modelling at a precinct scale. Figure 15.1 represents this trajectory. At present there is a growing collection of software tools that focus on particular aspects of precinct performance – such as those represented in this guide (Chapters 4-10). The CRCWSC has developed a complementary collection (see Chapter 14).

Figure 15.1: Three horizons of urban analytics
This guide takes us but a small distance up this innovation curve. Most of the material has focused on computer-based models targeting some important facet of precinct design performance: energy and water use; mobility; waste generation; influence of dwelling type on resource use and carbon emissions; regenerative impact of distributed technologies such as solar PV and storage and microgrids; integrated water systems; car and ride sharing; accounting for embodied energy as well as operating energy in relation to the carbon footprints of materials, buildings and cities; assessing the health and wellbeing co-benefits of living in a particular type of neighbourhood; and the capacity of different urban fabrics to adapt to global warming and climate change.

The precinct assessment toolkits to emerge from the CRCSI, CRCLCL and CRCWSC are considerable in scope. They provide a powerful capability for integrated assessment of precincts – at any stage of precinct development from ‘as conceived/planned’ to ‘as designed’ to ‘as built’ and ‘as operated’. The insights and benefits to be gained from research synthesis workshops employing integrated assessment of a particular precinct were outlined in Chapter 11.

Integrated modelling, using PIM as a platform, represents a challenge for the next generation of applied urban research (see Figure 15.2). Chapter 12 outlines the benefits to be gained for integrated precinct planning and design. Realisation of these efficiency, productivity and performance benefits, however, will require greater engagement from national and international spatial standards bodies as well as major firms involved in BIM, PIM and CIM to establish codes and standards for the interoperability of spatial data and spatial software. The benefits are considerable (BuildingSmart and SIBA (2015) and OGC, ISO and IHO (2018).

Source: Plume, Marchant and Mitchell (2017)
Figure 15.2: Integrated precinct modelling across the project life cycle

There are various vertical disconnects and imbalances between federal, state and local governments as well as with local communities that diminish the prospect of good governance in relation to metropolitan and precinct planning and achievement of more sustainable outcomes (Tomlinson and Spiller (2018). These are compounded by the horizontal disconnects within each tier, especially those at state government level where a city focus is required for strategic and statutory planning, among other functions (Figure 15.3).
State agencies are principally tasked with responding to broad spectrum state-wide needs, and in the absence of metropolitan governments in Australia (with the exception of the City of Brisbane, noting that this now accounts for only half of the population in the Greater Brisbane Metropolitan Area and one third of the Southeast Queensland Mega-Metropolitan Region) there are multiple ministries and agencies requiring co-ordination to develop smart, sustainable development strategies for their cities. The level of public dissatisfaction about liveability in Australia’s largest cities (McCrindle, 2015) and the continued missteps and shifts in long term metropolitan development strategies, highlights the negative impacts of these disconnects and imbalances and associated planning deficits.

Figure 15.3: Governance deficits in metropolitan planning – horizontal and vertical imbalances and disconnects

15.1 A New Platform for Transforming Urban Governance and Planning and Precincts

The mounting calls for better urban governance (Burton, 2017; Williams, 2018) and better urban planning (ASBEC, 2015; Commonwealth of Australia, 2018; Infrastructure Australia, 2018; PIA, 2018) are connected. A game-changer capable of providing a transition on both fronts has emerged in the form of a 21st century smart, networked decision support platform for applied urban research, synthesis and participation. Labelled the iHUB-Network (Newton and Burry, 2018), it is being developed as a readily scalable state-of-the-art multi-layered facility for applied urban research, synthesis and engagement that enables smart decision support for urban policy-making, plan-making and place-making (Figure 15.4).

Funded by a $1.8million Australian Research Council LIEF grant awarded in November 2018 to a consortium of five universities in Australia’s four largest capital cities, this initiative will enable ‘city as laboratory’ to be realised on a national scale, linking individual university labs as a single collaborative research space (including Swinburne’s Smart Cities Research Institute and Centre for Urban Transitions; University of NSW’s City Analytics Lab and Urban Pinboard; Monash University’s Urban Lab; Curtin’s Circular Economy Living Lab; and University of Queensland’s individual research centres in the Faculty of Engineering, Architecture and IT).

Using a common infrastructure, iHUB is designed to deliver superior computational, visualisation and broadband communications infrastructure capable of supporting a broad spectrum of applied and strategic research and engagement objectives with digital pin-ups, high speed computing and broadband, enabling real time distributed synchronous computing and communication nationally and internationally 24/7.
Each iHUB facility in the network has a highly reconfigurable meeting space (see Figure 15.5) with five principal infrastructure features:

- a space affording up to 64 individual presentations from laptops, tablets and smartphones to be compared and contrasted simultaneously within a digital pin-up space
- a room hosting high-end computing with advanced graphics capability with the power to process large urban data sets producing spatial visualisation in real-time making use of all combinations of screens
- connections by Australia’s fastest broadband network (AARNet) enabling teams of urban researchers and practitioners from across 4 states to collaborate, sharing each other’s high resolution visualisations drawn from local and geographically distributed urban data sets
- a digital pin-up space that can host exhibitions drawn from various sources as a visual backdrop to urban research as well as government, industry and community-initiated engagement meetings, or that can be a combination of exhibition space and interactive meeting space hosting both presentations and real-time visualisation of urban analytics simultaneously
- a ‘digital workbench’ for many powerful digital urban analytical tools that, to date, have not been able to interoperate. The digital workbench provides the ‘smarts’ that enables the design decision-makers to consider fresh data-driven scenarios together with future planning scenarios in real-time. Through sophisticated data capture, transmission and advanced analytics, and advanced visualisation, experts and end-users will be able to interact with both the data and each other in real-time.

In short, an iHUB facility provides a highly adaptable space where visual-analytic material from many sources can be used to cover a landscape of disciplines with vastly different modus operandi, where the visual representation of ideas, theories, facts, postulations, models and scenarios is the most appropriate common ground upon which to be informed, to negotiate, to advocate, and to instruct.
In addition to the infrastructure layer, the data layer initially established in the iHUB will operate as a distributed data system that draws on proprietary databases developed and managed within partner organisations and their affiliated networks as well as those with open access managed by governments and AURIN. The surge in data acquisition, processing and representation during the last decade, however, has not been adequately addressed by built environment and design (BED) professions insofar as the considerably improved data outputs are not routinely captured/accessed and converted to design inputs.

The software layer represents a significant repository of computer-based tools developed by the academic research community (iHUB university partners) including those attached to one or more of the three ‘urban’ CRCs (https://frontiersi.com.au/; http://www.lowcarbonliving crc.com.au/; https://watersensitivecities.org.au/), as well as those available as open source. Computer modelling of built environment performance (at building, precinct and city scale) has generally been undertaken in silos – as one-off grants to individual research groups or within CRCs, or consultancies working on (often domain-) specific projects with resultant tools rarely being applied to important urban planning and design issues and never integrated. They are extensive (see Figure 15.6), but currently exist as separate tools, mostly new prototypes awaiting wider exposure on actual projects (e.g. via integrated assessment in research synthesis projects; see Figure 15.1), subsequent hardening, and where strategically important, developed as integrated multi-factor models. There is an opportunity here to respond to repeated calls for creating a capacity for integrated urban systems analysis and modelling (SBEnrc 2017).
Figure 15.6: Clusters of BED-relevant software (federally-funded CRC tools in LHS cluster)
The engagement layer is where the principal benefits of the iHUB network are delivered: “Imagine politicians, planners, developers, architects, engineers, social scientists, and citizens being able to gather in a room to make collective decisions based on real-time data analytics? In such a facility, key stakeholders, experts, and end-users could probe ‘what if...’ scenarios using 3D simulation to demonstrate the effects of competing urban development possibilities. The collected diverse disciplinary expertise and interests could debate alternative speculations around future cities together and consensually decide appropriate courses of action. There has been no such facility in Australia to date, yet as a nation we have all the necessary ingredients but lack the ‘glue’ to bind them together.” (Newton and Burry, 2018).

This represents a possible future urban governance decision-making platform for local as well as metropolitan development policy-making, plan-making and place-making that could be transformative. For the first time key decisions can be tested for likely consequences in real-time. This enables all stakeholders to be present, sharing information and a wide assortment of insights with a fluency and timeliness only made possible by the confluence of rapidly improving computing technology and processes, combined with distributed urban analytics and design software.

There are at least two major classes of transformative collaboration capable of being enabled by the iHUB network facility:

1. **Integrated assessment and research synthesis** (see Figure 15.1), representing a new model for rapid engagement between researchers and end-users (government, industry and community – in multiple combinations) to unlock opportunities that stem from the new knowledge and analytics. These can be focused on critical urban development problems related to new transport, water, waste and energy infrastructure, infill housing in brownfields and greyfields, etc. Pioneered by CRCWSC ([https://watersensitivecities.org.au/?s=research+synthesis](https://watersensitivecities.org.au/?s=research+synthesis); see Chapter 11), this is an engagement methodology perfectly suited to the iHUB networked facility using 21st century digital infrastructures. It requires integrated assessment as a critical input, achieved by assembling real-time input from distributed research experts and practitioners and their specialist software tools generating spatial analytic outputs related to a specific urban place and challenge. These would be displayed on multiple digital pin-board screens in real-time, with digital mark-up tools (compared to powerpoints of outputs currently shown sequentially by experts parachuted into a workshop). Critical tacit knowledge from the assembled working group can rapidly assess and synthesise the outputs to create new planning and design options evaluated on the fly which, in many cases can be further assessed during the meeting (a major boost to creativity and productivity). Multiple applications are foreseeable:

- **Regenerative urban infill design and assessment.** Achieving targets of 70% urban infill is a common target for Australia’s largest cities, but is failing in several aspects related to environmental, social and economic outcomes, quality of precinct place-making and community engagement. iHUB is a space for researchers and practitioners to demonstrate potential solutions to local communities in an interactive digital environment that enables both design visualisation and performance assessment in multiple forums. There is a large and immediate market for this capability, which would provide academic researchers with new opportunities for a front-row seat in helping steer contemporary urban planning and design.

- **Strategic metropolitan planning for Australia’s capitals requires significantly greater horizontal and vertical integration among government agencies than is presently the case (e.g. across multiple state government agencies as well as between state and local government and community groups. iHUB also constitutes a new governance platform where researchers and representative urban stakeholders can facilitate informed evidence-based dialogue with government policy makers and planners.”
• With the proliferation of digital planning and design tools (such as those emerging in this guide) there is a critical need to ensure these tools are fit for purpose at the earliest possible stage of their development. The iHUB platform also enables researchers to study how planners, policy and decision-makers best interact and use digital planning and design tools in order to undertake city shaping activities. It also provides the leaders of major research projects, that are often spread across multiple organisations in different cities (and increasingly internationally) with a powerful new platform to better engage with and manage their teams.

2. **Integrated modelling.** To date, there has been no mechanism in the Built Environment and Design research sector for co-ordinating software development within domains (e.g. energy, water, buildings, mobility) much less cross-domain (integrated) modelling. An initial challenge is to develop software that allows existing bespoke tools to communicate with each other (e.g. data interfaces that allow communication between disparate software products). The software would also need to allow input from and output to commercial off-the-shelf software currently used by the design industry). There are many areas where this would add significant value to end users in government and industry in challenging areas such as greening suburban transport, local government’s task of Development Assessment of new urban projects (e.g. urban heat mitigation from higher density redevelopment), adaptive planning for cities in the context of climate change (e.g. sea level rise and catchment flooding - a multi-jurisdictional and multi-factor problem for city planners) – if the intermeshing of currently fragmented analytical tools could be undertaken. This also would also involve undertaking cross-scale modelling, aligned to leading BIM-PIM-CIM architectures, standards and protocols enabling cross-institutional software development and integration that needs national and international oversight in relation to the challenges of inter-operability and harmonisation (see Chapter 12); OGC, ISO and IHO (2018); http://www.lowcarbonlivingcrc.com.au/events/2017/08/industry-symposium-using-precinct-information-modelling-pim-support-carbon-management). iHUB provides the infrastructure and a capacity for this endeavour – a platform for synchronous distributed computing/collaboration/co-working among geographically dispersed domain experts and software engineers where the objective is integrating these scenario modelling tools into a common platform; allowing each speciality to interact with a shared model and thus produce a more complete suite of urban design and assessment tools; and enabling engagement and partnering with leading global organisations active in this space.

In summary, the iHUB platform will:

- enhance interdisciplinary engagement across the Built Environment and Design (BED) sector and affiliated academic fields of research in tackling wicked urban problems
- promote more effective urban governance involving enhanced horizontal engagement and integration across the multiple departments and agencies involved in strategic metropolitan planning
- facilitate vertical integration between state-level strategic planning (and zoning) and local government statutory planning and associated development approval processes associated with increasingly complex built environment projects
- provide real citizen engagement and participation associated with significant urban development issues involving some aspect of neighbourhood change (e.g. typically transport or building related)
- deliver integrated urban assessment and integrated modelling capacity for research synthesis workshops on major urban development proposals/projects
- provide real time, geographically distributed, synchronous communication and research collaboration platforms (enabling telepresence, co-working, co-designing etc.)
- partner in an urban data repository (open data) with agencies such as AURIN
- provide a new, unique training environment for graduate and postgraduate students in the BED sector
• provide a critical mass of local capability to match emerging global initiatives (e.g. Google Sidewalk Labs; Chandler, 2018) that have the capacity for a disruptive effect on Australia’s architecture, engineering and construction industries and contemporary urban development processes (Summers, 2019). These industries have been protected from the full force of globalisation thanks to their relative isolation geographically and an absence of competitors that are in the process of successfully harnessing the new digital information platforms, processes and tools that enable new modes of productive collaboration across an entire built environment project life cycle.

Clearly, precinct design assessment tools of the type featured in this guide are a necessary but not sufficient trigger for transformational change in built environment outcomes that seek to deliver on global, national, metropolitan and local sustainable urban development goals and objectives. They need to be embedded in new urban governance frameworks and processes supported by new digital platforms capable of effectively locking in built environment assessment – as designed, as built and as operated. This would help us achieve sustainable urban development in 21st century cities.

References


BuildingSmart and SIBA (2015) Integration of Geospatial and Built Environment - National Data Policy, Position Paper


Chandler, D. (2018) Forget sustainability and trust, you will get that in a box for ‘free’ from Google’s Sidewalk Labs, The Fifth Estate, 18 Sept


SBEnrc (2017) Big City Planning and Digital Tools - A Sustainable Built Environment National Research Centre (SBEnrc) Industry Report, Curtin University, Griffith University, Swinburne University, UNSW, Sustainable Built Environment Research Centre, Australia

