LOW CARBON LIVING CRC

Performance Assessment of Urban Precinct Design

A Scoping Study

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This study was undertaken by Swinburne University of Technology, University of New South Wales, CSIRO and buildingSMART Australasia on behalf of the CRC for Low Carbon Living.

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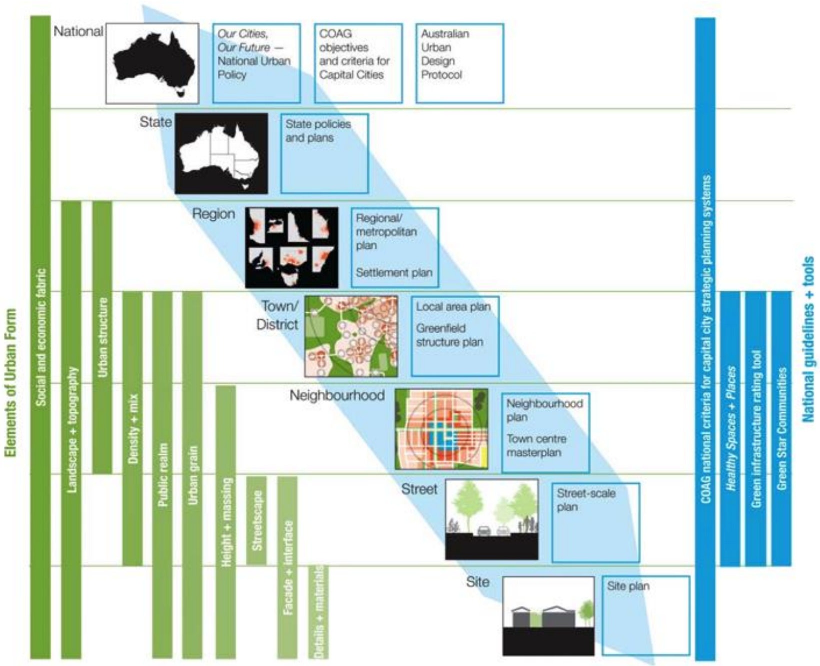
Executive Summary

Significant advances have been made over the past decade in the development of scientifically and industry accepted tools for the performance assessment of buildings in terms of energy, carbon, water, indoor environment quality etc. For resilient, sustainable low carbon urban development to be realised in the 21st century, however, will require several radical transitions in design performance beyond the scale of individual buildings. One of these involves the creation and application of leading edge tools (not widely available to built environment professions and practitioners) capable of being applied to an assessment of performance across all stages of development at a precinct scale (neighbourhood, community and district) in either greenfield, brownfield or greyfield settings. A core aspect here is the development of a new way of modelling precincts, referred to as Precinct Information Modelling (PIM) that provides for transparent sharing and linking of precinct object information across the development life cycle together with consistent, accurate and reliable access to reference data, including that associated with the urban context of the precinct.

Neighbourhoods are the 'building blocks' of our cities and represent the scale at which urban design needs to make its contribution to city performance: as productive, liveable, environmentally sustainable and socially inclusive places (COAG 2009). Neighbourhood design constitutes a major area for innovation as part of an urban design protocol established by the federal government (Department of Infrastructure and Transport 2011, see Figure 1). The ability to efficiently and effectively assess urban design performance at a neighbourhood level is in its infancy.

Figure 1: Neighbourhood design in context



Source:
http://www.urbandesign.gov.au/downloads/files/INFRA1219_MCU_R_SQUARE_URBAN_PROTOCOLS_1111_WEB_FA2.pdf

Study Objectives

This scoping study has been undertaken to identify the functionality, data and information platform required to deliver a 21st century *design assessment tool for precincts* that is scientifically sound for evaluating the carbon intensity, sustainability and resilience of current and future built environments. The CRC for Low Carbon Living has partners with four of the leading precinct scale design assessment tools (LESS – Hassell; MUtopia – Melbourne University; PrecinX – NSW Government; SSIM – AECOM) as well as GBCA's Green Star Communities Rating system. In this study, the term 'precinct' is used interchangeably with neighbourhood, district and community for the purpose of urban design assessment due to the manner in which such spaces can now be digitally represented. Precincts comprise a wide spectrum of built, natural and human objects, e.g. land parcels occupied by constructed facilities (generally buildings), including open space, often clustered into urban zones that share some common characteristics (uses, human activities) and supported by physical 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. A digital geospatial design representation of precinct confers greater flexibility in terms of how precincts can be modelled and assessed from multiple performance perspectives (e.g. carbon, sustainability, resilience, cost), from multiple spatial perspectives (e.g. 2D, 3D; as an entity as well as in its wider spatial context) and multiple temporal perspectives (e.g. across the project life cycle; across multiple future scenarios).

The motivation for this study relates to a need to more rapidly progress the development and maturation of tools capable of affecting positive change in urban systems from sustainability, resilience and low carbon performance perspectives. Linked to this is a need to improve urban development procedures that integrate information from urban assessment tools operating in real time into the decision making process, a feature of which involves protocols for negotiating better access to data, recognised as a key 'infrastructure' for research on human settlements. The outcome is an evidence base capable of identifying the most prospective areas to intervene to deliver high performing built environments.

Specific project objectives for this scoping study involve:

- Outlining the nature and benefits of using a Precinct Information Modelling (PIM) platform for data management in a 'big data' environment characteristic of urban precinct planning, design and management. Involved here is an understanding of the volume and variety of data streams associated with precinct design assessment and how that data is searched, accessed, transferred, analysed and visualised. The objective is to identify opportunities for more productive approaches to urban data management and performance assessment.
- An international review and synthesis of current methods and tools for urban design assessment to be used as a basis for developing a framework and criteria for evaluating the scope, functionality and gaps of existing precinct assessment tools, with particular reference to those developed by CRC partners.
- An international review and critical assessment of existing life cycle inventory (LCI) and life cycle assessment (LCA) databases and methods and their applicability to precinct design assessment in Australia
- A survey of a representative set of built environment sector organisations and end users to gauge their perspectives on the need for and functionality required in precinct design assessment systems; and
- A specification of the research required to create a world leading built environment design assessment system for delivering low carbon, sustainable and resilient precincts.

Structure of the Report

The Introduction to the report begins by establishing the significance of 'precinct' within a built environment context: where an evidence base on a project's performance is becoming a necessary precursor to urban development investment decision making within both a government and industry context; where core dimensions of built environment performance now involve sustainability, resilience, low carbon and life cycle cost indicators; and where a 21st century IT platform – PIM – is fundamental to a precinct assessment tool's efficiency and effectiveness of operation.

Chapter 2 creates a framework capable of being used to assess the functionality of existing and emerging precinct assessment and rating tools. Sustainability principles have been central to the themes that have underpinned initial attempts at assessment, but some 30 years after the Brundtland report, new themes that more explicitly target critical emergent built environment challenges – carbon intensity and resilience – are warranted. Together with the now traditional sustainability themes, they provide a more comprehensive frame of reference for evaluating precinct assessment tools.

Chapters 3 to 6 provide the results from which the Key Findings of the study are summarised (below). Chapter 3 is centred on an appraisal of the five precinct assessment and rating tools listed in the previous section, utilising the evaluation templates established in Chapter 2. Chapter 4 examines the data challenges that currently confront precinct assessment – both 'embodied' and 'operating' – that are inhibiting appraisal of life cycle performance of the built environment. Chapter 5 illustrates how data can be more effectively managed within a PIM context, and identifies a migration path for contemporary tools. Chapter 6 provides key findings from a market study of existing and potential end users of precinct assessment tools. When combined with the results of the research-based evaluations outlined in Chapters 3 to 5, the outcome is a set of recommendations for future research listed in Chapter 7.

Key Findings

The principal findings are summarised in the key points that follow.

Market momentum

There are two national precinct rating or certification systems operating in Australia (Green Star Communities and EnviroDevelopment) and more than ten precinct *assessment* tools (see Table 1; Figure 2.1 and Figure 2.6) – significantly more than in any other country. This is *evidence of a clear need having emerged in the marketplace for precinct design assessment*; but the response to date has been fragmented. In all cases, each tool has emerged in response to the needs and priorities of a set of sponsor or client organisations. A market study conducted as part of this project (Chapter 6) revealed that:

- Green Star Communities and EnviroDevelopment are playing a leading role across Australia in encouraging the development and application of urban sustainability assessment. Their combined work is engaging strongly with developers and state government agencies, and providing role models for local government.
- The government land organisations (GLOs), representing almost all state government land development agencies, have the potential to play a major role in a national strategy for low carbon, sustainable and resilient urban development. This needs to be in concert with assessment and rating tool developers (GLOs are currently licensed to use PrecinX), as well as national organisations such as ASBEC. A critical – and currently missing – element of this needs to be Federal government involvement in driving innovation and raising productivity in the urban design/planning sector (akin to its role in the buildings network and BIM).
- There are a number of design assessment tools (e.g. LESS and SSIM) that have been developed by private sector firms to assist government and private consortia optimise property development decisions. These are emerging as strong mechanisms to enable consultants and design professionals to deliver more robust precinct design solutions. However, they are limited to and shaped by projects to which they are applied.
- An opportunity exists to further develop these assessment and rating initiatives within a broader based carbon-sustainability-resilience assessment framework *and* through new built environment digital modelling technologies that bridge between buildings (BIM) and geospatial (GIS) data – termed precinct information modelling (PIM) and discussed in further detail as finding number 4.
- A key beneficiary of these developments would be local government, which is resource poor, limited in skills and finance but is being required to take over more responsibility for local stewardship of the built environment.

Table 1.1: Precinct assessment and rating tools operating in Australia

Precinct tool	Developer organisation	URL/key reference
Green Star Communities	Green Building Council of Australia	http://www.gbca.org.au/green-star/green-star-communities/
EnviroDevelopment Certification	Urban Development Institute of Australia	www.envirodevelopment.com.au/
IS Rating (Infrastructure)	Infrastructure Sustainability Council of Australia	http://www.agic.net.au/ISratingscheme1.htm#779315
LESS	Hassell	http://www.hassellstudio.com/en/cms-projects/detail/less-local-area-envisioning-and-sustainability-scoring-system/
MUtopia	University of Melbourne	http://www.mutopia.unimelb.edu.au/
PrecinX	NSW Government	http://www.landcom.com.au/
SSIM	AECOM	http://www.aecom.com/News/Innovation/_projectsList/Sustainable+Systems+Integration+Model+(Worldwide)
CCAP	Kinesis	http://kinesis.org/tools)
SDAPP (Sustainable Design Assessment in the Planning Process) framework	MAV	http://www.mav.asn.au/policy-services/planning-building/sustainable-buildings/sustainability-assessment-frameworks/Pages/default.aspx
Thriving Neighbourhoods	ICLEI	http://www.thrivingneighbourhoods.org/Thriving_Neighbourhoods_2012/Home.html
IRM	ARUP	http://www.thrivingneighbourhoods.org/Thriving_Neighbourhoods_2012/Home.html
One Planet Communities	Bioregional	http://www.oneplanetcommunities.org/

Precinct design rating and assessment challenges

The proprietary positions and institutional alignments surrounding each tool make comparative evaluations and gap analysis challenging and lead to a degree of confusion in the marketplace concerning tool selection. Precinct rating and assessment systems are currently voluntary. Consequently, their development and scope to date represents the interests and expertise of the participating organisations in the built environment, both government and industry. Underlying frameworks, themes, components, indicators, calculators and metrics in these tools vary considerably. This is characteristic of situations where governments are not mandating some level of assessment to be undertaken (against performance targets or benchmarks) on precinct scale development projects. It is instructive that a measure of energy regulation at building scale arose as a result of leadership by government, resulting in a joint specification with industry of those elements that should be in scope for assessment, together with the scientific validation required of indicators and their underpinning calculators/models. A CRC for Construction Innovation study (Ashe et al 2003) and a series of national workshops provided the basis for a decision by the Australian Building Control Board in 2004 to adopt sustainability as a fourth theme in the Building Code of Australia. Little subsequent progress has been made in this area. ASBEC is now developing a framework for the sustainability assessment of buildings in response to this hiatus. A comprehensive framework for built environment performance needs to be articulated, including performance targets.

Need for a 'top-down' framework for precinct design assessment and rating

A 'top-down' framework for examining the functionality of existing and future precinct design assessment and rating tools was developed for this project from an examination and synthesis of leading national and international research on what is required to create a high performing built environment at this scale. The core dimensions of performance represented in all precinct tools developed to date have been derived from the 'triple bottom line' sustainability principles. It was considered necessary, however, to elevate carbon, life cycle and resilience assessment to more prominent positions in built environment performance assessment, based on now well recognised challenges facing Australia's settlement system (Newton and Doherty, 2013; see Chapter 2).

By identifying these as key themes, together with precinct-related built environment categories, components and indicators, *a template for mapping performance metrics generated by current precinct assessment tools was developed and populated* – a task undertaken in Chapter 3. It identified key gaps in most of the current precinct urban design assessment tools as:

- Life cycle (embodied plus operating) carbon emissions assessment and effective GHG metrics;
- Resilience assessment across a full spectrum of regional climate change forecasts (e.g. higher, more extreme temperatures accentuating urban heat island effects; sea level rise combined with storm surges; flash flooding associated with locally intense rainfall events; more frequent and intense cyclones);
- Within a sustainability framework, a lack of sophistication in selected spatial modelling (e.g. access to services, walkability); demand modelling; and a lack of capacity for integrated cross-cutting analysis (e.g. land use–transport–environment interactions);
- Eco-efficiency (joint cost-environmental performance) assessment and life cycle costing of different design options;
- Ability to apportion costs and benefits between the different stakeholder groups in a development project;
- Lack of consensus surrounding core indicators required for precinct design assessment; lack of readily accessible data and standard performance benchmarks and rules for application to performance assessment (e.g. CO2/ha/dwelling/m2/person etc.) including across the precinct lifecycle;
- Lack of 'as operated' assessment functionality (post occupancy);
- Data quality and access standards;
- Balancing quantitative factors (e.g. costs, most environmental metrics with the human elements of design, stakeholders and governance;
- Foresight and its integration into 'futures' scenarios that can be examined at precinct level (CRC LCL RP3008 Visions 2050 is expected to advance practice in this area); as well as a standard process for informing a BAU or 'do nothing' scenario.

Taken together, however, the five assessment and rating tools at the centre of this study represent a good base on which to build greater precinct assessment functionality.

Need for a 21st century information platform

A common language is required to support the increasing demand for more accurate, analytical assessment of urban development in the digital age. We refer to this as PIM: technically, an open (standardised) object modelling schema or data model; not a new piece of software, but rather an information "standard" that establishes the way precincts are modelled for the purposes of assessment at any stage during the development life cycle. PIM has been identified as a platform capable of more effectively managing the broad information needs for built environment modelling and assessment (both spatial and non-spatial) at a precinct scale. It is also seen as providing those critical connections to building (BIM) and metro scale (GIS) information platforms. PIM offers clear *productivity benefits* linked to its capacity for delivering accurate, timely, consistent and relevant information within a precinct development and assessment context. This is due to PIM's ability to facilitate:

- More automated movement of data from distributed custodian sources (e.g. ABS, utilities) to precinct tool databases;
- Data exchange between the multiple calculators and existing tools used in assessment;
- More sophisticated and integrated analyses due to a consistent set of definitions of built environment precinct objects in the PIM data model – currently there is an inadequate facility for linking tools in order to create a more comprehensive systems model for precincts;
- Data exchange and reporting between the multiple partners and stakeholders and stages in a precinct development project process.

The CRC LCL proposal to federal government in 2011 identified the need for research on PIM as a core feature of the Low Carbon Precincts Program. This scoping study has identified areas for focus emerging from this study (outlined in Chapter 5) as well as with recently initiated CRC projects: RP2002 (Integrated demand forecasting and scenario planning for precincts: energy, transport, waste and water) and RP2007 (Integrated Carbon Metrics (ICM) – a multi-scale life cycle approach to assessing, mapping and tracking carbon outcomes for the Built Environment).

PIM-based systems are likely to emerge as the digital platform on which *ISO standards for urban communities (*in addition to other standards) can be best developed. To date, precinct scale assessment systems have emerged in advance of – and hence in the absence of – any process designed to achieve transparency and scientific verification, as well as any national and international standardisation of key indicators, metrics, benchmarks and methods.

Need for an evidence base

The incentive for government and industry to engage in more innovative precinct interventions and investments requires an evidence base that can quantify the benefits of implementing more resilient, sustainable low carbon urban design at this scale. There are challenges for carbon, sustainability and resilience assessment here.

Scientifically validated models for carbon assessment are a prerequisite for any prospect that carbon credits might be assigned under any future government or industry scheme that recognises the amount of carbon mitigation delivered by a particular urban development project. At present, built environment/property development has been excluded from such schemes. By comparison, the federal government permits rural landowners to create carbon credits by taking action to cut emissions via a range of land-based projects under its Carbon Farming Initiative (http://www.climatechange.gov.au). Yet this area is projected to deliver less than 4 million tonnes a year of emission reductions by 2020 (Arup 2013), a fraction of the mitigation potential offered by the built environment (McKinsey and Company 2009).

From a *sustainability* perspective, the challenge for precinct assessment tools is to demonstrate the eco-efficiency benefits that more innovative urban design can deliver; i.e. the economic, environmental and social benefits directly attributable to the built environment. The principal long-term beneficiaries here are governments and residents, but the uncertainties surrounding evidence on the eco-efficiency dividends from high performing precincts and a development consortium's uncertainty of what customers are willing to pay for 'greener', higher performing products (Newton and Newman 2013b) are inhibitors to progress in this area.

From a *resilience* perspective, the prospect of more costly extreme events at reduced return periods will intensify pressure on both governments (who will find it impossible to fund recovery from more frequent and more damaging disasters), the insurance and finance industries (given increased exposure to claims) and the property sector (given the prospect for massive write-downs in value of vulnerable assets) to sharpen locality-based risk assessment. The Australian community also needs to be informed for these very reasons. Precinct design assessment tools capable of examining resilience of built environments against known and forecast vulnerabilities are central to sustainable urban development in 21st century Australia. The Australian Business Roundtable for Disaster Resilience and Safer Communities (2013) report explicitly calls for such assessments and information.

The quality of *assessments* in each of the three core areas of sustainability, carbon intensity and resilience will become increasingly central to a development project's ability to attract investment, incentives, credits, government support (including partnerships) and community support.

Rating of a project is more broadly based and tends to attract market interest from a branding perspective, e.g. attracting building owners, employers/tenants, and residents to a precinct; increasing land/property/rental/resale value. Questions persist in relation to the transparency of methods and processes surrounding the establishment of weightings and credits for different themes and indicators in national rating systems (an issue shared with international rating systems such as BREEAM and LEED ND; Garde 2009; Sharifi and Murayama 2013). Opportunity exists to give the outcomes greater validation through the application of more scientific methods (e.g. Delphi) and greater geographic specificity.

The problem of data

In a finite, resource constrained world, accounting for material resource consumption is becoming increasingly important. The quality, currency and availability of data relevant to precinct design assessment is a challenge for all assessment tools where access to current 'operational' resource consumption data (energy, water etc.), waste generation and travel data is critical to analysis, but especially for those without a connection to government who can more readily secure such data. Here, PrecinX is a beneficiary of its ownership by the NSW government and its franchise with other state GLOs.

For data on water and energy consumption, carbon and other emissions to air, land and water that is 'embodied' in building product use in a precinct, all local assessment tools are at a disadvantage, compared to their European and North American counterparts, due to the disjointed and incomplete state of embodied or LCI databases of precinct objects in Australia (see Chapter 4). Furthermore, there is currently no accepted definition of built environment precinct objects capable of use in the aggregation of data held at building product level in LCI databases. The identified need for life cycle data for assessing the carbon signatures of built environment objects has led to the development of CRC LCL Project RP 2007 Integrated carbon metrics, whose objective is measurement of the carbon embodied in building and precinct objects in Australia.

Benchmarks for precinct design assessment

Benchmarks represent a standard or level against which performance can be measured and judged. Precinct assessment and rating systems assemble benchmarks for a range of indicators that recognise levels of performance that typically start from some average ('business as usual') metric (e.g. average household energy use per year for a suburb or municipality deemed to be representative of the project precinct). The extent to which such benchmarks can be further disaggregated is where attempts at data acquisition break down. The Australian Urban Research Infrastructure Network (http://www.aurin.org.au/) was established in 2010 in an attempt to make it easier to establish baseline performance metrics but is finding it difficult to access energy and water utility data. Benchmarks are then typically set by assessment and rating systems to higher standards of performance, such as 'national best practice' and 'international best practice', although there are challenges associated with assembling and validating such metrics. Identifying and validating national best practice benchmarks for a range of precinct metrics is a recommended topic for research by the CRC LCL in collaboration with the federal Department of Sustainability, Environment, Water, Population and Communities and state agencies. An international study of best practice in precinct development is being undertaken by CRC LCL Project RP2003: A review of national and international low carbon precincts.

Challenge of forecasting future precinct demand for resources and services

Precinct plans and designs are created in response to *forecasts of demand* for those urban functions and activities expected to be centred in that locale (e.g. housing, employment, active transport, recreation) or are distributed to adjacent areas (e.g. schools, health centres, public transit). Most demand estimation procedures in assessment tools are rudimentary and lack transparency (in relation to algorithms used, model assumptions and baseline data). In response to this identified need, CRC LCL Project RP 2002 'Integrated energy, transport, water and waste demand forecasting and scenario planning for precincts' has been initiated to provide more advanced and scientifically validated models for use in precinct assessment tools.

Distributed systems and the innovation potential of precinct supply side solutions

Demand profiles for precincts, whether energy, water, transport, building, waste or leisure-related, need to be able to be 'matched' with the most appropriate *supply side options* that are low carbon and eco-efficient in operation as well as meeting any other project-specific objectives/targets (e.g. carbon neutral, zero waste to landfill, recycled water for all non-potable use, price points for a percentage of housing that meets affordability criteria etc.). There is significant variability across the four assessment tools examined in relation to how supply options are identified. In the 21st century a range of *distributed systems* capable of operating at building and/or precinct scale are available with a level of performance commensurate with or superior to traditional centralised systems. Distributed systems permit the development of more autonomous, resilient, sustainable low carbon communities. It is critical that precinct assessment tools have access to decision support systems capable of undertaking supply side assessments for specific localities encompassing all relevant technology options. Some tools (e.g. PrecinX, SSIM, MUtopia, etc) have been attempting to use real energy, water and waste data, but there remains a significant gap in this area because such data tends to be limited to a restricted of technology options – what Newton (2008, 2013) has termed Horizon 1 innovations, i.e. those with proven performance, widely available commercially, and not the emerging, transformative, but potentially riskier technologies. In response to this identified need, there is opportunity for CRC LCL to develop a decision support tool for assessing the suitability of a wider range of distributed energy generation and storage options at building and precinct scale.

Aligning assessment and rating tools

The ability of assessment tool outputs to align with national rating tools for precincts will be a factor in determining how rapidly advances can be made in delivering high performing urban development. The importance of having a rating system that is widely endorsed by government, industry and the scientific community for assessing the built environment performance of precincts is critical. Determining what the key performance domains should be in a national rating system can be contentious. A comparison of the three leading international rating systems (Green Star Communities, BREEAM and LEED ND) revealed a reasonably high commonality of thematic focus but a significant measure of variation with specific indicators. Weightings (of importance) assigned to different themes and indicators also varied between rating systems as might be expected, given the different socio-political, economic, environmental, geographical and institutional contexts each is required to serve (Chapter 3). It is clear that all rating systems were conceived to respond to sustainability challenges; their focus on carbon and resilience is less well advanced. Rating and assessment systems are in their infancy, and there will continue to be iterative development among both. How they engage with one another to advance is a work in progress that CRC LCL and its partners have a significant opportunity to shape.

Precinct assessment and rating in Living Laboratories

Precinct assessment and rating in a *Living laboratories* context is proposed as a project for CRC LCL capable of advancing the development of tools in this area. In its 2011 proposal to the Australian government for funding, the CRC LCL committed to developing a minimum of nine Living Laboratories over the seven year course of its operation. A Living Laboratory has been defined as ' an organisational arrangement, where the impact of introducing a change process or a new product/service (intervention) can be monitored and observed in a real world community with diverse stakeholders' (*CRC LCL RP 3005 CRC Living Laboratories Framework: Final Report*, p. 2).

Recommended Actions

This study has confirmed the need for further R&D to advance the scope and performance of precinct design assessment tools. It is proposed that a CRC Living Laboratory project (possibly more than one) be established to enable all four assessment tools to be applied to the same precinct, to explore a common set of development scenarios and supply side options for delivering evaluations against an agreed set of benchmarks (via involvement with the Green Star Communities rating system). The knowledge gained from this project would be considerable and would enable the development of a set of common input data and output metrics for use in verification and validation of the key indicators used in precinct design assessment tools (current and future). Model validation is a paramount consideration amongst model developers and expert users. A validation scheme for the precinct assessment tools and for PIM is required and could be supplied via a Living Laboratory project.

Further insights would be gained by comparing the predicted 'as designed' assessments against an 'as built/as operated' set of metrics. Currently there are no tools that assess both predicted and operational performance. CRC LCL's Lochiel Park Living Laboratory offers these opportunities. Additional Living Laboratories projects are possible in greyfield and brownfield settings (e.g. Green Square, Fishermans Bend) to ensure that precinct assessment and rating tools have the flexibility to operate across states, in different urban settings and across the development project life cycle.

Introduction

1. Introduction

Project Context

The realisation of resilient, sustainable low carbon urban development in the 21st century will require several radical transitions. One of these involves the creation and application of leading edge tools (currently not available to built environment professions and practitioners) capable of being applied in all stages, scales and arenas of urban development to assess design performance against objectives and targets:

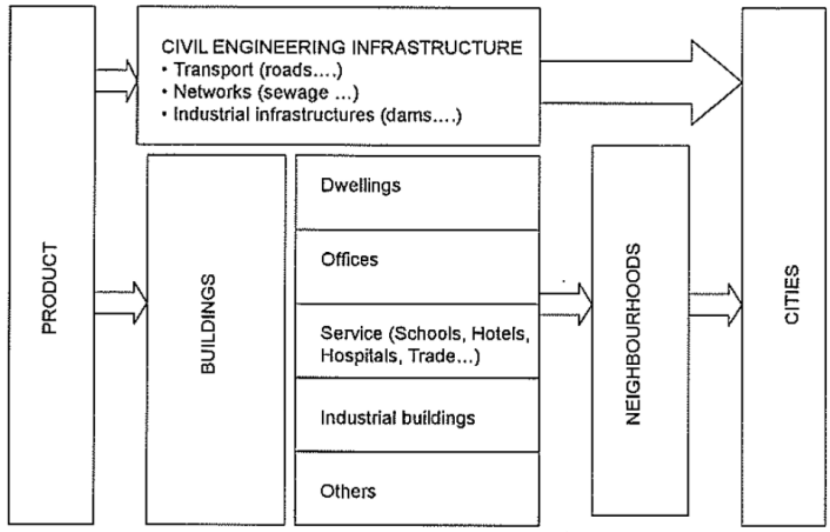
- Pre-design, schematic (sketch) design, detailed design, procurement, construction, and operation
- Building element, whole building, precinct, city
- Greenfield, brownfield and greyfield development; and
- Across the three principal dimensions of urban design performance: carbon intensity, sustainability and resilience.

The framework for a built environment assessment 'toolkit' was conceived some time back by ISO (see Figure 1.1), but does not exist in a form that can be rapidly accessed and applied by those involved in urban design, urban procurement, urban planning and urban management. Significant advances have been made over the past decade in the development of scientifically and industry accepted tools for the performance assessment of buildings in terms of energy, carbon, water, indoor environment quality etc. They continue to be pursued under a major new EU initiative: Roadmap to a Resource Efficient Europe (Hakkinen 2013) which is proposing new measures for 'significantly reducing the environmental impact of buildings throughout the life cycle'. Progress has been markedly less in relation to innovation in the design and assessment of urban precincts (neighbourhoods) which constitute the 'building blocks' of our cities (Sharifi and Murayama 2013) and represent the scale at which urban design makes its contribution to city performance.

In this report, as in the field of urban design assessment generally, the term 'precinct' is used interchangeably with neighbourhood, district and community. With the increasing adoption of digital city models, it is appropriate to define precincts in terms of the way 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.

Indeed, it has been argued (Codoban and Kennedy 2007) that the unsustainable nature of today's cities is due in part to poor planning at the neighbourhood level.

Figure 1.1: The urban sustainability framework; products, buildings, infrastructure, neighbourhoods and cities



Source: derived from ISO/TC 59/SC 17/N 172, 2005-11-02, ISO/CD2 15392, ISO /TC 59/IC 17/WG 1 (doc N041) Sustainability in Building Construction – General Principles

A number of precinct assessment tools have emerged in recent years, many via leading urban design and planning organisations (private sector and government) that have clients seeking decision support and evidence that their development projects meet certain performance targets. Functionality of these tools has tended to evolve in response to client needs and demands of specific projects (also see Neilson 2010). As such they have tended to emerge in a 'bottom-up' fashion, based on available data and indicators and with specific stakeholder needs in mind. Lutzkendorf et al. (2012) reinforce the importance of 'top-down' reviews to identify the 'necessary' as opposed to 'sufficient' functionality required in order to ensure *all* key goals of sustainable and resilient urban development are acknowledged, that requirements of carbon audits can be satisfied, that a life cycle approach is employed, as well as a systems approach that is capable of assessing key interactions and feedback loops, and that international best practice is being followed regarding standards for built environment representation and information (data) management. All of which combines to provide a functional specification for future precinct-scale tool development designed to support built environment stakeholders in their decision making processes – the principal objectives of this study. Table 1.1 outlines the scope of transition envisaged.

Table 1.1: Aspirational objectives for precinct design assessment tools

FROM (current practice)	TO (future performance)	Rationale for change
LOCAL: Australia specific context and application	Austral-Asian application	Ensures applicability to projects in large cities in rapidly urbanising Asia-Pacific region
ONE-OFF: single analysis/rating of a (near) final design	Multiple assessments from 'aspirational/intentions' briefing stage (at the level of choosing suitable locations for type of development) through 'experimental' sketch design (e.g. at the level of master planning) to detailed design (at the level of engineering design) and	Maximises opportunities for innovative design and stakeholder engagement; fast feedback; design aid as well as assessment tool; covers the life cycle of a project/development

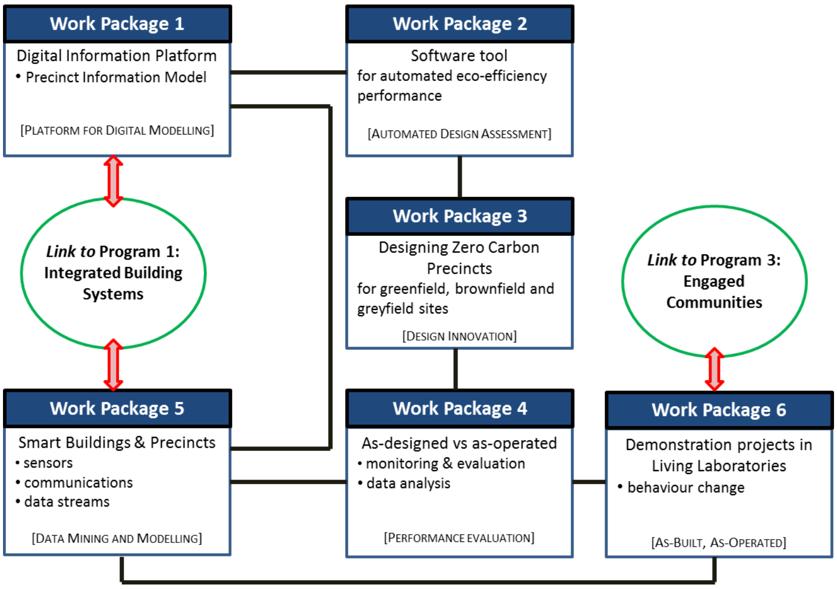
FROM (current practice)	TO (future performance)	Rationale for change
	assessment of operating performance	
PAROCHIAL: lacking in guidance from international frameworks and standards	Aligned with international best practice; standards-based	Enables development of design assessment tools that draw on international best practice methods, research, practice
COOKIE-CUTTER APPROACH: 'Precinct as self-contained project' defines the scope of the assessment problem	Precinct exists within a broader urban spatial/temporal context enabling precinct assessment to examine access and impact issues related to adjacent neighbourhoods, climate change scenarios; implications of future metro transport and land use plans, future demographics, 'horizon 3 urban technologies' etc.	Opportunity for designing-in greater levels of sustainability, energy efficiency, low carbon intensity and resilience to cities
ONTOLOGICAL SILOS: idiosyncratic set of definitions of built environment elements that feature in assessment tools; 'starting from scratch'	Object-based information platform linked to international initiatives for establishing agreed and uniform ontologies/concepts/definitions of built environment objects and their relationships e.g. IFC equivalents for precinct or urban scale objects	Enables automated search for relevant web-based data; facilitates data assembly and integration; linking tools to create broader based 'systems' assessments
IT'S ALL MINE: Proprietary data, calculators and benchmarks	Data commons — open access (e.g. AURIN, CRCSI, VANZI)	Enables comparison, best practice; minimises duplication of effort and time needed for data assembly; increases time for more innovative design and analysis tasks
20th CENTURY DATA PLATFORM: Project data is spreadsheet based for a limited set of applications	Data held in object-oriented database systems not bounded by user's technical expertise in Excel; provides platform for multiple users and applications; 'Database i' cloud-based systems	Spreadsheets limit assessment tool's functionality e.g. link to 3D parametric/GIS/PIM data objects and analytical models; spreadsheets also incompatible with the scale of analysis needed at precinct level and beyond
RESTRICTED FUNCTIONALITY: unable to support integrated analyses	Linked set of systems-based modules capable of integrated analysis	Urban design problems are dynamic and multi-faceted, requiring a robust, extensible TBL assessment capable of use in stakeholder engagement
SHORT-TERM DEMAND AND SUPPLY PERSPECTIVES: limited options available regarding alternative future scenarios related to urban consumption (demand) and supply side innovations	Assessment tool able to access specialist modules on decentralised energy, water etc. supply options; and leading edge CRC precinct demand forecasting modules	Future ≠ Present, therefore opportunities to envision possible futures enables selection of more sustainable, resilient, low carbon development pathways

Precinct scale design assessment is least developed among the spectrum of built environment models and tools, which include product declarations, whole building modelling and city modelling. Yet precincts constitute the critical operational scale at which a city is assembled (greenfields), is re-built (brownfields, greyfields) and is operated (where residents spend large proportions of their day either in domestic or workplace settings). They are the 'building blocks' of our cities (Sharifi and Murayama 2013) and represent the scale at which urban design makes its contribution to city performance. Precincts constitute the origins and destinations for homes, schools, workplaces and recreation and the trip generators associated with connecting each. In aggregate, they are a microcosm of urban life. It has been argued, however (Codoban and Kennedy 2007), that the unsustainable nature of today's cities is due in part to poor planning at the neighbourhood level. For example, the high levels of car usage and traffic congestion are a reflection of an *absence* of: mixed use development, variety in housing types, especially medium density, and lack of walkability and public transit access having been designed into urban neighbourhoods in recent decades (Inbakaran and Howes 2011; Department of Infrastructure and Transport 2011). Purely in CO2 terms, variability in the housing and transport attributes of different suburbs means that neighbourhood-scale carbon emissions can vary by as much as 50% across Australian cities (Newton et al. 2012; Crawford and Fuller 2011). Precincts constitute a critical focus for the achievement of any carbon neutrality target for cities since this is the scale at which an optimal combination of urban design innovation, urban technology innovation and behaviour change can jointly occur.

Scoping Study Objectives

Delivering low carbon precincts is a core research objective of the CRC for Low Carbon Living. The work package structure for Program 2 Low Carbon Precincts (see Figure 1.2) locates this objective in work package 3 (wp3). Critical to its success, however, will be an ability to apply leading edge precinct design assessment tools (wp2) that operate within a precinct information modelling (PIM) framework (wp1) and are supported by an information rich environment of distributed data relating to actual performance of the built environment (wp 4 and 5).

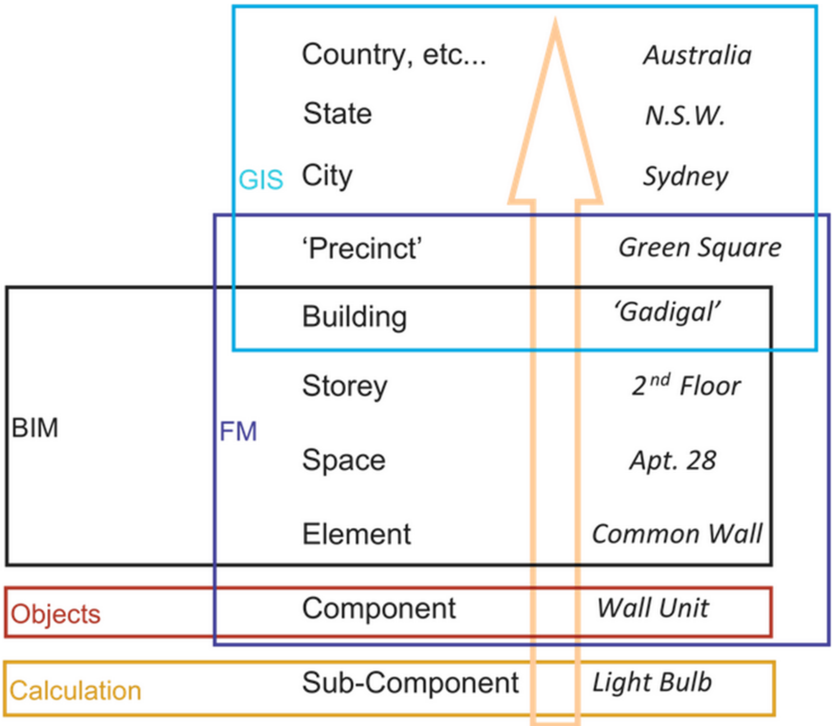
Figure 1.2: CRC Program 2 research targets and work packages



Source: CRC for Low Carbon Living Research Proposal to Commonwealth of Australia (2012)

In an era when the digital information platform has rapidly advanced, along with its ability to drive innovation in multiple applied fields, urban planning and design now have methods for representing urban data as 'objects' – in building product libraries, in building information models and as parts of geographic information systems(GIS) that operate at macro scale. Attention is shifting to spatial representation at a neighbourhood scale – what we have termed 'precinct information modelling' that meshes BIM and GIS (see Figure 1.3). It offers the potential to automate precinct design assessment, delivering innovation for urban design in terms of it being able to realise more sustainable low carbon urban development as well as increased productivity for the built environment professions and the urban development industry in general.

Figure 1.3: The scale of things; PIM in a build environment context



Source: UrbanIT, after Andreas Kohlhaas (used with permission)

In an era when urban design has also become *performance-based* rather than prescriptive (an objective of AMCORD, the Australian Model Code for Residential Development (Department of Housing and Regional Development 1996)), and where performance criteria and assessment are becoming central to National Urban Design Protocols (Department of Infrastructure and Transport 2011; again, see Figure 1) and urban innovation more broadly, this project seeks to identify opportunities for the CRC, its partners and the wider urban planning and design professions to advance evidence-based precinct design assessment tools. The CRC is well positioned in this respect with five CRC partners involved in proprietary precinct tool development: Green Star Communities (GBCA), LESS (Hassell), MUtopia (University of Melbourne), PrecinX (NSW Government) and SSIM (AECOM).

The project objectives for this study entailed:

- Outlining the nature and benefits of using a precinct information modelling (PIM) platform for data management in a 'big data' environment characteristic of urban precinct planning, design and management. Involved here is an understanding of the volume and variety of data streams associated with precinct design assessment and how that data is searched, accessed, transferred, analysed and visualised. The objective is to identify opportunities for more productive approaches to urban data management and performance assessment.

- An international review and synthesis of current methods and tools for urban design assessment to be used as a basis for developing a framework and criteria for evaluating the scope, functionality and gaps of existing precinct assessment tools, with particular reference to those developed by CRC partners.
- An international review and critical assessment of existing life cycle inventory (LCI) and life cycle assessment (LCA) databases and methods and their applicability to precinct design assessment in Australia
- A survey of a representative set of built environment sector organisations and end users to gauge their perspectives on the need for and functionality required in precinct design assessment systems
- A specification of the research required to create a world leading built environment design assessment system for delivering low carbon, sustainable and resilient precincts.

Precincts in a Built Environment Assessment Context

Australia's built environments are rated among the world's most liveable, but are also demonstrably among the highest consumers of natural resources and emitters of waste and greenhouse gases internationally (Newton 2011, 2012). This is a result of the manner in which its cities have been designed, the types of materials and technologies embodied in their construction and the manner in which they are operated. The manner of their design, construction and operation is being challenged to break away from an era – now passed – when practitioners and populations alike foresaw little or no resource or environmental constraints on urban development. These constraints are now clear (Newton and Doherty 2013):

- the carbon intensity of current energy systems and their implications for climate change (Climate Commission 2012)
- water security under a changing climate regime (Wong and Brown 2013)
- (un)sustainability of large urban metabolic material resource flows (Turner 2011; ARUP and Curtin University 2013)
- increasing levels of waste generation, with lagging rates of recycling and reuse (Lehmann and Crocker 2012)
- from a transport perspective, continued car dependence and urban traffic congestion (Newton et al. 2012)
- from a food production perspective, continued removal of productive farming from the fringes of expanding cities (Pearson and Dyball 2013)
- from a biophylic perspective, retaining and restoring green space in urban development (Beatley 2013).

Twenty years of State of the Environment human settlements reporting in Australia highlights the persistence of these issues (http://www.environment.gov.au/topics/science-and-research/state-environment-reporting).

An over-arching challenge is the carbon intensity of our urban environments, linked to our unsustainable production and consumption practices and lifestyles, all reflected in the metabolic signatures of precincts where end use of resources is concentrated: indirectly through the material, water and energy embodied in the built environment, and directly through resident consumption practices. It is estimated that urban environments account for 80% of all global carbon emissions (Zoellick 2011).

Prospect of a '4° world' by the end of this century would represent an unprecedented challenge to modern civilisation, given that it has developed as it has during a climate regime of relative constancy (Steffen 2006). Estimates of the triple bottom line (TBL) economic, social and ecological costs of this level of change are massive (Stern 2006; World Bank 2012). Carbon mitigation must continue to be society's principal TBL challenge. An 80% reduction in CO2 emissions relative to 1990 levels has been identified as a target that could mitigate irreversible climate change (Garnaut 2008; IPCC 2013). The Australian federal government's climate change strategy focuses primarily on emissions from the large stationary power stations that supply electricity to cities. Distributed low and zero emissions energy technologies receive less attention although the renewable energy target (RET) of 20% by 2020 is beginning to see significant take-up of solar PV in suburban neighbourhoods (Newton and Newman 2013a).

A principal weakness of the federal government's carbon strategy is its lack of challenge and incentives to sectors such as the built environment to develop and implement a low carbon roadmap to guide its own future planning and investment. McKinsey and Company (2009) developed cost curves for greenhouse gas abatement that identified aspects of the built environment as among the most prospective for intervention by government and industry. Their focus, however, was at the scale of individual buildings and specific technologies. The incentive for government and industry to engage in more innovative *precinct* interventions and investments requires an evidence base that can quantify the benefits of implementing more resilient, sustainable low carbon urban design at this scale.

Scientifically validated models for *carbon assessment* are a prerequisite for any prospect that carbon credits might be assigned under any government or industry scheme that recognises the amount of carbon mitigation delivered by a particular urban development project. At present, built environment/property development has been excluded from such schemes. By comparison, the federal government permits rural landowners to create carbon credits by taking action to cut emissions via a range of land-based projects under its Carbon Farming Initiative (http://www.climatechange.gov.au). Yet this area is projected to deliver less than 4 million tonnes a year of emission reductions by 2020 (Arup 2013).

From a *sustainability* perspective, the challenge for precinct assessment tools is to demonstrate the *eco-efficiency benefits* that more innovative urban design can deliver, i.e. the cost, environmental and social benefits directly attributable to the built environment. The principal beneficiaries here are governments and residents, but the uncertainties surrounding the eco-efficiency dividends from high performing precincts and a development consortium's uncertainty of what customers are willing to pay for 'green products' without demonstrable return on investment (Newton and Newman 2013b) are inhibitors to progress in this area.

From a *resilience* perspective, the prospect of more costly extreme events at reduced return periods will intensify pressure on both governments (who will find it impossible to fund recovery from more frequent and more damaging disasters) and the insurance and finance industries (given increased exposure to claims) to sharpen locality-based risk assessment. Property investors have been slow to recognise the extent to which real estate in particular locations can lose value in the light of climate change impacts (Perinotto 2013). The Australian community also needs to be informed. Precinct design assessment tools capable of examining resilience of built environments against known and forecast vulnerabilities are central to enable urban development. They are what will provide the information on locality-specific development risk called for by the Australian Business Roundtable for Disaster Resilience and Safer Communities (2013).

Therein lies a key context for this study: to progress the development of tools to scientifically assess precinct performance from a carbon, sustainability and resilience perspective. Tools applicable to greenfield, brownfield or greyfield property developers. Tools that are capable of providing the platform for supporting the manipulation of designs and assessing what difference they make – against a prior design or some benchmark or target performance. Tools to provide decision support to the range of stakeholders involved in property development. Precinct tools that are capable of integrating data from building and household scale with broader urban contextual information (refer again to Figure 1.3).

Building Scale Assessment

Building scale performance assessments need to satisfy, at minimum, the requirements in the Building Code of Australia (http://www.abcb.gov.au) that encompass structural safety, fire safety, health, amenity and, most recently, sustainability objectives – currently limited to energy. Building energy and carbon assessment is now well advanced, with scientifically validated and industry accepted tools being applied in Australia to evaluate and rate new housing, major residential extensions (e.g. AccuRate) and commercial buildings (e.g. Energy Express, GBCA's Green Star), a number of which had their origins in the 1970s as a response to the first oil shock and the search for energy efficiency. NABERS emerged more recently as a method for auditing the energy performance of buildings, and the Australian Building Greenhouse Rating System exists as a system for rating the greenhouse performance of commercial buildings. What these tools have demonstrated to government and industry is that there are major improvements possible to building performance that are cost effective. They provide the evidence base for assigning the added market value of green buildings to owners and tenants. Recent reports (World Building Council 2013; Paevere 2009) indicate that green buildings are more marketable, have lower operating costs, are linked to enhanced occupant productivity and are less exposed to future regulatory and insurance risks.

Extension of operating energy building assessments and ratings to life cycle energy and carbon assessments (incorporating the amount of CO2 embodied in the building materials and construction process) represent the next phase in the process of decarbonising buildings. As the operating energy efficiency of buildings increases, the search for further reductions in the carbon profile of buildings will necessarily throw the spotlight onto embodied energy (Newton et al. 2012). Development of prototype assessment tools in this area are likely to be slow to emerge (Chen et al. 2010). The fragmented state of building material life cycle assessment in Australia compared to Europe and North America (see Chapter 4) constitutes a major impediment to their take-up. Lack of interest by government regulators is another. Extension of building performance assessment beyond energy has been limited. An exception is BASIX, an assessment system operating in NSW that examines the energy and water efficiency of residential buildings (http://www.basix.nsw.gov.au). Also at building scale are LCA based design support tools such as ENVEST (http://www.clarityenv.com.au/ENVEST) and eTool (etool.net.au).

New directions for automated carbon assessment of buildings direct from 3D CAD models have been established with the first BIM-enabled tool LCADesign (Seo et al. 2009) emerging as a prototype in 2008, but they are still in their infancy (Owens et al. 2013). A challenge for this scoping project is to specify the most prospective routes by which representative data at building scale, across key performance domains, and for representative building types/typologies can be introduced into a PIM-based precinct assessment model.

City Scale Assessment

Assessments of performance at city scale are typically broader than those for buildings. The criteria set by COAG (2009) are indicative: productive, competitive, liveable, sustainable and socially inclusive. They cover the traditional TBL goals of sustainable urban development. Governance is sometimes added as a fourth dimension. Resilience is a concept that needs to be added to the pantheon of performance dimensions for cities, viz. an ability to manage and learn from major challenges and to bounce back after some adversity or shock (exogenous or endogenous) to the system (Pearson et al. 2013) The long-term strategic plans for each of the nation's metropolitan regions attempt to present a blueprint for development capable of delivering improved performance on each of these dimensions. An ability to evaluate city performance at a *process* level (COAG Reform Council 2011) and an *outcome* level (State of Australian Cities 2012; Australia State of the Environment: Human Settlements 2011) is now seen as fundamental by government. The latter typically exist as studies of city performance involving sets of single indicators. Of greater value are indexes that combine several indicators into a smaller set of lenses on city performance (e.g. Vampire index, SEIFA, ecological and carbon footprints) that often reveal striking variations within and between cities that call for some public policy response (e.g. Brookings Institute 2008 study of carbon footprints of American cities). Also emerging are dual factor studies that assess the co-variation of combinations of leading indicators or indexes revealed by bivariate mapping and graphing; for example, sustainability and liveability (Newton 2012); happiness and GDP (Worldwatch Institute 2008 cited in Jackson 2009); health and income inequality (Wilkinson and Pickett 2009); sustainability and equity (UNDP 2011) among others.

Less common are city models that attempt to represent the interaction of multiple elements of an urban system. Attempts to evaluate the impact of alternative land use-transport urban forms – the two most fundamental components of a city's structure and performance – has generally been lacking. In Australia, the 1997 National Inquiry into Urban Air Quality (AATSE 1997; Newton et al. 1997) was the first to examine the significance of urban form on energy use and GHG emissions. It found that a 40% reduction in transport CO2 emissions could be gained by more compact forms of urban development. Subsequent studies (ASBEC 2010; Newton et al. 2012; Newton and Newman 2013a) have confirmed the importance of more intentional and integrated planning of transport, housing and employment within cities.

Calthorpe Associates (2011) have developed a macro-scale model for California capable of examining future development scenarios to 2050 that involve alternative land use options (primarily relating to rates of infill, levels of density and housing mix) and policy options (BAU vs 'green' scenarios). The scenarios revealed significant variation in outcomes, relating to land consumption, urban travel, energy use, fiscal impact and GHG emissions (over 80% reduction in transport CO2 emissions were achievable by more compact urban development and progressively stronger vehicle and fuel policies).

For this study, particular focus will be on how well geographic information systems (GIS) – the spatial platform that supports city scale indicator development and modelling (see Stone et al. 2009) – can perform three critical functions of relevance to precinct information modelling:

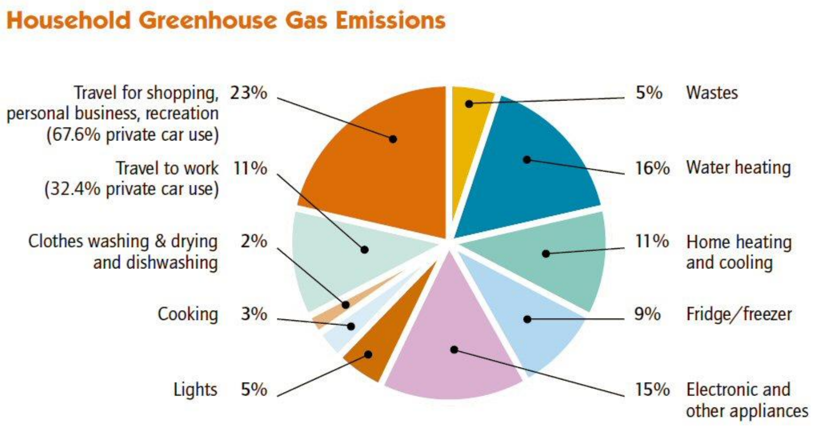
- provide the data and spatial algorithms for contextual analysis in precinct performance assessment, e.g. accessibility of a precinct and its households to a range of private and public sector services in the areas immediately contiguous to it, such as schooling (pre-/primary/secondary), public transport, health services, public open space, food outlets etc.
- interoperability with BIM outputs (e.g. building scale data representation of land use objects for a precinct that include: residential, commercial and special use buildings; urban infrastructures etc.)
- provide the data on key infrastructure networks that will service the precinct (type of infrastructure – distributed, centralised, hybrid, location and attributes, including existing capacity; walkability of precinct etc.)

Household Scale Assessment

Household-level consumption is responsible for approximately 20% of Australia's GHGs (estimated around 18 tonnes/household/year; EPA 2013). The sources of these emissions are illustrated in Figure 1.4.

Averages hide the considerable variability that exists with household scale behaviours involving urban consumption (e.g. energy and water use, urban travel, waste generation) and over-arching GHG emissions. Recent research on the determinants of household consumption (Newton and Meyer 2011) indicates that a significant proportion of the variability is due to household contextual factors: their structural attributes (e.g. household size, household income); the type and vintage of dwelling occupied; and their location within the city (access to public transport). The 'one tonne house' study in Sweden revealed that a household's ability to live in energy efficient housing and access low carbon transport were the critical factors in reducing its carbon signature (http://www.onetonnelife.com). Individual behavioural and structural factors appeared to be of lesser significance in explaining variability in urban consumption (Newton and Meyer 2013) – a challenge for behaviour change practitioners to provide an evidence base for their claims.

Figure 1.4: Sources of household GHG emissions



Source: EPA Victoria (2013) (http://www.epa.vic.gov.au). Figure adapted from Wilkenfeld's (2002) end use of allocation of GHGs for 1999, published in Department of Environment and Heritage (2007) Global Warming. Cool It!, Canberra.

Estimating household demand for energy, water, housing type and space, and urban travel, as well as waste generation will rely on access to models capable of representing the influence that those demographic, housing and broader based urban factors listed above (and others) exert on the different categories of urban consumption. Understanding how household demographics and housing preferences will change in the future, as well as whether smart meters and other technological innovations or other public policy instruments can influence voluntary household consumption, will all be critical to demand forecasting. Estimating non-residential demands for a precinct represents another layer of required information, but is typically easier to forecast than domestic demands (refer to Othman and Jayasuriya's (2006) benchmarking study for CH2 water systems; Moller and Thomas' (2009) study of right-sizing for HVAC and Paevere's (2009) study of indoor environment quality requirements).

New Arenas for Meshing Supply and Demand at Precinct Level

Property developers in 21st century cities also need to be in a position to select from among a range of supply side energy, water, waste, transport and communication technologies capable of delivering services at building or precinct scale. Traditionally most of these have been supplied as part of a centralised city-wide network of some description, but developments of decentralised or distributed systems are providing opportunities for a transition to greater local self-sufficiency (resilience); for example, building scale solar PV or precinct scale trigeneration; stormwater collection at building scale (e.g. rainwater tanks) or diversion to precinct-scale holding ponds employing treatment and reticulation systems. Precinct assessments will need to be able to match profiles of demand with the most eco-efficient supply side solutions.

Precincts in an Information Modelling Context

City of Bits (1995) was coined by Bill Mitchell as the title for a book highlighting the transformational role that information technology (IT) was beginning to play in reshaping the function and form of cities with the creation of new industries, new jobs and the use of a powerful suite of telematics technologies (e.g. internet, personal computers, software and mobile phones; see also Newton 1993). The metaphor is also relevant to the manner in which cities can be now be represented via IT in the context of urban design: as an assembly of objects together with their digital attributes (e.g. type of housing, energy use, water use) and relationships between objects (e.g. connection between a particular housing type and some other urban object, such as parking, transport).

The approach to precinct information modelling that has been proposed as part of the program of work in Program 2 of the CRC LCL is based around a more robust way of representing precinct-scale information using a rigorous object-based paradigm. The significance and novelty of this approach is best understood by first reviewing the way precinct tools represent precinct information within the context of urban planning and design at the precinct scale – the focus of this study.

Precinct assessment tools are being used increasingly at the master planning phase of the urban development cycle to assess performance against a number of metrics associated with urban resilience, sustainability and carbon load. As such, these tools tend to operate in a silo fashion, focused on a very coarse-grained data model of a precinct, frequently with only a token recognition of both the broader urban spatial context and the life cycle of the urban development process moving from planning through design to delivery and operation of the urban precinct.

The precinct assessment process typically operates in an iterative cycle between two separate professional teams. On the one hand, there are the urban designers who develop a design proposal that is then passed off to the specialist consultant team who do the design assessment; that process repeats in an iterative fashion until a final master plan is agreed; the output of the process is generally a written report that might offer multiple alternate scenarios and assessments against base case and target standards.

From an information modelling perspective, one of the key issues is the manner by which information is exchanged between those teams and ultimately carried forward for detailed design and implementation of the master plan. The designs are generally documented as digital models or drawings, using CAD software tools such as AutoCAD or SketchUp. Those schemes then need to be converted into the data format required of the assessment tool, typically either a spreadsheet or some proprietary data format. That process is most often “manual”, whereby a skilled person interprets the design proposal and populates the data required for the analysis. There are some automated processes, for example, ArcGIS does have an add-in for AutoCAD so that data can be imported. Clearly there are major productivity gains capable of being achieved here in relation to the process of urban design.

Within the most representative types of precinct assessment tool, the information is modelled using standard GIS data structures, irrespective of whether the computational engine being used is a spreadsheet or a GIS-style application. The precinct assessment information model consists of a set of well-defined data object types. Geographic regions are treated as closed polygonal boundaries with an associated set of properties or common attributes. An example might be a land use zone (industrial, commercial, parkland, etc.) or it may represent a walkability zone around a transport hub. Geospatially located urban entities are represented as features, again with associated properties stored as name/value pairs. Examples would be amenities such as schools, post offices or medical services. Another example of such a feature might be buildings of a defined type, such as low rise residential, or even a cluster of buildings such as an industrial park. These latter examples may typically have a footprint, represented as a polygon. Transport or urban services distribution systems can be represented by networks consisting of connected nodes in any topological structure. Those provide the ability to measure connectedness or operational distances between nodes or other geospatially defined features. It is important to recognise that these data constructs are also commonly used to hold reference data drawn from external data sources such as aggregated census data, existing geographic features and contextual information (e.g. location of urban amenities that lie outside the precinct).

The PIM development advocated by the CRC takes a more rigorous approach to modelling precincts. It is based on the same kind of approach increasingly being adopted in the construction industry for modelling buildings and other forms of major infrastructure (bridges, tunnels, etc.). Known as BIM (building information modelling), this class of information modelling treats buildings as assemblies of component parts (objects) that are described geometrically, have properties associated with them, as well as explicitly-defined relationships. Those relationships are fundamentally of two types: objects are related to other objects in the model in terms of containment, connectedness, functional dependency, etc. (e.g. a land parcel may belong to a planning zone while also related to one or more buildings contained within that site); in addition, objects are part of a class hierarchy that defines many of their functional characteristics (e.g. a traffic signal controlling pedestrian and vehicular flow in a precinct). Such mechanisms, if applied in a consistent and rigorous manner, lead to precinct models that have a great deal more meaning embedded within the structure of the information than is possible when precincts are reduced down to generic concepts like nodes, links, zones and annotated features.

These concepts are elaborated in Chapter 5 where current research in precinct modelling is reviewed and an analysis undertaken of the precinct modelling approaches adopted in the four precinct assessment methodologies developed by the project partners.

Approach to Examining the Functionality of Precinct Design Assessment and Rating Tools

2. Approach to Examining the Functionality of Precinct Design Assessment and Rating Tools

This chapter establishes a framework, criteria and templates for evaluating the functionality of precinct design assessment tools, the results of which are provided in the chapter which follows. Precinct design and assessment is currently guided by a combination of three levels of approach: overarching *frameworks and principles* targeted at three leading 21st century built environment challenges spanning sustainability, resilience and carbon intensity; *assessment systems* that establish performance indicators for evaluating precinct designs; and *rating systems* that assign a score to the total project based on how a set of core indicators perform against some benchmark, providing a signal to the market on its relative attractiveness and value.

Three Levels of Approach to Design Evaluation of Precinct Scale Projects

In contemporary urban design scoping and evaluation practice there are three distinguishable approaches in operation (see Figure 2.1). They are: frameworks, rating systems and assessment systems, all of which have the potential for alignment and nesting, but given their respective origins are at some distance from that point at present.

Frameworks

Frameworks are generally associated with high level and relatively abstract representations of some significant topic: in this instance, the performance of built environment precincts. They provide the broad principles and guidelines for envisioning urban development from conception through design to construction and operation. Presently there are three global built environment-related issues that have come to prominence in 21st century reporting and publication, which are taken here to be a measure of their relative significance in decision making concerning future urban development (see Figure 2.2). They are: carbon emissions, sustainability and resilience; and represent the frame of reference within which criteria and templates are established for evaluating the functionality of current and emerging precinct design assessment tools.

Figure 2.1: Lenses on precinct design assessment and rating

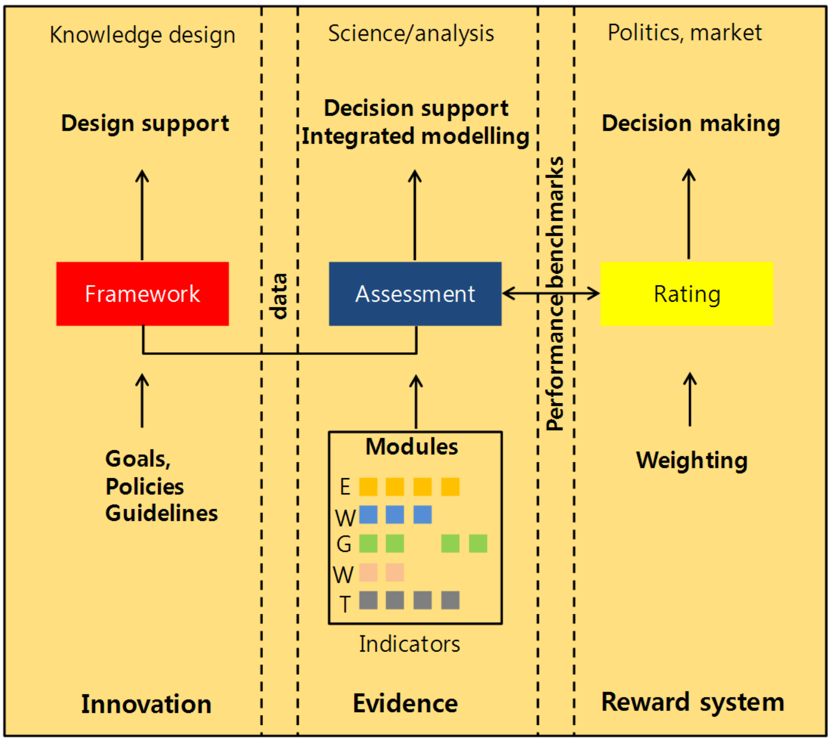
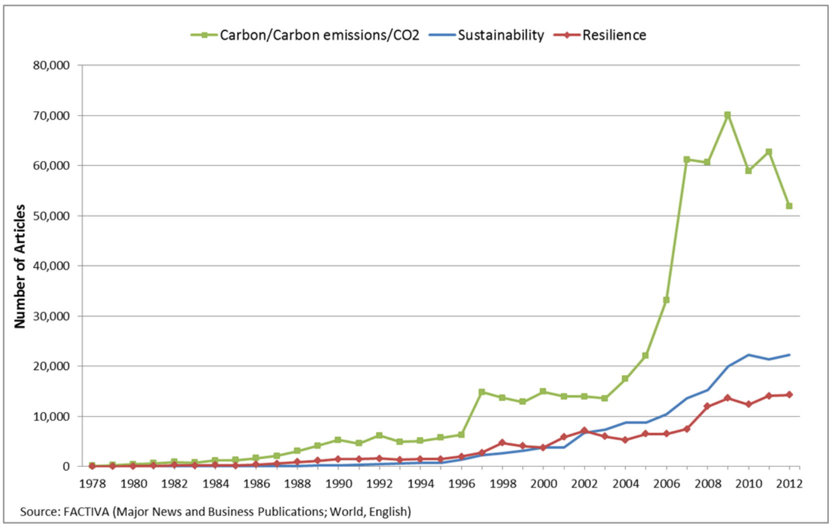


Figure 2.2: 21st century global built environment-related issues



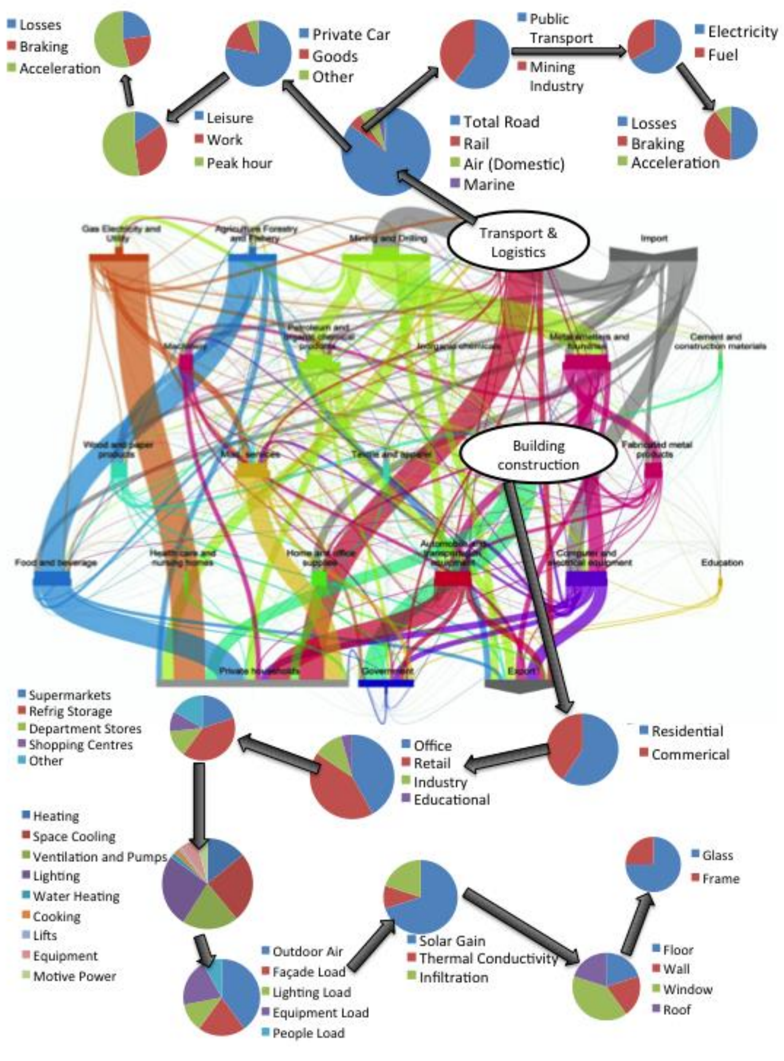
Carbon performance

This focuses on the mitigation potential and co-benefits from low/zero carbon designs and how they can be measured and assessed. Wiedmann et al. (2013) suggest that the built environment can be represented as part of a multi-scale, nested segmentation of the economy (see Figure 2.3). Each segment can be further sub-divided as an object for which a carbon signature/assessment is required, where each is represented by direct (operational) as well as indirect (embodied) carbon emissions (see Chapter 5). Such a nested, multi-scale assessment provides an understanding of a) where embodied and operational carbon emissions reside, b) where further research efforts should be directed and c) where intervention or substitution will have the biggest mitigation effect. In addition to mitigation, precincts designed for low carbon outcomes can also deliver ‘carbon co-benefits’. These are explained by Thompson (2013) as health and productivity benefits which derive from reduced air pollution linked to low carbon transport and increased levels of physical activity due to enhanced walkability of urban neighbourhoods. Further co-benefits have been associated with a healthier diet linked to local food sourcing, improved energy security through a more diverse energy supply and less dependency on oil, and new employment opportunities linked to low carbon green growth opportunities (Newton and Newman 2013b).

An ability to accurately characterise the carbon signatures of a large segment of built environment objects that exist at precinct scale represents a key objective of precinct design assessment and are a topic for major discussion in Chapter 5.

Precinct scale assessment systems with an explicit focus on carbon emission measurement include: CCAP (Kinesis); a significant component of PrecinX; and One Planet Communities (Bioregional)

Figure 2.3: Carbon mapping - the figure shows an indicative example of a 'drill-down' into carbon flows of the transport and building construction sectors



Source: Wiedmann et al. (2013)

Sustainability

This embraces the potential to realise three fundamental urban development goals -- environmental, social and economic -- in precinct design outcomes. Sustainability is a concept that was defined and gained significant currency with the Bruntland Report in 1987 but whose seeds were sown in earlier works, including UN-sponsored projects such as Ward and Dubos' (1972) study *Only One Earth*, which was "*the first attempt to examine our environmental problems not only from a global perspective, but in their social, economic and political dimensions – not just in their obvious manifestation, but in their totality, which includes population, misuse of resources, the impact of technology, unbalanced development, and the world-wide dilemma of urbanisation*".

Over the intervening 40 years, much of government's interest and investment in sustainability studies has been focused on individual indicators, principally within the three domains of performance: "in their obvious manifestations…but[not] in their totality". Within industry, sustainability has been introduced as triple bottom line (TBL) accounting, again based around leading indicators for each of the three areas identified above (Elkington 1997). The closest that a vast majority of studies come to integrated analysis – the raison d'être for sustainability assessments – are the three intersecting circles of the Venn diagram now synonymous with the concept.

In many ways, the publication of the *Sustainable Australia Report 2013* (National Sustainability Council 2013)is a further example of a multiple indicators presented as 'silos' without any exploration of underpinning cross-connections, let alone possible causality. Nor are there any targets or performance benchmarks established for any of the nominated key sustainability indicators. In short, there has been little if any progress since the Australian government's first publication of urban environmental indicators in 1983 (Dept of Home Affairs and Environment 1983).

Based on the National Sustainability Council study, core sustainability indicators relevant to precinct design performance can be identified as:

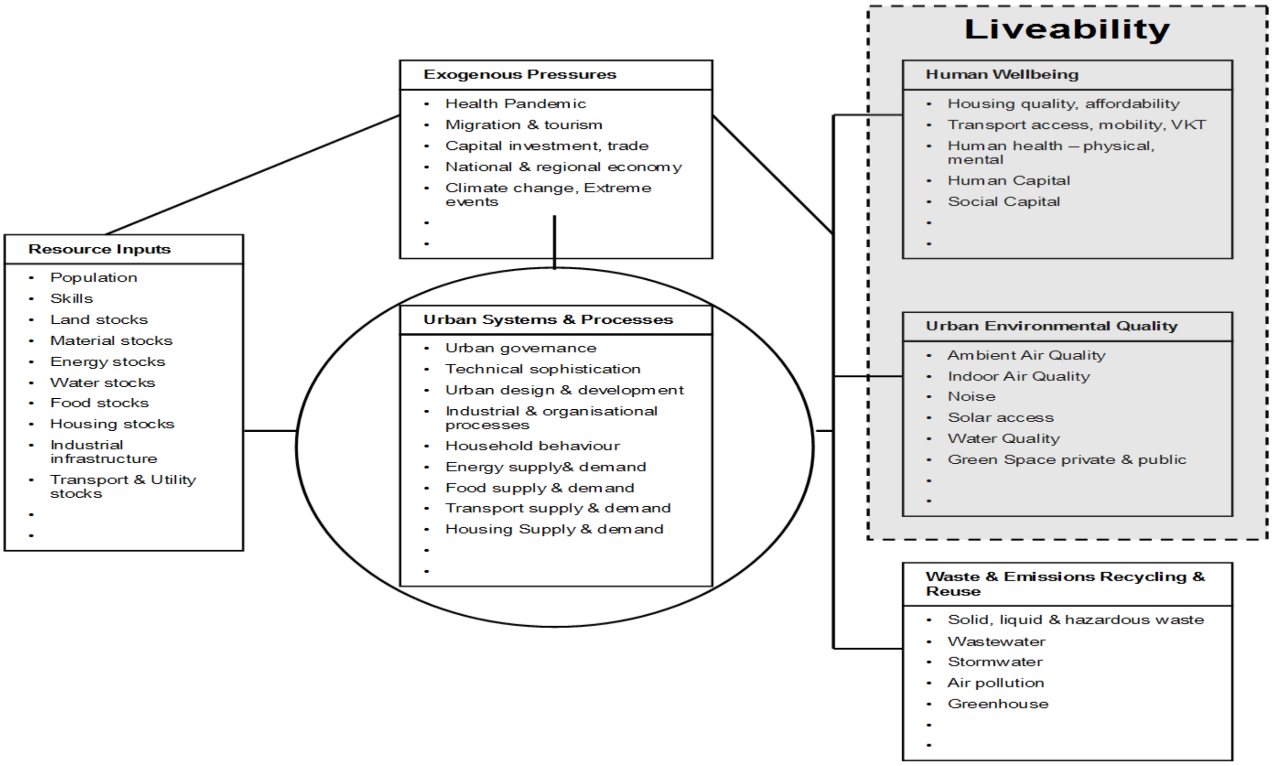
- *Social and human capital-related*: education attainment (access to schools with above average NAPLAN scores); employment to population ratio (local employment opportunities); feelings of safety (composite indicator of local crime statistics)
- *Natural capital*: GHG emissions; air quality; ground cover; water consumption; recycling rate
- *Economic capital*: income disparity (social mix); housing supply (but needs to be differentiated by type); housing affordability (housing price points); mode of transport to work; VKTs.

A similar set of themes and indicators have been established by ASBEC (2013) for application to the built environment.

They both constitute sub-sets of key indicators represented in the extended urban metabolism model of urban systems created for national state of the environment reporting on human settlements (see Figure 2.4; Newman et al. 1996; Newton et al. 2001; Newton 2006); they are also partially represented in stocks and flows models of urban systems (Turner 2011).

Liveability has emerged more recently as a significant dimension within the sustainability paradigm against which cities (and localities) are being assessed (EIU Liveability Index; Kallidaikurichi and Yuen 2010; MWH 2013). There continues to be debate surrounding what to include in this multi-factor index, however, although most liveability indices comprise some combination of the indices listed in Figure 2.4 (see Ley and Newton 2010). Questions persist surrounding whether such indices are best suited in design assessments where greater specificity is required for identifying the impacts of particular design interventions (Newton 2001). Issues also surround the weighting and/or substitutability of the different dimensions of sustainability (natural capital, economic capital and social/human capital) and their representative indicators (Markulev and Long 2013).

Figure 2.4: Liveability in wider urban context



Source: Newton (2006)

Most precinct assessment and rating tools have been strongly influenced in their development by sustainability frameworks; although many of the indicators employed vary and a number could be classed as opportunistic or surrogate in nature (i.e. publically available but not as closely aligned to the issue as desired). An absence of targets or benchmarks for these national sustainability indicators, and the fact that few are articulated in metropolitan strategic plans leaves the prospect for voluntary, project initiated targets becoming the basis for establishing 'best practice' for these key urban performance outcomes.

Examples of precinct assessment and rating tools developed primarily within a sustainability framework are: Green Star Communities, EnviroDevelopment, LESS, SSIM, PrecinX, MUtopia, CASBEE.

Resilience

Resilience examines the level of risk, vulnerability and potential to respond represented by precinct scale built environments to a range of future shocks. Core questions involve how natural urban and socio-economic systems function under stress. An early definition of resilience was seen to involve 'the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks' (Walker et al. 2004; Walker and Salt 2006). To date, the role of urban design, landscape architecture and urban planning is poorly articulated in a resilience context.

More recently, resilience has been defined by the United Nations (2009) as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of some extreme event in a timely and efficient manner, including through the preservation and restoration of its essential basic structure and functions. For built environment design, a primary focus should be on its ability to resist impacts of extreme events. Planning and design represent key elements in the context of urban development and its resilience.

An urban development precinct, no matter whether it is a greenfield, greyfield or brownfield site, needs a risk, vulnerability and resilience assessment. *Risk indicators* would relate to probabilities of occurrence of specific hazards and their intensity of impact, e.g. earthquake, flooding, bushfire, storm surge, most of which are expected to intensify with climate change and possibly have more frequent return periods. *Vulnerability indicators* would reflect the extent to which a built environment demonstrated structural robustness and redundancy in its physical assets; as well as strength in its social and economic systems. *Resilience indicators* need to reflect actions capable of being taken to reduce vulnerability, including preparedness for an extreme event as well as recovery capacity (stocks of human, social and financial capital). Not every location/site has equivalent risk to some exogenous or endogenous shock, and depending on the hazard, can be better or worse in bouncing back. The following major disruptions can be distinguished:

- *Socio-economic change*. Included here are: economic crisis, conflict, terrorism, poverty, political instability/change, health pandemic. The extent to which urban design *per se* can be linked to higher or lower levels of vulnerability in these areas –compared to other areas that have demonstrable connections (see below)—would tend to relegate them to the preserve of governance.
- *Climate change impacts*. A number of reports highlight the significant challenges that climate change presents to the built environments of Australia (CSIRO 2006; Commissioner for Environmental Sustainability Victoria 2012). They are summarised in Table 2.1

Table 2.1: Urban infrastructure vulnerability assessment to forecast climate change impacts

Infrastructure	Climate change Impacts	Primary built environment impacts				Flow-on impacts
		Environ-mental damage	System damage	System over-burden	Reduced system perform-ance	Impact to residents
Water and sewage	Extreme weather Increased daily rainfall Sea level rise Sea level rise	▯	▯	▯		Price increases Service disruptions Health concerns
Energy	Extreme weather Increased temperature Heatwaves Increased daily rainfall Sea level rise Ground movement		▯	▯	▯	Price increases Service disruptions Blackouts
Telecom	Extreme weather Bushfires		▯			Price increases Service disruptions
Transport	Extreme weather Increased temperature Heatwaves Increased daily rainfall Sea level rise Ground movement	▯	▯		▯	Service disruptions Safety concerns

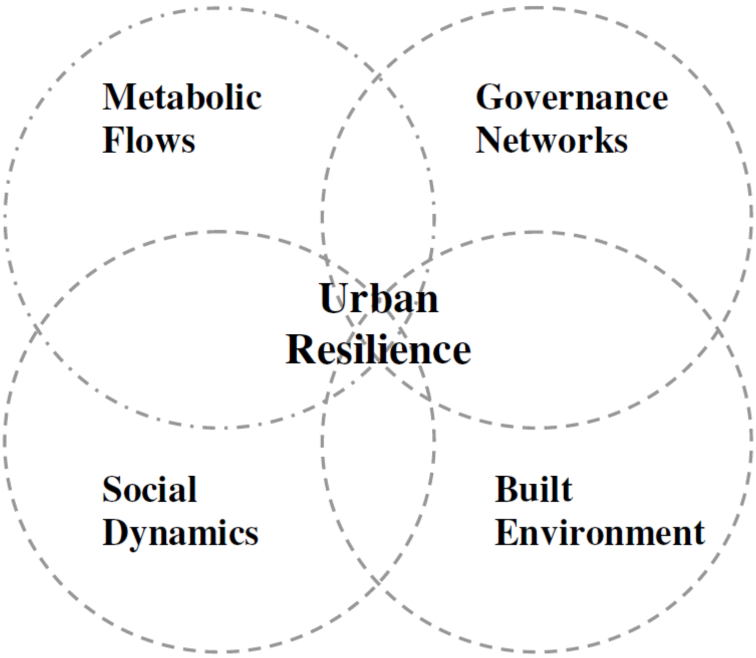
Infrastructure	Climate change Impacts	Primary built environment impacts				Flow-on impacts
		Environ-mental damage	System damage	System over-burden	Reduced system perform-ance	Impact to residents
Buildings	Extreme weather Increased temperature Heatwaves Increased daily rainfall Sea level rise Ground movement		▯		▯	Service disruptions Health and safety concerns Productivity concerns

Source: CSIRO (2006)

The extent to which urban design of the built environment can directly influence resilience in the face of climate change forecasts *is* measurable. Here, notwithstanding some of the uncertainties that surround a number of future forecasts (worst case to best case scenarios), the precautionary principle would suggest that urban development being undertaken now, with an estimated life of 50+ years, warrants decision making capable of standing tests of future climatic conditions across the spectrum of conditions foreshadowed in Table 2.1. This will impact decisions around design life for particular locations, need for redundancy, adaptability, dis-assembly, re-locatability etc.

Currently, no precinct design assessment systems adequately incorporate resilience criteria or assessment functions. Assessment tools and rating systems provide ‘place holders’ for resilience assessment but there is little evidence of application. A raft of resilience indicators are emerging in the literature, and there appears to be little evidence of consensus (Normandin et al. 2009). *Resilience-driven conceptualisations of a precinct* are likely to be required, such as those from the Resilience Alliance (2007) who have specified four themes as being central to an understanding of the resilience of urban systems (see Figure 2.5). Especially when widespread and potentially huge impacts of climate change are expected, the prospect for pro-active change is paramount.

Figure 2.5: Model of urban resilience



Source: Normandin et al. (2009)

Precinct Rating Systems

Built environment rating systems typically identify the principal criteria against which a particular development project must perform, the benchmark performance expected to achieve a credit/point score for different aspects of performance. A weighting can also be assigned to each of the criteria to reflect the relative importance each has to goals set by government and market (e.g. in relation to carbon emissions, water use). The overall rating is intended to send a message to the market in relation to added commercial or amenity value with the expectation of attracting a premium price at sale and return on investment.

In Australia there are broad-based (i.e. beyond energy) industry-driven rating systems for buildings (Green Building Council of Australia – GBCA), infrastructure (Infrastructure Sustainability Council of Australia – ISCA) and precincts: Green Star Communities (GBCA) and EnviroDevelopment (UDIA). All are voluntary, and focus on new construction as opposed to retrofits. In aggregate they cover the full spectrum of built environment objects that are relevant for built environment assessment: buildings, infrastructure and precinct services. There are areas of overlap, but as yet there is no harmonisation. There are institutional as well as technical barriers in play. In this study, our examination of PIM (see Chapter 6) will articulate an information platform capable of providing a basis for integrating (or more seamlessly interfacing) these different proprietary rating systems. The benefits are considerable:

- Data sharing
- Precinct scale assessment of buildings, infrastructure and services
- Ability to apportion the costs and benefits of buildings, infrastructure and precinct services to both providers (development sector) and beneficiaries (e.g. building owners, infrastructure owners, local government, residents and workers); see Piechowski and Quick (2011).

Precinct Assessment Systems

Precinct assessment systems can be characterised as spatial information systems that calculate/estimate/predict how one or more of the characteristic features of a precinct design is expected to perform once constructed and occupied. They are used primarily for decision support among those tasked with designing a precinct to achieve an explicit set of precinct performance objectives. These features can be specific precinct objects (e.g. particular building), a class or group of precinct objects (e.g. all apartment buildings) or some higher level aggregation of objects – ultimately to that of the entire precinct. There is no agreement on descriptions/definitions of precinct objects across assessment tools. They are all 'proprietary' (idiosyncratic); again, see Figure 1.

Criteria for Undertaking Functional Assessment of Precinct Design Tools

There are many facets to an evaluation of precinct design assessment tools, given their role as the 'scientific engines' in any rating scheme (again, see Figure 2.1). We begin this process with an overview of recent reviews of built environment assessment and rating tools relevant to precinct scale.

Previous Reviews of Precinct Assessment and Rating Tools

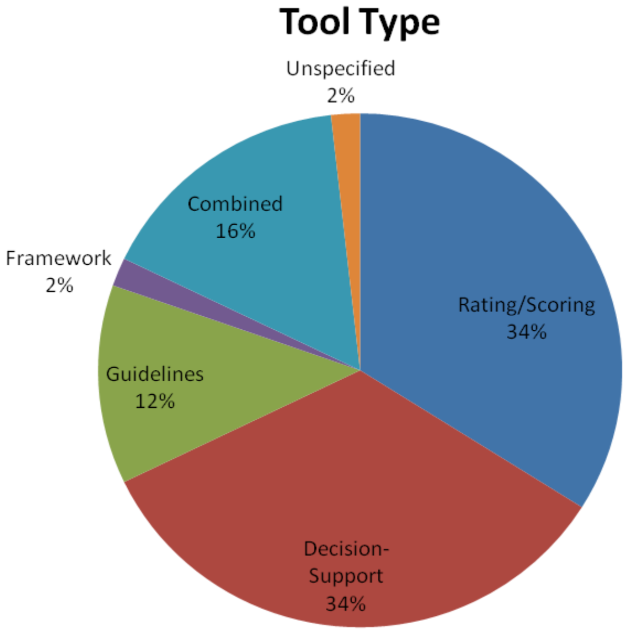
The key findings from several national and international reviews of precinct assessment and rating tools are summarised below and highlight some of the issues confronted in the present study:

- All reviews are *partial* in scope and coverage and are targeted towards answering specific questions; for example, suitability for use in national rating systems (Aurecon 2010); in climate adaptation assessment (Neilson 2010); in regulatory enforcement (Howard et al. 2007) or decision support (Bunning et al. 2013). Others are broader based but typically rely on desk-top analyses that provide an indication of the function of the tool, developer(s) involved etc. A recent example of the latter is the report by the International Federation of Landscape Architects (Neilson 2010) on 50 built environment assessment tools representative of most international activity in this area (see Figure 2.6). It suggests that two-thirds of tools are either decision support or ratings oriented, and represents a useful expansion on what is represented by the three level framework in Figure 2.1.

  In the current scoping study, focus is primarily on five built environment precinct tools developed by CRC partner organisations; one involves rating (Green Star Communities) and the others decision support.

- The externally reviewed tools focus on *predicted performance* of the 'as designed' precinct; none extended to assessment of performance 'as operated' (Neilson 2010). The focus of this study is on the former – how urban design can aspire to deliver a low carbon, sustainable and resilient *built environment*. Audits of new construction can ensure compliance between 'as designed' and 'as built' elements of a plan, but it is contentious whether 'as operated' should be part of precinct design assessment. Garde (2009, p. 430) argues that the focus should be on high performing precinct design elements that 'contribute to the sustainability of projects by themselves, without requiring occupants to change their behaviour'. In the limited instances where there is some post-occupancy monitoring undertaken, the performance goals formulated at the outset of a project are infrequently realised in practice (Sharifi et al. 2010).

Figure 2.6: Built environment assessment 'tool' types



Note: 'Rating' tools employ scoring mechanisms to 'rate' (via points, stars, etc.) the performance of aspects of particular development projects against a range of benchmark parameters; 'Assessment' or 'Decision-support' tools are designed to assist in decision making by enhancing understanding performance of individual indicators and ideally the interactions of various parameters within particular design and planning scenarios, and build capacity for more effective analysis and responses to complex project and urban sustainability challenges; 'Frameworks' articulate the broad goals, direction, responsibilities for urban development that is sustainable, resilient and low carbon. Guidelines typically emerge from these frameworks and articulate strategic directions and criteria for project development and decision making and implementation

Source: Neilson (2010)

- The range of themes and indicators employed in assessment and rating tools is extensive and there are obvious differences in focus that reflect the objectives of the tool developers and their clients (Sharifi and Murayama 2013; Sharifi et al. 2010; Neilson 2010). Among the most significant omissions identified were equity, urban environmental quality, green infrastructure and urban landscape. A prime reason for this is the absence of any legislative or regulatory framework, thereby permitting subjectivity in choice of indicators and benchmarks. In most assessment systems there is, at best, a rudimentary set of performance benchmarks providing pointers to some expected level of performance: typically a baseline or BAU (current/average representation of system performance) and a higher 'target' level of performance (e.g. *EnviroDevelopment* sets a somewhat arbitrary target such as '20% reduction below current regulatory requirements' for several indicators). There is no standard structure, format or content in the reviewed precinct assessment and rating tools (Gil and Duarte 2010), reflecting the 'bottom-up' (client-based) atheoretical nature of their development. Nor do they tend to have a robust methodology or conceptual framework to capture interrelationships between different dimensions (Sharifi, Murayama and Nagata 2012). A case has been made for the development of a national (Australian) 'sustainability' assessment framework (Neilson 2010). A framework needs to be developed that takes into account the interrelationships between the various precinct objects and their attributes as well as with wider spatial contexts beyond the precinct (Sharifi and Murayama 2013).
- Despite significant industry interest (Howard et al. 2007; also Chapter 7), most precinct tools still face the challenge of implementation, and level of

application remains low. Reasons for this include: the voluntary status of precinct assessment, perceived economic costs, and the complexity and ambiguity associated with the process at present (Sharifi and Murayama 2013). Most tools rely on experts for their application, and have only recently entered the tertiary curriculum for broad-based education and training (MUtopia at both Melbourne and Monash universities). As will be discussed in more detail in Chapter 7 in relation to market analysis, government regulation is not calling for precinct scale assessment. In order to overcome the implementation problem, there is an urgent need to forge a closer collaboration between government, industry, research and urban design professionals (Neilson 2010). This was the raison d'être for the creation of the CRCs for Water Sensitive Cities and Low Carbon Living and is at the heart of a proposal to the federal government for an Innovation and Productivity Precinct for the Built Environment (Holliday 2013).

Templates for Evaluating Assessment Tools

In this study we attempt to develop a more rigorous 'top-down' conceptualisation of an assessment system by proposing a three-level overarching framework relevant to carbon intensity, sustainability and resilience, within which key thematic areas can be aligned in a more structured manner. This is the framework within which the themes, categories, components and indicators are assembled for built environment precinct assessment (see Table 2.2). This constitutes the template for evaluating the functionality of precinct assessment tools. Poveda and Lipsett (2011) distinguish assessment and measurement as different operational issues. They are concepts that go hand in hand, as Table 2.2 suggests. In the *measurement* process, components and indicators related to carbon, sustainability and resilience themes and categories need to be identified and data collected and analysed with technically appropriate methods. Availability, appropriateness and currency of data are issues examined in following chapters.

Table 2.2: Conceptual and operational frame of reference for evaluating functionality of precinct assessment tools

Overarching framework	Theme	Category	Component	Indicators	Metric
Carbon					
	Buildings	Residential	Total	Embodied	
			Total	Operational	
			By type, e.g. detached, semi-detached, apartment	Embodied	
			By type, e.g. detached, semi-detached, apartment	Operational	
		Non-residential	Total	Embodied	
			Total	Operational	
		Non-residential	By type: (e.g. office, retail, specialised)	Embodied	
			By type, e.g. office, retail, specialised	Operational	
	Transport	Private	Car Car share	VKT/fuel type (emissions)	
		Public	Bus		

Overarching framework	Theme	Category	Component	Indicators	Metric
			Train Tram		
		Active	Walking Cycling		
		Other	Parking		
Sustainability					
Environment	Waste	Generation	Municipal (incl. food)		
		Generation	C&D		
		Recycling	All types		
	Water	Demand	Potable Non-potable		
		Supply	Stormwater	Building scale, Precinct scale	
			Greywater		
	Energy	Demand	Electricity		
	Energy	Demand	Gas		
		Supply	Solar Wind Tri and cogen Geo-thermal Thermal Hydro Hydrogen		
Economics	Employment			Local jobs	
				Access to jobs	
	Housing affordability		Capital Operating		
	Construction cost	Building	Capital cost		
		Infrastructure	Capital cost		
	Operation and mainten-ance		Cost		
Social	Liveability			Walkability	
				Access to services: (retail, community, schools, open space, health)	
				Provision of open space within precinct	
				Security/Safety	

Overarching framework	Theme	Category	Component	Indicators	Metric
				Access to public transport	
	Population density				
	Social mix				
Resilience					
	Local food	Supply			
	Climate change	Heat waves Local flooding Sea rise / storm surge		Vulnerability to …	

There are a range of other significant criteria in addition to the core carbon, sustainability and resilience measures that have been identified for evaluating precinct assessment and rating systems (see Table 2.3).

Table 2.3: Criteria for evaluating precinct design assessment tools

Criteria	Indicator
Spatial Scale	Region; city; precinct; building
Development Arena	Greenfield; greyfield; brownfield
Project Phase	Program definition; location selection; Master Plan sketch; Master Plan; Detailed design – infrastructure; Detailed urban design – precinct; Detailed design – individual buildings; construction; operation
Precinct Development Process/Governance	Capacity for information sharing and engagement across project partners and precinct stakeholder groups
Precinct Information Sources	Spatial coverages (e.g. land use, existing built environment); demand side data (operating, embodied); supply side data (e.g. DG technologies); benchmarks
Precinct Technical Architecture and Information Platform (TAIP)	Indicators of TAIP: software platform (spreadsheet, proprietary GIS, web application); implementation platform (open-source, proprietary); user interface (form-based text, proprietary graphics, web-based graphics); licensing (in-house, commercial); software interoperability (none, CAD, BIM); underlying data model (cellular, custom, GIS)
Conformance with National/ International Standards	ISO or similar reference
Design visualisation	Ability of tool to enable 2D, 3D, fly through, immersive design representations
Commercial Performance	Usability; system maturity; verification of measurement; communicability

These are:

- Spatial scale: most assessments focus at a specific scale, responding to the strategic issues characteristic of that scale.

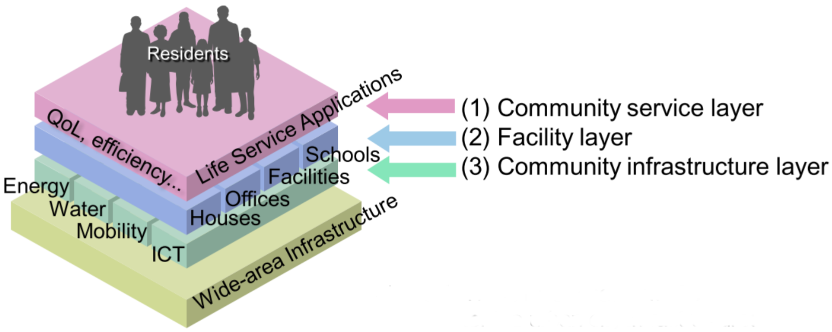
- Development arena: Most precinct assessment and rating systems were initially developed for application to greenfield projects. More recently, brownfield and greyfield development projects are being encouraged within Australian metropolitan planning strategies (Newton 2010; Newton et al. 2012), in an attempt to engineer more compact urban development and redevelopment. Whether current tools are well equipped for 'infill' development at a range of scales is unclear. In Europe, HQE2R (2004) was specifically developed as a tool to guide decision making in urban redevelopment projects.
- Phase of Project Development: There are several phases in the life cycle of an urban development project, each with different decision needs and stakeholder interests.: Most precinct design assessment tools embrace the following stages: program definition, location selection, sketch master plan, master planning, and detailed precinct design. Detailed design and assessment of individual buildings and infrastructures typically follows, and it is at this point that a PIM platform offers the opportunity for transfer of data, reports, designs, costings etc. from sketch through to detailed design stage in a project. Assessment tools for precinct development also tend to stop before construction and operation phase. However, as BIM-oriented models now demonstrate for buildings, extension of functionality into construction and facility management is now feasible and commercially attractive from a cost and productivity perspective. PIM offers similar opportunities (see Chapter 6).
- Precinct Development process: A coherent, over-arching precinct development process is also something that should operate to integrate the various critical design elements in an optimal manner (Falk and Carley 2012): working together better; quality management processes, including those working with local communities in engagement processes; agreed planning frameworks (state/local alignment); financial (risk/return) management; managing the development project partnerships. A PIM framework facilitates a seamless circulation of data and reports around the multiple partners/actors in a development project.
- Precinct information sources: address the availability and ease of assembling data relevant to precinct design assessment – a significant challenge for precinct assessment tools. At least three categories of data are relevant:
  - *Spatial coverages* related to the precinct and surrounding area, e.g. land use (zoned, actual); location of infrastructure networks; ecosystem features – with attribute data attached where possible
  - *Demand side data* includes forecasts of the physical (e.g. water, waste, energy) and social service (e.g. education, health, mobility) demands expected to be satisfied by the precinct design. Both quantitative and qualitative data are in scope
  - *Supply side data* represents the performance attributes of precinct objects in terms of their capacity to meet specified demands (includes buildings, transport systems, energy, water and waste services etc.). Performance attributes can relate to both embodied and operating elements of a product (see Chapter 5).
- Precinct information platform: In this study, information management systems used in precinct assessment tools are compared against a precinct information model (PIM) schema. For example, whether standardised mechanisms exist to integrate precinct information; persistence of information moving through various project stages; role of urban visualisation; management of multi-scale data (e.g. outputs from BIM models; ability to carry forward intentions/requirements to the implementation phase of precinct development; scope of analytical information requirements; see Chapter 6). There are several ways in which to characterise a precinct assessment tool:
  - *Software environment* – this reflects the extent to which the tool relies on other software platforms for its implementation rather than being

entirely free-standing and developed from scratch; it is also reflected in the extent to which the tool interoperates with other related applications as part of a larger business process.

- *Licensing context* – this has two dimensions, one relating to the tools dependence on a separately licensed application (such as ArchGIS or Microsoft Excel) rather than an open-source technology, but it also relates to the dissemination of the tool or the extent to which it may be commercially available as opposed to in-house.
- *User interface* – this is concerned with the way the tool presents to the end user, ranging from form-filling to a highly visual interface, including the use of charts and tables.
- *Underlying data model* – the richness and flexibility of the underlying data model impacts both its usability and applicability across a range of performance indicators.

- Standards in Precinct Planning and Design: The growth in number of tools created for assessing the sustainability performance of precincts from a planning and design perspective, combined with a lack of national and international consensus on how an evaluation of such urban development projects should occur, has highlighted the need for standards applicable across both 'jurisdictions' (national: see Hyde et al. 2007; EarthCheck 2013; and international: see Tranchard 2013). ISO/TC 268 *Sustainable Development in Communities* was established in March 2012 with an initial focus on 'smart infrastructures' (see Figure 2.5 – community infrastructure layer), with a priority for developing a common language (see Chapter 6 on PIM) and set of globally harmonised metrics for assessing and comparing the performance of key infrastructures such as energy, water, mobility, waste management and ICT from a sustainability and resilience perspective (Ichikawa 2013; Lair and Bougeard 2013). To date, there has been little or no attempt to harmonise key features of Australia's precinct rating and assessment tools.

Figure 2.7: ISO model of multiple information layers required for precinct representation and performance assessment



Source: Ichikawa (2013)

- Engagement and visualisation: What 'layer 4' in Figure 2.5 highlights is that cities and their precincts must be designed for people – the occupants of these places and spaces (as residents, workers, visitors). Gehl (2010) is currently the best known advocate globally for this perspective, and argues that a small scale –precinct – perspective is too frequently neglected in contemporary urban design projects; that urban neighbourhoods are best created and evaluated by processes that can capture the human 'lived' scale of a place, as could be *visualised* while *walking* the locale. Methods for examining these dimensions of performance of a precinct at design stage are generally absent from contemporary assessment and rating tools. They would require, at minimum, addition of advanced visualisation and immersive technologies linked to BIM and PIM platforms.

- Commercial performance: The five precinct assessment and rating tools that are the prime focus for this study are either in the prototype/pilot testing phase (e.g. MUtopia, Green Star Communities) or are proprietary tools developed for use in the private (LESS, SSIM) or public and private (PrecinX) sectors. As such, a number of criteria relevant to the evaluation of commercial tools are not currently applicable, but are important to note in terms of possible future development, namely: usability, system maturity, verification and communicability of outputs.

Appraisal of Functionality of Rating and Assessment Tools

3. Appraisal of Functionality of Rating and Assessment Tools

This chapter begins with a brief introduction to Australia's Green Star Communities Rating System and its degree of alignment with other leading international precinct rating systems (LEED ND and BREEAM). Following this the four precinct design assessment tools associated with CRC partner organisations are examined in the context of the criteria established in the previous chapter.

Precinct Rating Systems

Green Star Communities

Green Star Communities is Australia's leading sustainability rating system for the built environment at a precinct level. It has been established by the Green Building Council of Australia (GBCA) in two stages. First, as a '*national framework* for sustainable communities' that propose national best practice principles for guiding their future development. Sustainability principles are at the heart of this framework:

- Enhancing liveability
- Creating opportunities for economic prosperity
- Fostering environmental responsibility
- Embracing design excellence
- Demonstrating visionary leadership and strong governance
- Recognising innovation

Second as a *rating tool*, providing a set of indicators against each principle with benchmarks and associated credit points that can be assigned depending on the level of performance achieved by the precinct design. Also, a set of governance processes by which rating certification can be achieved. Green Star Communities rating tool is in a pilot phase, being applied to 11 major projects, including: Barangaroo, Sydney; Tonsley and Bowden, Adelaide; Ecco Ripley, Ipswich; Caloundra South, Southeast Queensland; and University of Melbourne, Parkville Campus, Melbourne. A spectrum of assessment tools will supply the evidence to the rating tool to enable an appropriate designation of credit points to be assigned.

LEEDnd (LEED for Neighborhood Development)

The US Green Building Council (USGBC), the Congress for the New Urbanism (CNU) and the Natural Resources Defense Council (NRDC) have collaborated to develop a rating system for neighbourhood planning and development based on the combined principles of smart growth, New Urbanism, and green infrastructure and building. The goal of this partnership is to establish a national leadership standard for assessing and rewarding environmentally superior green neighbourhood development practices. Prerequisites and credits in the LEED-ND rating system address five high level topics:

- Smart Location and Linkage
- Neighbourhood Pattern and Design
- Green Infrastructure and Buildings
- Innovation and Design Process
- Regional Priority Credit

In a similar fashion to Green Star Communities, there are a set of performance criteria and benchmarks under each major topic that can attract credit points (see LEED 2009).

BREEAM Communities, UK

Launched in 1990, BREEAM was the world's first environmental assessment method for new building designs and is now applied in its various forms in over 50 countries.

Building on the knowledge and principles embodied in the BREEAM family of tools, BREEAM Communities has been launched as an independent, third party assessment and certification standard for development projects at a precinct level (BRE 2012). It is a framework for considering the issues and opportunities that affect *sustainability* at the earliest stage of the design process for a development as well as subsequent detailed design.

Issues for assessment and rating by BREEAM Communities are grouped into five impact categories and a sixth category that promotes the adoption and dissemination of innovative solutions:

- Governance: Addresses community involvement in decisions affecting the design, construction, operation and long-term stewardship of the development
- Social and economic wellbeing: Addresses societal and economic factors affecting health and wellbeing such as inclusive design, cohesion, adequate housing and access to employment
- Resources and energy: Addresses the sustainable use of natural resources and the reduction of carbon emissions
- Land use and ecology: Addresses sustainable land use and ecological enhancement
- Transport and movement: Addresses the design and provision of transport and movement infrastructure to encourage the use of sustainable modes of transport
- Innovation: Recognises and promotes the adoption of innovative solutions within the overall rating where these are likely to result in environmental, social or economic benefit in a way which is not recognised elsewhere in the scheme.

Comparison of Rating Tools

A high level comparison of the three leading international precinct rating tools (Table 3.1) reveals a measure of commonality at a thematic level given that 'sustainability' principles have been key drivers in the creation of each, as well as management/governance processes. However, on drilling down to the category and indicator levels, significant variations emerge, as do the allocation of credit points, all of which reflect the fact that each tool is reflective of different national and institutional priorities; as well as different regional contexts, where some issues will be elevated in importance over others (e.g. water scarcity). Learnings continue to be shared between these major rating organisations (viz. EcoDistricts Summit 2012 in Portland), but significant gaps are evident, especially in relation to equity, resilience, and life cycle carbon accounting (see Table 3.1 and Figure 3.1); most of the 'carbon' metrics are legacy energy measures.

Table 3.1: Key features of three rating tools

		LEED – Neighbourhood	BREEAM – Communities	Green Star – Communities
Life cycle	Strategic Planning		✓	✓
	Development Planning	✓	✓	✓

	Design	✓	✓	✓
	Construction	✓		✓
	Operation			
Key issues	Environmental	✓	✓	✓
	Social	✓	✓	✓
	Economic		✓	✓
	Planning and Design	✓	✓	✓
	Management			✓
Key category (available points)		Smart Location and Linkage (27 points Neighbourhood Pattern and Design (44 points) Green Infrastructure and Building (29 points) Innovation and Regional Priorities (10 points)	Land use and ecology (18 points) Transport and movement (15 points) Governance (8 points) Resources and energy (31 points) Social and economic wellbeing (47 points)	Governance (21 points) Design (11 points) Liveability (23 points) Environment (26 points) Economic prosperity (19 points) Innovation (10 points)
Rating system/Benchmark		Total 100 points (10 points extra 40-49 Certified 50-59 Silver 60-80 Gold Platinum > 80	Total 119 points Pass > 29 Good > 39 Very Good > 54 Excellent > Outstanding >84	Total 100 points (10 points extra) 44-59 4 star (Best Practice) 60-75 5 star (Australian Excellence) < 75 6 star (World Leadership)

Figure 3.1: Energy and carbon related indicators in each tool (%)

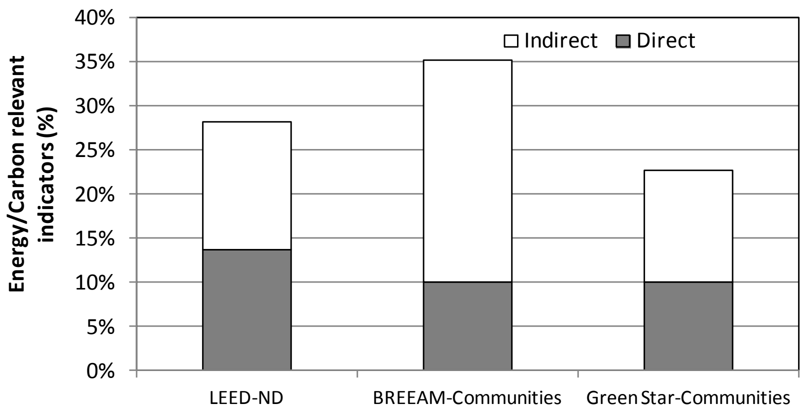


Table 3.2: Energy and carbon related indicators in each tool

	LEED-ND	BREEAM-COM	Green Star-Communities
Direct	Building energy efficiency (2) Heat island reduction (1) On-site renewable energy source (3) District heating/cooling (2) Infrastructure energy efficiency (1) Certified Green Building (5) Solar orientation (1)	Energy strategy (11) Transport carbon emission (1)	Heat island effect (1) GHG emission (6) Green building (4)
Indirect	Reduced automobile dependence (7) Bicycle network and storage (1) Compact development (6) Local food production (1) Existing building use (1)	Green infrastructure (4) Adapting to climate change (3) Existing building and infrastructure (2) Sustainable building (6) Low impact materials (6) Resource efficiency (4) Cycling network (1) Access to public transport (4)	Environmental management (2) Site planning and layout (3) Urban design (4) Materials (2) Transport (3) Access to amenities (1) Local food production (1)
Points	31 points (15: Direct, 16: Indirect) of 110 points	42 points (12: Direct, 30: Indirect) of 119 points	25 points (11: Direct, 16: Indirect) of 110 points

Evaluation of Precinct Assessment Tools

In this section we examine four precinct assessment tools that have been developed by partner organisations of the CRC: LESS (Hassell), MUtopia (University of Melbourne), PrecinX (NSW Government) and SSIM (AECOM). Following a brief overview of these tools, an examination of each tool attempts to identify:

- Alignment with a core carbon-sustainability-resilience (C-S-R) assessment framework identified as central to a 21st century urban design assessment tool
- Gaps in indicator coverage in these core areas, including issues of data availability
- Use of benchmarks in evaluating levels of performance
- The information and software platform issues associated with each.

Precinct Assessment Tools

LESS

LESS (Local-area Envisioning and Sustainability scoring System) is a design decision-making framework developed by Hassell to generate sustainable design solutions that lessen emissions, use of resources and social disparity. It is an integrated assessment system for urban sustainability designed to achieve the following objectives:

- to function as a Decision Support System during design phase
- to function as a Sustainability Management System post-occupancy; and
- to provide: an ever growing knowledge bank; a sustainable design template; and a design articulation and marketing tool

LESS facilitates mapping, measuring and monitoring of sustainability by assessing four domains – social, infrastructure, governance and environment – to allow for a TBL assessment. It operates in the following steps in a typical state of the environment reporting framework (http://www.environment.gov.au/topics/science-and-research/state-environment-reporting):

- Define drivers: human activities causing pressures (e.g. population change, consumption and production of goods/services, scientific and technological advances and socio economic/political conditions)
- Pressures: the stresses from human activities on natural systems (e.g. transport, building, land use, resource extraction)
- States: recordable conditions of the natural environment (e.g. air, water, ground quality, changes in biodiversity, land degradation)
- Impacts: impacts on human systems (e.g. health, security and safety, economic (in)efficiencies, social inequity)
- Responses: capacity to examine potential human response to impacts (government, industry, community).

In LESS, sustainability is represented by domains (environment, economy, social) and themes (e.g. effective economy, mind body and spirit, earth, water air and fire, connectedness, future proofing a built environment). Each of these themes is built up from issues, and each issue has a set of indicators. LESS is project based, and has a capacity to benchmark within and between projects. It is an indicator driven tool. Depending on the project, different indicators are used in evaluation (typically in relation to a client-specified target). Reporting is represented graphically (e.g. spider format), by showing baseline vs improvement for each theme. Composite indices are also derived.

MUtopia

MUtopia is a tool developed by the University of Melbourne. Integrated domain models (energy, water, waste, transport, social, economic) inform a 3D spatial platform supporting urban infrastructure modelling in the context of sustainable design. Models are simulated under alternative scenarios to generate customisable 2D and 3D reports. Outputs are provided for a wide spectrum of themes and indicators, e.g. liveability, GHG emissions, water consumption, travel time, waste generation and life cycle cost. The MUtopia tool is informed by AGBC's Green Star tools, One Planet Living and LEED frameworks, and sustainability principles more generally. These three rating systems help specify the data required in the fields of energy, water, waste, transport, food, liveability and governance. This forms the basis for the MUtopia tool, the key features of which are:

- Open architecture, scalable and adaptable, cloud-based
- Integrated GIS + BIM using Precinct Information Model (PIM)
- Advanced visualisation capabilities for rendering and reporting
- Predictive modelling capabilities, what-if scenario simulation
- Multi-user architecture, collaborative design and simulation platform
- Public engagement capabilities via a web portal for community consultation
- Monitoring capabilities with sensor networks
- Data security

Users (land agencies, developers, architects/urban planners, engineering consultants, community) determine the scope for analysis in the form of user requirements, which shape the MUtopia platform. The tool can be used in multiple phases of a development project: preliminary planning; stakeholder communication; master planning; community consultation; design; monitoring.

PrecinX

PrecinX is a planning and design tool developed for the NSW government (Landcom) and other government land organisations (GLOs) to evaluate the sustainability of a neighbourhood or large urban development project. It was designed to assist land developers, urban planners and regulatory authorities make decisions about new urban development (Landcom 2009). Originally targeted at greenfield precinct development, it is now being employed in urban redevelopment projects in NSW and interstate (via GLOs, local governments, utilities and private developers). The tool comprises several key modules, predominant among them being: transport, energy, embodied CO2, water, housing yield, operational affordability and financial analysis (capital and recurrent costs) – reflecting the principal interests of government and the private sector in these areas. It provides the capacity to compare the performance of a precinct as designed, against a set of government planning targets. Its focus on embodied as well as operating carbon emissions established PrecinX as a leader in the area of urban carbon auditing, driven by government's need for a carbon assessment and reporting tool.

SSIM

AECOM's Sustainable Systems Integration Model (SSIM) is an urban sustainability analysis tool that was developed to assist clients to understand the environmental, social and cost implications of decisions. It is focused on optimising sustainability decisions master planning and infrastructure delivery.

SSIM has developed over the last seven years as a set of models that have been designed to work together to allow ongoing support through an urban planning and infrastructure decision making cycle. The following points highlight the staged approach.

Stage 1 – Master Plan Comparison (Urban Design)

SSIM Stage 1 uses an integrated GIS based land use spatial planning tool that seeks to optimise the sustainability outcomes of master plans by quantifying the relative performance of appropriate environmental, social and economic factors. It is generally applied during initial concept plan development and consists of the following elements:

- Project goals and targets are agreed in a workshop with client, key stakeholders and project team
- A set of performance indicators (e.g. access to transport, access to open space, energy consumption, water consumption) are selected
- Data is assembled for site and region, benchmarks are established and are assessed against performance indicators
- GIS is used for indicator calculation, individually as well as in a more integrated TBL fashion
- Results are generated in tabular and graphical form to facilitate communication and decision making.

In Australia the quantitative metrics have generally been aligned with the GBCA's Green Star Communities Framework and the qualitative metrics with the federal government's Urban Design Protocol for Australian Cities.

Stage 2 – System Alternatives (Infrastructure Design)

SSIM Stage 2 evaluates 'Base', 'Good', 'Better' and 'Best' system or infrastructure alternatives during detailed development and testing of the preferred master plan. Taking the energy systems as an example, the 'Base' system may be 100% power supplied from the grid, the 'Good' system may be a mix of solar and grid power, 'Better' may be district energy provision with supplementary solar power, and 'Best' may be a closed loop system with the reuse of onsite waste materials. This process can be applied to a broad range of systems such as:

- Water reuse and water savings methods
- Transportation options for alternative public transport networks
- Energy and carbon emissions
- Ecological systems
- Social sustainability and community assets
- Green building measures (building fabric, water, cooling, heating and so on)

For each system, its sustainability performance and costs are assessed in a cost/benefit analysis and results are compared to project goals and targets.

Stage 3 – Program Optimisation

SSIM Stage 3 provides multiple Programs by assembling different combinations of 'Base', 'Good', 'Better' and 'Best' System Alternatives from Stage 2. It brings together the development outcomes from Stages 1 and 2 to allows for a range of alternative design and infrastructure scenarios to be tested quickly across multiple environmental, social or cost considerations.

- Each program is assessed in its totality and for its sustainable performance.
- When all programs have been finalised, they are compared to each other and the preferred program is selected.

The output results include total resource reduction and/or reuse and ultimately show reduction in greenhouse gas emissions, water and waste use and reuse potential. Economic outputs include total initial and recurring costs. Social outputs include provisions for social infrastructure, balance and social and economic diversity.

The method for the SSIM is heavily tailored to the project context maximising the relevance to the project decisions being made and the options available to the client and project team. Its fundamental intent is to improve transparency and facilitate decision making. Rather than relying on standard assumptions and data sets it is more reliant on the broader global AECOM engineering and design expertise to ensure the most relevant environment, social and cost factors are considered and technologies are applied.

This report includes an analysis of a single application of the SSIM tool for the purpose of a SSIM Stage 1 Urban Form analysis tailored for a state government land use project which is with a public forum. It is acknowledged that this is only a small part of the SSIM suite used for the purpose of illustration and comparison in this report.

Alignment with C-S-R Framework

In a similar manner to precinct rating systems, the four assessment tools have all been strongly influenced in their development by sustainability principles, and the commonly cited TBL themes are represented in all. There is little evidence of a capacity for eco-efficiency assessment, especially in a life cycle costing perspective (fundamental to driving more sustainable investment). Elements of other frameworks aligned to the sustainability model such as SoE and that of One Planet Living (e.g. refer to their 10 guiding principles at http://www.oneplanetliving.org) are also drawn upon in various ways. Carbon assessments are beginning to feature, most prominently in PrecinX, but have not been subject to scientific validation, a critical step if opportunities for claiming carbon credits for urban development and the built environment ever materialise. Estimating embodied carbon for precinct assessment remains a challenge. Resilience assessment across all climate change dimensions is yet to emerge.

Gap Analysis in Precinct Assessment Indicators

The objective of this part of the project was to examine, to the degree possible, the array of themes, categories, components, indicators and metrics identified in the evaluation matrix developed for this study that emanated from the C-S-R framework (see Chapter 2, Table 2.2). Following an initial overview provided by all tool developers, it was decided that in order to better understand commonality and/or divergence of concepts and metrics used in the area of precinct assessment, each organisation with a relevant software tool was asked to complete two Excel worksheets – one showing all the concepts and associated properties which would be used within their tool for a "typical" project, and the other showing the measurements ("metrics") calculated against those concepts/properties. Via further technical discussion involving one of the study team members visiting each tool developer's site to run through at least one and sometimes two completed applications of the tool, the level of "concept coverage" for each tool was assessed as well as the range of indicator output metrics recorded. This analysis is important to establish what might be seen as a core set of common concepts/indicators, as well as key gaps.

The preliminary results of this analysis are outlined in Table 3.3 and more detailed output and metrics are listed in Appendix 1.

Table 3.3: Output metrics associated with precinct assessment

Theme	Category	Component	Indicator	Metric				Credit
				L	M	P	S	GS
Framework: Carbon								
Buildings	Residential	Total	Embodied	Tco2e/m2	Tco2e/m2	Tco2		
		Total	Operational	T co2e/year	T co2e/year Tco2e/capita/yr	Tco2e/year	T co2e/year	ENV-5 ENV-6

Theme	Category	Component	Indicator	Metric				Credit
				L	M	P	S	GS
		By type	Embodied		Tco2e/m2	Tco2e/dwelling Tco2e/capita		
		By type	Operational	T co2e/year	T co2e/year Tco2e/capita/yr	Tco2/dwelling Tco2/capita	T co2e/year	ENV-5 ENV-6
	Non-residential	Total	Embodied	Tco2/m2	Tco2e/m2 Tco2e/capita	Tco2		
		Total	Operational	Total co2e/year	T co2e/year Tco2e/capita/yr	Tco2/year	T co2e/year	ENV-5 ENV-6
		By type	Embodied	Tco2/m2	Tco2e/m2	Tco2 (infrastructure)		
		By type	Operational	Total co2e/year	T co2e/year Tco2e/capita/yr	Tco2/year (infrastructure)	T co2e/year	ENV-5 ENV-6
Transport	Private	Car Car share	VKT/fuel type (emissions)	Trip distance to work	T co2e/year Km/day	Total Tco2/year Tco2/capita/year based on Km/day (cars and public transport) And Hrs/week (cars and public transport)		
	Public	Bus Train Tram		No. trips Km/capita/ year	T co2e/year Km/day			
	Active	Walking Cycling			T co2e/year Km/day			
	Other	Parking		No. spaces / occupant	No. spaces / occupant	No of spaces per dwellings and occupant. Car share analysis.		ENV-11
Framework: Sustainability - *Environment*								
Waste	Generation	Municipal (incl food)		Tonnes/ capita	Total Tonnes Tonnes/capita			
	Generation	C&D			Total Tonnes Tonnes/capita			ENV-10
	Recycling	All types			Tonnes Recycling rates			ENV-10
Water	Demand	Potable Non-potable		KL/capita	KL/year	ML/year per m2, per dwelling and per person	KL/year	ENV-7
	Supply	Stormwater		KL/area	KL/year	ML/year (per m2, per dwelling and per person) Peak flows and pollutant loads	KL/year	ENV-8
		Greywater		KL/user	KL/year	ML/year (per m2, per dwelling and per person)	KL/year	ENV-8
		Blackwater				ML/year (per m2, per dwelling and per person		
		Sewer				ML/year Peak flow		
Energy	Demand	Electricity		KWh/yr	KWh/yr	MWh/year Peak demand	MWh/year (and peak KW)	ECON-8
		Gas		GJ/yr	GJ/year	GJ/year	MWh/year	ECON-8

Theme	Category	Component	Indicator	Metric				Credit
				L	M	P	S	GS
	Supply	Solar Wind Co/tri-gen Thermal Geothermal Hydrogen		KWh/m2/ day	KWh/year	MWh/year		
Framework: Sustainability - *Economics*								
Employ-ment			Local jobs	Total and Per ha	Total no. of jobs	Total no of jobs	Employ-ment m2/capita	ECON-1
			Access to jobs	Work trips out	Distance to job hubs (km)	Jobs with 5 km radius	Pop. within 2km of empl. lands	ECON-1
Housing Afford-ability		Capital		% of annual income	Land & Housing cost/income	Number MIH or affordable dwellings	Avg / capita investment	ECON-5
		Operating			Utility Bills + transport cost/income	Utility bills and transport costs/savings		
Construc-tion cost	Building		Capital cost	Times annual income	Constr costs Rawlinson data			
	Infrastruct-ure		Capital cost	$k/capita	Constr costs Rawlinson data	Capital $	Capital $	
Operation & mainten-ance	Building		Cost	% of annual income	Operating cost/income			
	Infrastruct-ure		Cost	% of GDP		Recurrent $		
Framework: Sustainability - *Social*								
Liveability			Walkability	Total km of pedestrian paths	Walkability score	Walkability index	Time/ gradient	LIV-1
			Access to services	Facilities/ 1000 people	Pop within X mins access services	Land use mix of precinct	Pop. Within m of various services	LIV-1
			Provision of open space	Total area or %	Percentage of Open space	Amount of open space	Ha/1000 people	LIV-3
			Security / safety	Crime incidents per 1000 people	Crime Rates		Qualitative assessment	LIV-5
			Access to public transport	m to transport stops	Average distance to PT	Average distance and frequency of public transport	Time/slope	
Population density				People/dwell People/m2	People/dwell People/m2	People per dwelling Population and housing density	Custom to master plan and local context	
Social mix				SEIFA + Social Mix Index	Integrated Liveability Index	ABS demographic data	Local demo-graphcs	

Theme	Category	Component	Indicator	Metric				Credit
				L	M	P	S	GS
Framework: Resilience								
Local food	Supply			Avg distance to source % agric. Land within 10km	Access to local food production (km)			LIV-4
Climate change	Heat waves Local flooding Sea rise Storm surge		Vulnerability to	Area (m2) sea level rise, shade, green space, water bodies	Climate change vulnerability index for buildings and infrastruc	Climate change sensitivity tesintg		GOV-6

Key: L=LESS; M=MUtopia; P=PrecinX; S=SSIM; GS=Green Star – Communities

Benchmarks in Precinct Assessment

Benchmarking options provided in the tools represent a key element in urban performance assessment, providing a basis for transitioning from 'business as usual' (where we are now) to where we want to be: ideally world best practice in low carbon, sustainable and resilient urban development. Table 3.4 represents a preliminary assessment of benchmarks as featured in the precinct assessment and rating tools.

Table 3.4: Benchmarks in existing assessment tools

Tool/Benchmark	Green Star – Communities	LESS	MUtopia	PrecinX	SSIM
Levels	Best Practice Australian Excellence World Leadership	BAU*	BAU* Desired performance level obtained by running multiple scenarios to identify 'best' outcome	BAU* (Metro Average) Reference Model (best or optimal outcome)	BAU* Good Better Best
Indicator/ theme	Total score/points	Chosen indicator(s) level	Chosen indicator(s) level	Chosen indicator(s) level	Chosen indicators / targets or relative merit. Environmental / social vs economic (Capex, Opex Life Cycle)
Procedure	Evaluation ^lbased on criteria and assigned points Depending on overall points, applies star rating	Evaluation for each indicator under selected criteria and issues. Standardised scores in aggregated domains (Environment, Economy, Social)	Evaluated for each indicator and represented as individual results for each indicator	Evaluated for each indicator (GHG, water, transport and economic) Represented results based on key issues (climate change, water, household budget, quality of life)	Qualitative and quantitative analysis. Only weighted if it can be transparently demonstrated.
Example	Star rating assigned 4 star 5 star for Australian excellence 6 star for world leadership	Indicators with bench-marks assignedIssues such as: Climate change Air Design Land	Energy (based on NABERS star rating) e.g. Australian Excellence (7 star) Global Best Practice (8 star)	Energy Carbon Water Transport Water use Stormwater Sewer loads	Land use energy (MWh/yr) Operational CO2 (Mt CO2e/yr) Water consumption (kL/yr) Wastewater generation (kL/yr)

Tool/Benchmark	Green Star – Communities	LESS	MUtopia	PrecinX	SSIM
		Water Natural resources Waste Transport Example target: Mitigation of heat island effect with shading (50%)		NABERS and Green Star Ratings	

Information And Software Platforms In Precinct Design Assessment Tools

PrecinX does not use graphically-produced spatial data as the basis of its assessments (although the software developers are looking at extending it to include this capability). Instead, the approach taken is to build a software tool using the relatively inexpensive, widely available and generic spreadsheet capabilities of Microsoft Excel. The software presents as a series of interlinked forms covering each theme for assessment. The spatial reference point is defined by entering a project location. Subsequent data items may be answered by either accepting the default value generated for that location, or by entering an override value. The Excel file also contains the reference data and formulae used to inform the defaults in a number of hidden worksheets. Since the software interface consists of carefully defined input forms, it does not allow the same flexibility for adding ad hoc considerations compared to the other three tools which provide functionality for adding and modifying data attributes (though users can work with the tool developer to add new features). However, this apparent lack of flexibility does mean that there is a commonality of assessment methodology across different projects.

The software components of LESS are built around the ARC-GIS spatial database. Project designs are developed in-house using a variety of other generic design modelling software (for example, AutoCAD or SketchUp), the design files being structured in such a way that they can be imported via an add-on directly into ARC-GIS where possible, or manually otherwise. Assessment indicators are held in a separate database and organised hierarchically into categories – Domains/Themes/Issues/Indicators in that top-down order. Spatially tagged reference data (such as census data, local government areas, locations of public facilities, and transport routes) is included on separate information layers over the base design. With experience over multiple projects, libraries of indicators and also GIS features have been assembled for selective use on future projects. The sustainability assessments are done via formulae in Microsoft Excel spreadsheets, but as common calculations emerge from ongoing usage of LESS, these formulae are gradually being converted to the Python scripting language within ARC-GIS.

SSIM is promoted to be a methodology to inform more sustainable decision making rather than a purely standards-driven tool. It is a tool developed by AECOM as a way to harness and package expert services and maximise transparency of decision making. The SSIM Stage 1 method relies on ARC-GIS software with a structure – for design option imports, indicators, and assessment formulae (using Python scripting). The use of SSIM is considered for a project in stages of application. SSIM Stage 1 deals with master planning and options for urban form. SSIM Stage 2 then focuses much more specifically on a chosen design option in terms of defining and assessing services infrastructure against agreed indicators on criteria from multiple themes on a “business as usual/better/best” basis. SSIM Stage 3 additionally considers the interactions between chosen solutions across the multiple themes.

Unlike the other two GIS-based assessment tools (LESS and SSIM), MUtopia is a custom-built platform utilising open-source technologies including the PostgreSQL database with the PostGIS extension to facilitate storage and calculation of spatial data. MUtopia is also web-based, and the web application uses both the Google Earth application programming interface (API) and OpenGL libraries (WebGL) for high-performance 3D urban visualisation. The web server implements modelling and simulation using a novel “cell-based processing machine” paradigm. Data stored in “cells” may be constant values, user inputs or mathematical expressions that may refer to other cells. Almost any criteria can be modelled and assessed in this way in real time. The server exposes its capabilities to the web application through a RESTful API, enabling straightforward integration with other systems.

Data for Rating and Assessment

4. Data for Rating and Assessment

One of the central problems identified for existing precinct assessment tools is the difficulty of access to reliable and accurate reference data used to measure either existing or forecast performance at a precinct level. Broadly speaking, there are three data challenges associated with the measurement of carbon load in precincts: sourcing accurate environmental load data; gaining access to existing precinct operational data; and determining reliable forecast data across different domains. These are each introduced separately in the following paragraphs.

The first challenge involves calculating the environmental load of the elements or components of a precinct in terms of resource use and environmental emissions, taking into account all stages in its life cycle development. This is generally referred to as life cycle assessment (LCA) and involves the development of a life cycle inventory (LCI) of the products or elements that make up the designed object, in this case an urban precinct. Greenhouse gas emissions are a part of that, but measures also include energy and water consumption, waste production, etc. This is the least developed and understood type of reference data used in current precinct assessment and therefore offers a very significant data challenge going forward. For that reason, much of this chapter is devoted to a discussion of this type of reference data.

The second data challenge revolves around gaining access to urban data that is already collected, generally has a high degree of fidelity, but is often hard to access due to proprietary and privacy concerns. This is the sort of data that is collected by existing organisations and relates to the operation of existing precincts. This includes census data, but extends to data collected by local councils or other government instrumentalities (law enforcement, health, transport, etc.) and utilities (energy and water distribution, waste management, telecommunications, etc.). It is useful in precinct assessment in various ways: understanding current patterns of usage when forecasting impacts of design decisions during the development of new precincts; establishing base level performance targets; or identifying the current context within which a precinct is being developed. The AURIN project (see http://aurin.org.au/), funded under the Australian Government's Super Science scheme, is going some way towards providing access to much of this kind of data, but there remain unresolved confidentiality issues as well as questions about how to link that data to the kinds of precinct objects that form the basis of precinct assessment tools. This is one of the issues that must be addressed in the PIM project discussed in Chapter 6.

The third data challenge relates to forecasting. There are several dimensions to this challenge. One is concerned with the science involved in forecasting demand for energy, water, waste and transport at a precinct level that then leads to the environmental loads discussed in the first data challenge identified above. This area is poorly understood at present, especially given the complex factors that interact to drive demand across the range of environmental loads. This aspect is not explored further in this chapter as it is picked up in the CRC project RP2002, already underway within Program 2.

However, there are other aspects to this data challenge. One is concerned with future materials Reference to publications dating back a quarter of a century on new materials will identify now-familiar terms such as super-conductors, advanced ceramics and plastics, composite materials, light metals, fibre-optics, blended cements to name a few and all with laboratory-based performance properties projected to warrant rapid commercialisation and substitution in the manufacturing and construction marketplace (Forester 1988). Some made it to market, many did not. Closer to the present, in one of the few recent overviews of material science innovation from a built environment perspective (Turney 2009), reference is now made to nanotechnology, biomimicry, closed loop manufacturing, industrial ecology, embedded intelligence, new adhesives based on surface science, green chemistry, new materials for renewable energy generation and storage. Built environment precincts of the future will be shaped by the introduction of these new materials; but as with other innovations, the challenge will be in understanding the comparative cost benefit of the new versus existing products, made more difficult by the fact that existing building products manufactured in Australia are not subject to product declaration legislation as in Europe (that requires a specification of resource inputs, environmental emissions and performance in use data characteristic of the LCI databases discussed later in this chapter). Another relates to forecasting the future social and economic structure of a precinct, addressing issues such as demographics, employment, access to services, etc. Precinct planning must be undertaken in the light of accurate and reliable projections of future growth and demand across a wide spectrum of factors, so this remains a major challenge in the development of low carbon precincts.

Within the broad context of those data challenges, this chapter focuses on the need for reliable environmental performance data, with particular emphasis on the carbon load associated with the precinct elements that are commonly identified at the master planning phase of precinct development.

Overview Of Environmental Load Data

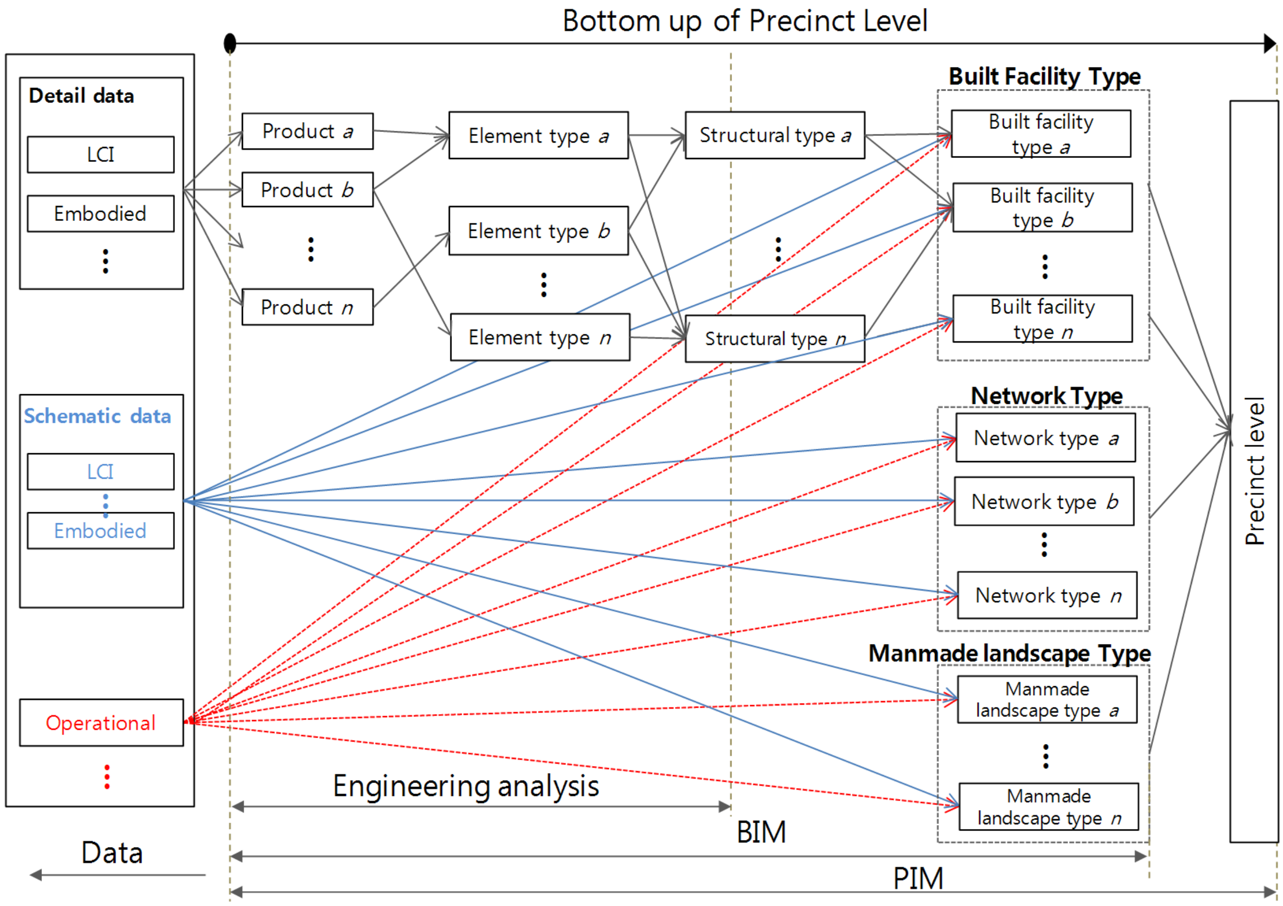
Precinct tools such as those described in previous chapters are being developed to facilitate the appraisal of precinct design performance from the early master planning stage through to detailed design and implementation to meet a growing demand from developers, regulators and urban designers. The first step towards undertaking such appraisals is to identify the component parts of the precinct that contribute to the environmental load of a proposed precinct design. From there, data must be collected that is linked to those precinct objects to enable an aggregated calculation to be undertaken. This chapter traces through that process, extrapolated from existing methodologies that have been proposed or employed at the building scale.

Figure 4.1 illustrates the data linkages required as input into a fully functional precinct design and assessment tool. There are many different types of objects that exist within precincts: residential buildings (such as detached, semi-detached); commercial buildings (such as office, retail, educational); transportation system components (such as road, footpath, parking bay); and green space (such as reserve, park). These precinct objects are grouped on the right hand side of Figure 4.1 as: built facility type (which would include detached, semi-detached house, office, retail, railway station, etc.); network type (any service network, whether a utility distribution system or a transport network like road, train, etc.); and manmade landscape type (park, reserve, wet land, etc.).

Figure 4.1 distinguishes between detail and schematic data to reflect the different levels of granularity commonly addressed in precinct design. Ultimately, precinct components are assemblies of products to form elements that have a structural realisation that permits much more accurate measurement of environmental load. By contrast, at the schematic stage of design, precinct components might be areas of land use (residential, commercial, etc.) or network systems (transport, utilities, etc.) where the environmental data is more generalised. As the figure shows, where design details are known, the data is linked at the product level and aggregated up the precinct scale, while at the schematic design stage, less precise measures may be adopted (e.g. km2 of residential zone, km of footpath, km of 2-lane roadway, m2 of reserve, etc.).

Figure 4.1 also highlights the need to recognise the environmental load of precinct objects during operation, noting that this may vary for different precinct objects. For example, a built facility type (e.g., detached house) consumes fossil fuels for its operation which would be measured in kg of CO2e/m2/year. A network type precinct object, such as a transportation link, would have an operation load measured in CO2e/week of transport, derived as a combination of time, distance (km to work/CBD, etc.), frequency (trips/week, etc.), fuel and vehicle types (gasoline, gas, electric or hybrid).

Figure 4.1: Data linkages for precinct level analysis



The breakdown of precinct objects in Figure 4.1 into three broad types is sufficient for this discussion, but it raises the need for a more rigorous precinct data model that identifies the types of precinct objects needed for effective environmental load calculations as well as providing links for the capture of other types of reference data. The nature of such a precinct information model (PIM) is described in Chapter 5, along with initial analysis of the types of precinct objects that may be appropriate.

Given that broad classification of precinct objects types, the total environmental impact of a precinct may be calculated as the simple sum of both the embodied and operating environmental load of each separate precinct object. This may be expressed as follows:

$$EIP_k = (Emb_{Built\ Facility} + Opr_{Built\ Facility}) + (Emb_{Network} + Opr_{Network}) + (Emb_{Manmade\ landscape} + Opr_{Manmade\ landscape}) + \cdots$$

$$= \sum_{j}^{N} (Emb_j + Opr_j)$$

where,

EIP_k : *Environmental Impact of Precinct k (k : precinct name)*

$Emb_{BuiltFacility}$: Embodied data for Built Facility (Detached, Semi – Detached, Office, Retail etc)

$Emb_{Network}$: Embodied data for *Network* (Road, Train, etc)

$Emb_{Manmade\ landscape}$: Embodied data for *Manmade landscape* (Park, reserve, green area etc)

$OPr_{BuiltFacility}$: Operational data for Built Facility (Detached, Semi – Detached, Office, Retail etc)

$OPr_{Network}$: Operational data for *Network* (Road, Train etc)

$OPr_{Manmade\ landscape}$: Operational data for *Manmade landscape* (Park, reserve, green area etc)

Emb_j : *Embodied data for precinct object type j (j : Built Facility, Network, Manmade landscape etc)*

Opr_j : *Operational data for precinct object type j (j : Built Facility, Network, Manmade landscape etc)*

The distinction between embodied and operational data is discussed further below, but it is important to note that the operational impact of a precinct object may be affected by its relationship with other objects within the precinct, making the calculation of operational impact quite complex. It is also important to emphasise again that as a precinct is developed and moves from the master planning phase through to implementation and construction, providing more fine-grained detail, the data needs to calculate impact become more product oriented.

Environmental Data Requirements at the Precinct Level

This section provides a more detailed review of the data requirements for precinct objects, taking as a starting point the fairly coarse level of granularity typical of precinct analysis where an entire building is treated as a single precinct object. In this case, there are two dimensions to the way buildings are traditionally classified: building type and construction. Table 4.1 illustrates a possible classification based on two standards used widely in Australia. ABCB (1996) classifies 'building' into 10 different types depending on the design, construction and expected use (Table 4.1). Rawlinsons (2011) provides a slightly more detailed classification to represent construction costs more accurately.

The way that load is measured can vary for different building types: for example, embodied carbon for detached dwellings may be represented as either kg of CO2 per square metre or per person, leading to dramatically different results (Newton and Meyer 2011); while operational energy for commercial building is typically measured in kWh per square metre.

Table 4.1: Building Classification

ABCB*		Building type (corresponding Rawlinsons**)
Classification	Explanation	
1 (a)	Single dwelling or attached dwelling	Detached house (brick veneer, full brick) Holiday single unit (brick wall)
1 (b)	One or more buildings constituted boarding house, guest house, hostel (small scale)	-
2	2 or more dwelling (flat, apartment)	Townhouse (low density)

ABCB*		Building type (corresponding Rawlinsons**)
Classification	Explanation	
		Apartment (high density) Holiday multi-unit (brick wall)
3	Residential building for number of persons (hotel, motel, school)	Hotel Motel Serviced apartment
4	Dwelling unit which is part of commercial use (caretaker's/manager's flat etc.)	-
5	Office building	Office (low rise) Office (medium rise) Office (high rise)
6	Retail building	Neighbourhood shop Supermarket Shopping centre Department store (regional) Café Restaurant
7 (a)	Car park building	Car parking
7 (b)	Storage building (warehouse etc.)	Warehouse
8	Building where a process takes place (laboratory, factory, workshop etc.)	Factory Workshop Laboratory
9 (a)	Health care building (hospital, clinic etc.)	Hospital (inpatient) Hospital (outpatient)
9 (b)	Assembly building (community hall, sports hall etc.)	Community hall Indoor arena Religious building Entertainment (cinema) Educational building (primary) Educational building (secondary) Educational building (technical) Educational building (university – lecture) Educational building (university – science)
9 (c)	Aged care building	Aged care Nursing home
10 (a)	Non-habitable building (garage, shed etc.)	-

ABCB*		Building type (corresponding Rawlinsons**)
Classification	Explanation	
10 (b)	Structure (wall, swimming pool etc.)	-

**ABCB (1996) The Building Code of Australia, Vol. 2, Australian Building Codes Board, Canberra

** Rawlinsons (2011), Australian Construction Handbook, 29th edn, Rawlinsons, Perth

Treloar et al. (2000) note that each of these different building types exhibit environmental impact that varies at different stages during their life cycle, generally classified into embodied and operational load. In a broader context, the data requirements for different themes, categories, components and indicators in precinct design and assessment are extensive and vary considerably. This constitutes one of the principal barriers to more extensive application of precinct assessments – from sketch through to more detailed design (see Table 4.2).

Table 4.2: Data requirements of precinct tools

Component	Data requirement of Life cycle					Example data requirement
	Design	Contr.*	Opert.*	Maintn.*	EoL*	
Parks	✓	✓	✓	✓	✓	Type, area, planting, material, energy, water and carbon emissions (embodied, operation), waste generation etc.
Green space	✓	✓	✓	✓	✓	
Other open space (reserve etc.)	✓	✓	✓	✓	✓	
Building	✓	✓	✓	✓	✓	Type, material/energy/water consumption, carbon emission (embodied and operation) etc.
Transportation	✓	✓	✓	✓	✓	Mode (rail, road, water), distance and travel time (to job, shop, home etc.), energy use and source
Water	✓	✓	✓	✓	✓	Material (pipe network), water supply and demand, water/energy consumption (embodied and operation)
Energy	✓	✓	✓	✓	✓	Energy supply (renewable and grid), demand (embodied and operation) by type
Waste		✓	✓	✓	✓	Waste generation (embodied and operation)
Other type of infrastructures	✓	✓	✓	✓	✓	-
Values		✓	✓	✓		Construction, operation and maintenance cost for each of components (building etc.)
Employment			✓			Employment rate (%) in precinct
Others		✓	✓	✓		-

*Contr.: Construction; Opert.: Operation; Maintn.: Maintenance; EoL: End-of-Life

Data related to the resource use and environmental emissions associated with the built environment of a precinct revolve around two principal sources (see Figure 4.2):

- those *embodied* in the materials used in construction and development

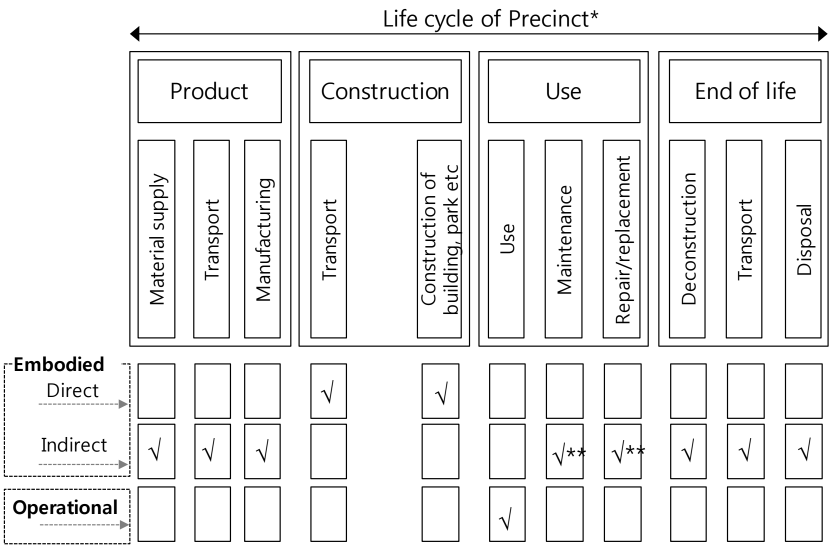
- those connected with the *operation* of the precinct.

Embodied Data

At a product level, embodied impacts are related to the manufacture of materials or products including their transportation.

Environmental emissions (including carbon) released from construction activities in a precinct are also part of the embodied energy/carbon impact. Environmental impacts in the ‘use’ phase in Figure 4.2 can be further classified into three parts; use (operation), maintenance and repair/replacement. Environmental impacts due to use of precinct components are operational impacts (see next section), but impacts from maintenance and repair/replacement are included in the embodied impacts (e.g. due to consumption of material/product during replacement or maintenance of building components). These embodied impacts are referred to as ‘recurring embodied impact’ because they are repeated over the life cycle of precinct.

Figure 4.2: Classification of embodied and operational data involved in the life cycle of a precinct



* Recycling/reusing is not considered in this case
** can be called recurring embodied, which is resultant due to repair/replacement of material/product of precinct components (building, park, transport etc)

The end-of-life of a precinct component involves deconstruction and transportation to a management/disposal site. Thus, over the full life cycle of a precinct, embodied data is required for extraction/manufacturing as well as the construction, maintenance/repair and end-of-life phases of a precinct’s built environment components.

Some examples of embodied data requirement are shown in Table 4.3.

Table 4.3: Embodied data example of impacts

Component	Impact	Embodied data example	Life cycle included		
			Construction including product manufacturing	Maintenance/Repair/Replacement of products during use of	End-of-life including transportation and waste
Building/ Transport/ Park/ Reserve	Energy	kWh/m2 (or MJ/m2) of different type of residential building (detached, semi-detached, apartment etc.) kWh/m2 (or MJ/m2) of different type of commercial building (office, retail, hospital, educational, entertainment etc.). kWh/km (or MJ/km) of transportation systems (railway,			

Component	Impact	Embodied data example	Life cycle included			
		road etc.) kWh/km (or MJ/km) of water supply network (pipe etc.) kWh/m2 (or MJ/m2) of park/reserve development				
	Carbon	Kg CO2e/m2 of different type of residential building (detached, semi-detached, apartment etc.) Kg of CO2e/m2 of different type of commercial building (office, retail, hospital, educational, entertainment etc.). Kg of CO2e/km of transportation systems (railway, road etc.) Kg of CO2e/km of water supply network (pipe etc.) Kg of CO2e/m2 of park/reserve development/construction				
	Water	KL of potable water/m2 of different type of residential building (detached, semi-detached, apartment etc.) KL of potable water/m2 of different type of commercial building (office, retail, hospital, educational, entertainment etc.). KL of potable water /km of transportation systems (railway, road etc.) KL of potable water/m2 of park/reserve development/construction				
	Waste	Kg of construction waste/m2 of different type of residential building (detached, semi-detached, apartment etc.) Kg of construction waste/m2 of different type of commercial building (office, retail, hospital, educational, entertainment etc.). Kg of construction waste /km of transportation systems (railway, road etc.) Kg of construction waste /m2 of park/reserve development/construction				

Operational Impact Data

As shown in Figure 4.2, operational impacts result from a range of ‘use’ activities in a precinct, whether centred on buildings, transport, or other day to day activities that consume resources and generate environmental impacts (emissions etc.). For example, operating energy for a precinct is represented by a range of sources such as electricity, gas and oil, each of which can be generated from a range of technologies with different eco-efficiency (cost = environmental impact) signatures. The links that different precinct objects (e.g. building/residential) have with different resource demands – e.g. energy and fuel for heating, cooling and lighting – each of which have potential for being supplied via different technologies and infrastructures, illustrate the multi-dimensionality of operational data (as was the case with embodied data).

The scope of operational data required for precinct design is illustrated in Table 4.4.

Table 4.4: Operational impact data required for precinct design

	Type	Energy	Carbon	Water (by total)	Waste (by total)
Building	Residential (Detached, townhouse, apartment etc.**)	kWh/m2/ year* (or MJ/m2/ year)	Kg of CO2e/ m2/year*	kL of potable water/m2/ year	Kg of MSW/m2/ year Kg of recycled waste/m2/ year
	Commercial (Office, retail, education, hotel, shopping centre, hospital etc.)	kWh/m2/ year* (or MJ/m2/ year)	Kg of CO2e/m2/ year*	kL of potable water/m2/ year	Kg of MSW/m2/ year
Transport	Rail (Heavy/light, passenger/freight, etc.)	kWh/km	Kg of CO2e/km		
		Distance of travel (km) Trip number (frequency)			
	Road (Vehicle type, passenger/freight, private/public,fuel type, etc.)	kWh/km	Kg of CO2e/km		
		Distance of travel (km) Trip number (frequency)			
Park	Park/reserve, etc.	kWh/m2/ year (or MJ/m2/ year)	Kg of CO2e/m2/ year kg of CO2e/m2/ year***	kL of potable water/m2/ year	Kg of MSW/m2/ year

*** By total and end use (Heating, cooling, lighting, cooking, electric appliances, and others)

*** See Table 4.1 for more detailed building type

*** Absorbed CO2 by planting

LCI Databases

The environmental data described in the last section is collectively held in LCI databases. This section reviews the availability of LCI data suitable for precinct analysis. Such data is calculated from all inputs to manufactured products used in construction of the built environment in terms of raw materials and energy, and outputs in terms of emissions to air and water and solid waste.

Two different approaches are used in LCI. One is a bottom-up approach, termed process-based analysis, in which the total environmental burden is calculated by summing up the burdens in each life cycle stage of a product: extraction of raw material, transport, manufacture, distribution and final disposal. This approach is useful when analysts have specific and detailed data for particular products or processes (Jones et al. 2009). The other is a top-down approach in which sector-wide input-output relations between processes are represented in a matrix form (viz. input-output (I-O) tables; Flores 1996; Horvath 1997).

LCI Databases in Australia

Over the past 15 years or so, several organisations in Australia have embarked on developing LCI data for a selected range of building products (see Table 4.5), full details of which are found in Appendix 2.

Table 4.5: LCI database in Australia

Name	Target	Data #	Source	Usability	Boundary	Method
AusLCI	National LCI	<30	Mix*	Open	Cradle-to-gate	Process
Australasian LCI	LCI for SimaPro	<100	Mix	Open	Cradle-to-gate	Process
BP LCI	LCI for building products	<50	Industry	Open	Cradle-to-gate	Process
CRC CI - LCI	LCI for LCADesign tool	<100	Industry	Open - w/ licence	Cradle-to-gate	Process
Embodied carbon for AccuRate	Embodied carbon data for AccuRate tool	<70	Mix	Open	Cradle-to-gate	Process
FWPA	National LCI for timber products	<10	Industry	Open	Cradle-to-gate	Process
RAIA -(Royal - Australian - Institute of Architects)	Embodied energy for building products	<100	Lawson	Open	Cradle-to-gate	Process
I/O	Embodied energy data for building products	<100	Academic**	Open	Cradle-to-gate	I/O

*Industry, academic and government

**Literature from Deakin University, Melbourne University, University of South Australia etc.

International LCI Databases

One of the distinctive characteristics Life Cycle Inventory efforts in Australia compared to other parts of the world has been the lack of coordination, the minimal representation of industry and the insubstantial detail reflected in the final output in Australian databases, many of which are held in a proprietary fashion and not made public. Consequently, the data collection processes lack coordination, and documentation is variable. In other countries, the process of effectively engaging industry has not only led to a comprehensive Life Cycle Inventory database, but also the process of data collection has informed industry of the value and use of a the database. As a result, it becomes a usable resource for industry and government.

International experiences in developing Life Cycle Inventory databases for a range of products show that it is a time consuming activity, particularly in obtaining adequate and consistent data. Many of the projects have taken years with consequent high costs of collection. The wood products industry in Australia was one of the few able to build on the international experiences in both determining protocols for data collection and Life Cycle Inventory process modelling.

The leading international databases are found in Appendix 3.

LCI Data Availability And Applicability In Australia

As explained in the previous sections, there are many LCI and/or embodied energy/carbon data which are available in Australia and internationally. Some of these focus on building materials, while others include a wider range of products and their environmental impacts. This section reviews these databases further in terms of type and coverage of products, availability, security and granularity in order to determine their suitability for use by precinct design assessment tools in Australia.

Review of Current Sources

Life Cycle Assessment (LCA) results may vary greatly depending on the different LCI models and databases used (see Appendices 2 and 3). This is because each set of LCI data has been developed with different methods, for different purposes, boundary conditions, geographical area, assumptions and data sources. The variance can be large (Suh and Huppes, 2005; Curran and Notten, 2006).

Here we undertake three different types of comparison:

- General (Table 4.6);
- Technical and data quality (Table 4.7); and,
- Data coverage (Table 4.8).

The general comparison covers the purpose, provider/developer, number of data items, indicator coverage (full LCI or just single emission inventory e.g. CO2), source data and its availability (Table 4.6).

Table 4.6: General overview of LCI/embodied data which are available in Australia

DB	Purpose	Provider	Unit	Data #	Cover-age	Data source	Usability
AusLCI	National LCI	ALCAS	Emission/SI unit (kg, m2 etc.)	<30	LCI	Industries, academic research	Open
Austral-asian LCI	LCI for SimaPro software	Life Cycle Strategies	Emission/SI unit (kg, m2 etc.)	<100	LCI	Academic research and industry	Open
BP LCI	LCI for build-ing products	BPIC*	Emission/SI unit kg, m2 etc.)	<50	LCI	Industry	Open
CRC CI LCI	LCI for LCADesign tool	Equate	Emission/SI unit (kg, m2 etc.)	<100	LCI	Academic research	Open with licence
FWPA embod-ied carbon	Emb. C for AccuRate	FWPA via Hearne Scientific	Kg CO2e/SI unit (kg, m2 etc.)	<70	Emb. C	Academic research	Open
FWPA LCI	LCI for timber products	FWPA	Emission/SI unit (kg, m2 etc.)	<10	LCI	Industry and academic research	Open
RAIA	Emb. E for building products	RAIA**	MJ/SI unit (kg, m2 etc.)	<100	Emb. E	Academic research	Open
Others	Emb. E for building products	Various (mostly academic)	MJ/SI unit (kg, m2 etc.)	<100	Emb. E	Academic research	Open

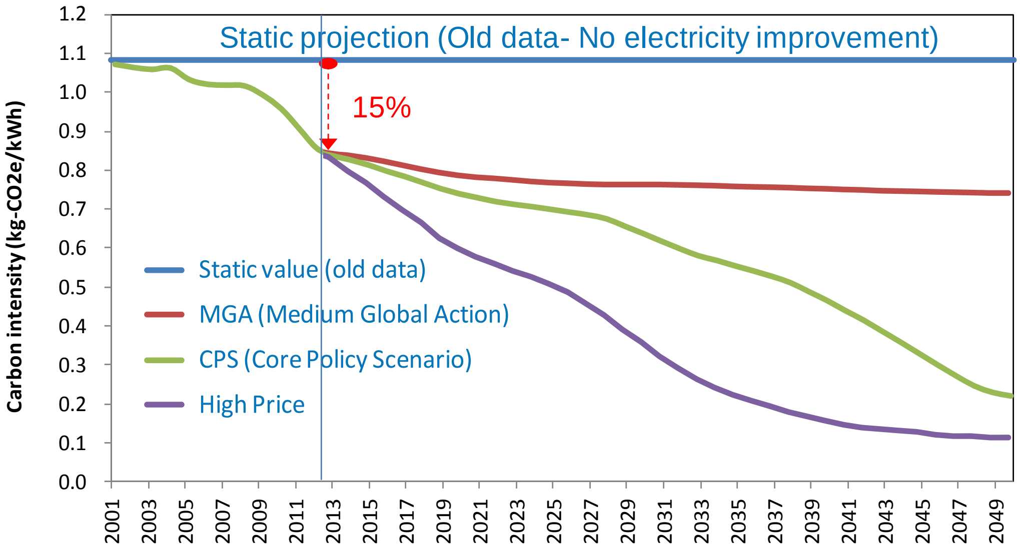
*Building Products Innovation Council

**Royal Architecture Institute for Australia

(Seo 2012)

Technical and data quality comparisons are in Table 4.7 and illustrate the major reasons why LCA results may vary depending on the LCI database used. Some cover cradle-to-factory gate, while others cover full life cycle (e.g. cradle-to-grave); different life cycle boundaries can cause different results in LCA. Also, the results can vary depending on the data quantification approach used: process, I/O, or combined process and I/O (called hybrid). Comparisons in this area have been made by Crawford and Treloar (2004) and Acquaye et al.(2011). Discrepancy of LCI results is also related to data age, since recent technology is typically more energy efficient and carbon intensity of power is declining (see Figure 4.3). Depending on the different scenarios, future carbon intensity could vary from 14% to 80%.

Figure 4.3: Variation of carbon intensity of power generation in Australia



Medium Global Action: Stabilise GHG at 550 ppm by 2100

Core Policy Scenario: 550 ppm stabilistion and 5% cut on 2000 by 2020 and 80% by 2050 (A$23/ton CO2e in 2012-13, rising 5% per year plus inflation for two years

High price: More ambitious 450 ppm stabilisation target and 25% cut on 2000 by 2020 and 80% by 2050. A$30/ton CO2 in2012-13, rising 5% per year with inflation for two years

Source: The Treasury (2011)

Table 4.7: Technical and data quality of LCI/embodied data availability in Australia

Database	Bound-ary	Method	Data Age	Alloc-ation	Techno-logy	Uncert-ainty	Standard-isation
AusLCI	C-to-g* C-to-G**	Pro-cess	2000-10	Yes	Yes	Yes	ISO 14048
Austral-asian LCI	C-to-g*	Pro-cess	1995-2005	Yes	Yes	Yes	ISO 14040/44
BP LCI	C-to-g*	Pro-cess	2010~	Yes	Yes	Yes	ISO 14044
CRC CI LCI	C-to-g*	Pro-cess	1995~ 2005	N/A	N/A	N/a	N/A
FWPA embod-ied - carbon	C-to-g*	Pro-cess	2000-05	N/A	N/A	N/A	N/A
FWPA - LCI	C-to-g*	Pro-cess	2008-09	Yes	Yes	Yes	ISO 14048
RAIA	C-to-g*	Pro-cess	1990-95	N/A	N/A	N/A	N/A
Others	C-to-g*	I/O		N/A	N/A	N/A	N/A

*Cradle-to-gate (factory)

** Cradle-to-Grave

Finally, product coverage is shown in Table 4.8, listing the range of materials categorised by usage domain.

Table 4.8: Product coverage of LCI/embodied data available in Australia

Group	Material	LCI database (including embodied data)							
		AusLCI	Austral-asian LCI	BP LCI	CRC CI LCI	FWPA emb.C	FWPA LCI	RAIA	Other**
Agricultural	Fertiliser		✓						
	Pesticides		✓						
	Plant								
	Others		✓						
Chemical	Acids		✓						
	Organics		✓						
	In-organics		✓						
	Others		✓						
Construction	Binders		✓		✓	✓		✓	✓
	Brick			✓	✓	✓		✓	✓
	Concrete		✓	✓	✓	✓		✓	✓
	Covering			✓		✓		✓	✓
	Insulation			✓	✓	✓		✓	✓
	Paint				✓	✓		✓	✓
	Sealing				✓	✓		✓	✓
	Others			✓	✓	✓		✓	✓
Wood	Wood			✓		✓	✓	✓	✓
Fibres	Fibres								
Fuels	Coal		✓		✓				
	Oil		✓		✓				
	N. gas		✓		✓				
	Renewable								
	Others								
Glass	Glass		✓		✓	✓			
Metals	Alloys		✓		✓				
	Ferro		✓	✓	✓	✓			

Group	Material	LCI database (including embodied data)							
		AusLCI	Austral-asian LCI	BP LCI	CRC CI LCI	FWPA emb.C	FWPA LCI	RAIA	Other**
	Non-ferro		✓	✓	✓				
Minerals	Minerals		✓						
Plastics	Plastics		✓		✓	✓			
Paper	Paper		✓						
Energy	Electricity	✓	✓		✓				
	Heat		✓		✓				
	Others		✓		✓				
Water	Water								
Transport	Air		✓		✓				
	Rail		✓		✓				
	Road	✓	✓		✓				
	Water		✓		✓				
Building element	Building element			✓*		✓			✓
Building	Residential								✓
	Commercial								✓
	Other								✓
Others	Others		✓		✓	✓			✓

*windows

**some academic researchers focus on building elements, different buildings

AusLCI is the national LCI database. Data is transparent and follows ISO guidelines (ISO 14048). At present, however (June 2013), the products covered in AusLCI are limited to several items (wood, transport and energy). Australasian and CRC CI LCI databases cover a wider breadth of product items. However, CRC CI LCI data lacks transparency in their data development, may now be somewhat out-dated, and doesn't follow any standard for its formatting, meaning that its compatibility for other purposes and tools is low. Australasian LCI data covers broad Australian unit processes, is relatively transparent and follows ISO 14048 format, but its coverage of building and construction material/products is limited – a problem for any application to precinct design tools.

BP LCI, FWPA LCI, FAIA and other academic databases are more focused on building material/product than other manufactured products. RAIA data is frequently used by Australian industry for their embodied energy quantification, but its age represents a weakness for many products. On the other hand, BP LCI data, with recently updated FWPA timber LCI data, has increased its breadth of data for building/construction industry application.

Internationally, there are numerous LCI databases that cover more than several hundred processes/products including building material/products (e.g. 3EID, ICE and SimaPro). However, there are several complicating issues when applied in Australia, e.g. monetary unit for 3EID such as kg of CO2/million yen; quantification approach (I/O approach for 3EID and process approach for others). The geographical boundary issue is the most difficult hurdle to overcome, due among other things to vastly different sources of energy used in manufacturing processes (Figures 4.4 and 4.5) that are not applicable in Australia.

Figure 4.4: Energy mix in different countries based on 2008 (based on EIA 2011)

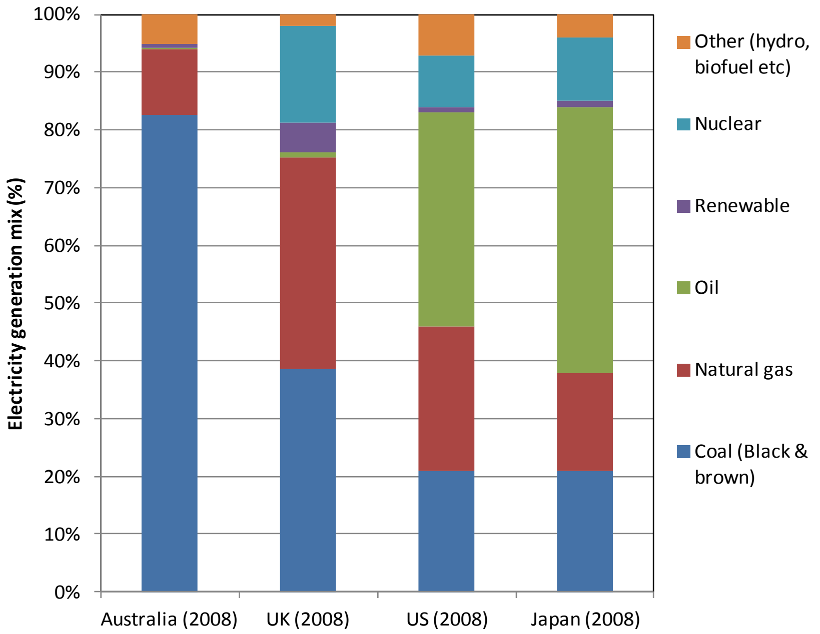
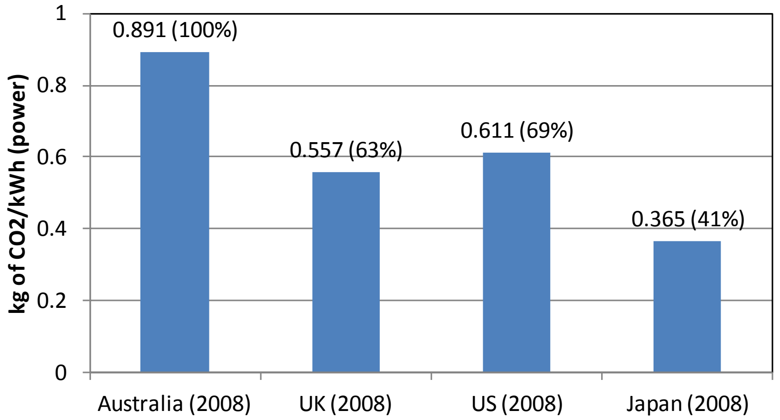


Figure 4.5: Carbon intensity of power generation (1kWh) in different countries 2008 (based on EIA 2011)

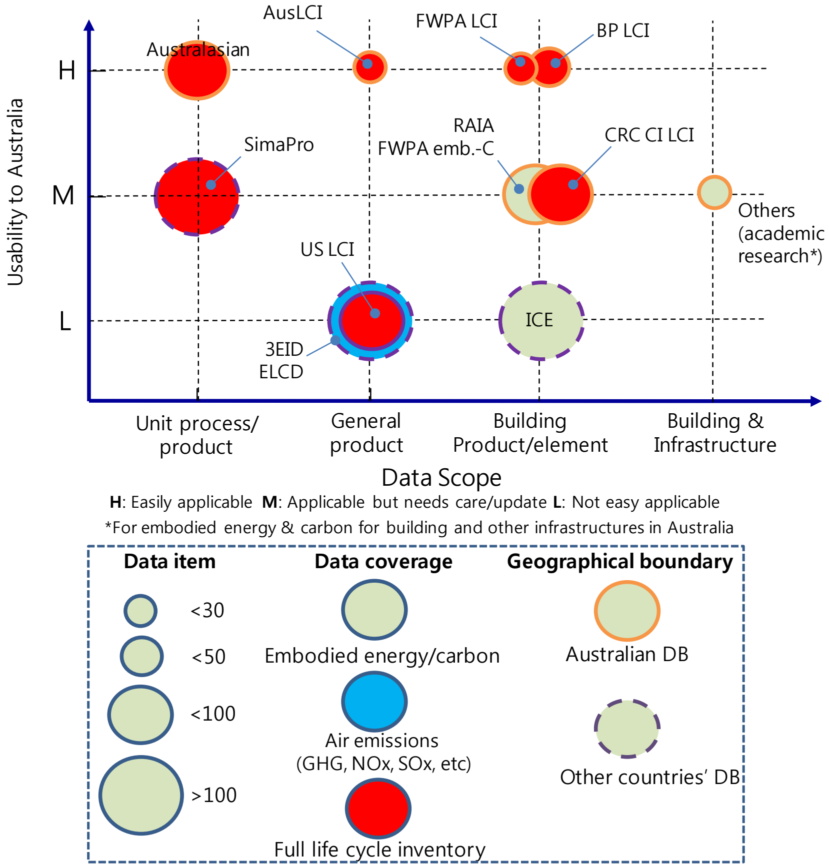


Of the international LCI databases, SimaPro contains data on most basic processes, with a European context rather than Australian. Since SimaPro data has process-based inventories of many common systems, these unit processes can be compiled into modules of information by a user to create a customised inventory. This means that a user can create data by replacing a basic unit process with an Australian unit process. This is referred to as "Australianised" data, but still requires some caution in data usage due to technology, data age and other issues previously discussed.

Usability of Current LCI Sources in Australian Precinct Design Tools

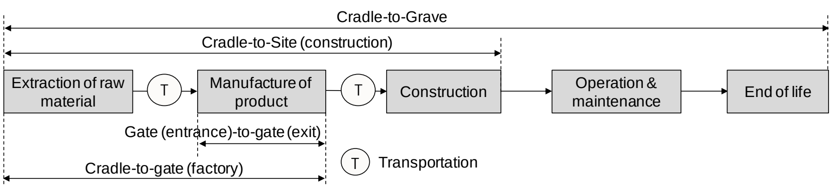
Figure 4.6 indicates the applicability of selected LCI databases to built environment assessment in Australia, taking into account their scope, data coverage, boundary conditions and geographical coverage.

Figure 4.6: Usability of LCI/embodied databases to Austalian precinct design tools



One of the key considerations of LCA or embodied carbon assessment is the system boundary. For the purpose of analysing LCA of a building or a building product, the system boundary always starts from the very beginning of the life cycle, i.e. extraction of materials. But the boundary will end in different stages depending on the goal and scope of the assessment. A system boundary has to be set up to cover the production processes in all involved life cycle stages. Within the boundary, a quantity of materials and energy is used and subsequently a certain amount of pollutants including GHG are emitted. Figure 4.7 shows different types of system boundary for building, which can be classified into several types.

Figure 4.7: Different system boundaries in life cycle of building/precinct



Most Australian LCI or embodied energy/carbon databases have been developed using Australian contextual information (energy mix for power, locally available technologies etc.) which make them fundamentally applicable to Australian tools and applications. However, each has comparative strengths and weaknesses. For example, AusLCI was initiated as a national LCI database and consequently has good structure. However, AusLCI has limited items (less than 30 and mostly in the energy area). It doesn't cover building material components and products. Australasian LCI database covers more than 100 items and provides full input and output information of process and data, but it has limited cover of building items and precinct components. To be usable, it needs to develop precinct components using Australasian database. By way of contrast, the BP LCI database covers a considerable number of building products used in the Australian construction industry, but it is a dataset restricted to gate-to-gate input and output data (see Figure 4.7). This dataset needs to link to other datasets that provide data on earlier stages in the manufacturing process (e.g. cradle-to-factory gate). FWPA timber LCI database covers full life cycle of timber products (cradle-to-gate (factory) in Figure 4.7). Being limited to timber products, it covers few building items.

RAIA, FWPA embodied carbon database and the CRC CI LCI database are largely focused on building materials and products. Nevertheless, these tools are ranked "M" for their usability (Figure 4.6), which represents "Applicable but needs care/update". This is because these databases have some hurdles to overcome in their applications. For example, RAIA provides embodied energy data for many building materials and elements but the database relates to 1990s manufacturing and energy technologies. CRC CI LCI and FWPA embodied carbon data also cover many Australian building material products, but these have not been reviewed by a third party and therefore lack transparency of data analysis.

There are local academic research datasets that evaluate building or other urban infrastructure and therefore have some application to Australian precinct tools (Troy et al. 2003; Pullen 2009) but are limited in scope.

As previously discussed, many overseas LCI/embodied energy/carbon databases are not easily applicable to Australian tools. They have been developed for specific purposes (e.g. national LCI database – US LCI and 3EID), and have different geographical contexts (e.g. ECLD for European common database; ICE embodied databases). SimaPro database covers a large range of unit processes and products but it does not encompass precinct components. Like the Australasian database, it can be made applicable for use in Australian precinct tool assessments by developing precinct component data using SimaPro internal database.

Table 4.9 provides a summary of the limitations and hurdles for existing LCI/embodied energy/carbon databases and the requirements to become directly applicable to Australian precinct assessment tools.

Table 4.9: Hurdles and limitations of existing LCI databases and requirements

Database	Hurdle/Limitation	Requirement
AusLCI	limited items Not cover precinct components	Increase coverage for precinct components
BP LCI	Gate-to-gate	Need to full life cycle (cradle-to-gate)
FWPA LCI	Limited items (only timber products)	Not individual database, it needs to integrate with other database
Australasian	Doesn't much cover building products Not cover precinct components	Increase coverage for precinct components
RAIA	Outdated data	Need to update data Need to cover precinct components
FWPA emb. Carbon	Lack of transparency	Need to increase its transparency Need to cover precinct

		components
CRC CI LCI	Outdated data Lack of transparency	Need to update data Need to increase its transparency Need to cover precinct components
Others	Limited items Mostly specific cases	Increase items Can be applicable in the same condition (climate, building type etc.)
US LCI	Different geographical boundary	Not applicable
3EID	Different geographical boundary Different unit (monetary base)	Not applicable
ELCD	Different geographical boundary	Not applicable
ICE	Different geographical boundary	Not applicable
SimaPro	Doesn't much cover building products Not cover precinct components	Increase coverage for precinct components

Pathway For Applying LCI Data To Precinct Objects And Precinct Design Assessments

To deliver a life cycle assessment capability to precinct design will require development of a clear definition of precinct objects and their constituent elements capable of being linked to specific LCI data items (in one or more of the LCI databases with appropriate information). This data would then be aggregated to provide performance metrics at precinct scale in the relevant thematic areas (e.g. energy, carbon, water, materials or waste).

Some tools (e.g., Mutopia, PrecinX etc) have embedded LCI data attafched to a selected set of precinct objects. However, a detailed and comprehensive dictionary of precinct objects and their LCI profiles does not exist, but needs to be created (see Chapter 5). A nested process is envisaged commencing with 'land use' as the highest level classification. Successive links are made until a spectrum of precinct objects are identified and defined in a manner that facilitates connection to LCI data, whether detailed LCI data for those that have a high degree of details and schematic LCI data for others. For example:

Table 4.10: Examples of precinct objects to hold LCI data

Classification	Precinct Object	Data
Land use	Built Facility Type (building etc.) Network Type (road, transport etc.) Manmade Landscape Type (Park etc.) Etc.	Schematic LCI data (e.g. kg of CO2-e/m2 of residential building)
Built Facility Type	Commercial (Retail, Office etc.) Residential (Detached, semi-Detached etc.)	Schematic LCI data (e.g. kg of CO2-e/m2 of Detached house)

	Etc.	
Commercial/ Residential	Structural/Element Type (concrete slab, glass curtain wall etc.) Etc.	Detailed LCI data (e.g. kg of CO2-e/m2 of glass curtain wall)
Structural Type	Product Type (concrete, cement, timber, etc.) Etc.	Detailed LCI data (e.g. kg of CO2-e/m3 of concrete, kg of CO2e/kg of cement)
Product Type	Material Type (gravel, sand, plastic etc.) Etc.	Detailed LCI data (e.g. kg of CO2-e/kg of gravel)

A PIM data model to support precinct analysis is described in Chapter 5. For the purpose of this Scoping Study, it is a tentative model that encapsulates the types of precinct objects discussed in this chapter to support life cycle analysis at the precinct scale. The development of the dictionary of precinct objects discussed in this section needs to be undertaken as a CRC research project in its own right, addressing the many issues identified with respect to existing LCI databases. In order to ensure data interoperability, the PIM data model must be developed at the same time to ensure that the resulting LCI data, as well as other appropriate reference data, can be accessed by any precinct analysis tool that interoperates with that PIM data model standard.

Information Platform for Precinct Design and Assessment Applications

5. Information Platform for Precinct Design and Assessment Applications

This chapter reviews the role and impact of precinct information modelling (PIM) in the context of precinct design and assessment as exemplified in the four assessment tools reviewed in this study. It begins with a brief review of techniques and approaches to precinct-scale modelling and, in particular, efforts underway to bridge the gap between GIS modelling and analysis techniques and the increasing adoption of BIM technology in the design, delivery and management of buildings and infrastructure. This is followed by an analysis of the general operational structure of the four precinct assessment tools, leading to a more detailed analysis of the way precincts are modelled and the types of information objects manipulated in each tool. From there, a preliminary precinct data model is proposed as an example to illustrate how a common information structure could be defined that encapsulates not only the set of concepts defined in each of the four exemplar tools, but also provides a link to the LCI data discussed in Chapter 4 and used commonly in the assessment metrics for precincts.

In order to clarify how such a precinct data model could be employed, a simple example based on a hypothetical greyfield development is described. The chapter then concludes with an outline of the key principles that must be upheld or addressed in the development of a comprehensive PIM data model that will support precinct assessment within a broader context.

Current Local and International Precinct Modelling Initiatives

The focus of this Scoping Study is on precinct assessment, but in order to carry out any kind of computer analysis of performance there must be a computer model of the precinct. The first issue that arises for all the precinct assessment tools reviewed is the disjunction between the computer model used to carry out the assessment and that used to represent a proposed precinct design from an urban design perspective.

A concept common to all four assessment tools reviewed in terms of their representation of a precinct for analysis purposes is that of “location”. PrecinX does this indirectly by setting a project location and linking reference data and analysis to that. The other three tools all utilise geo-located graphic data via GIS functionality. Since GIS is fundamentally a relational database technology (albeit with object spatial extensions), the applicable semantics (schema) for a project implementation are open-ended, user-definable and variable, but the underlying database system technology is tried and proven. In the context of planning and design organisations, the software most frequently used to model design options (which are to be the subject of the sustainability assessments) is traditional layer-based computer-aided drafting (CAD) or, increasingly, object-based building information modelling (BIM) software. The same type of software is then used to take those options forward into fully detailed designs, once the analysis is complete.

Although GIS and BIM are both, in essence, data repositories for spatially defined objects, the difference in the way those objects are represented is not solely related to the scale of representation: GIS technologies, when dealing with regions and precincts, generally work at a coarse level of granularity, while CAD and BIM deal with buildings and their interiors (see Figure 1.3). As already noted, the information schemas (the way the information is represented and linked) are fundamentally different. The literature shows that within the last decade there have been initiatives from both spatial representation perspectives to blur the boundaries between them.

One group of initiatives concerns expanding the extent of entities modelled using the available data structuring mechanisms of the relevant platform. In scale terms, the most obvious boundary across which geographically-based and building-based information occurs is at the level of cadastral lot. For the building designer, a lot is the legal site on which to build. For the planner, precincts and larger zones ultimately are composed of lots and other land uses. The GIS community has proposed extensions down to more detailed (spatial) elements, while BIM advocates have proposed extensions upwards to geographic features. From GIS, the BISDM – Building Interior Space Data Model Version 3.0 – schema models GIS features down to the level of interior spaces to take advantage of GIS locational and topological functionality to support use cases such as space analyses, evacuation routing, way-finding and facilities management (Rich et al. 2011). From the BIM side, the CI-3 IFC Extension project for GIS (Espedokken 2011) proposed extensions to the Industry Foundation Classes (IFC) standard ISO-PAS 16739 to encompass additional concepts related to “property”, which have now been incorporated into the most recent release of the standard – IFC4 (Liebich et al. 2013). This initiative was supported by work undertaken at UNSW under an ARC Linkage Grant (Plume and Mitchell 2011). A related initiative from the BIM side is a project termed InfraBIM, concerned with improving interoperability for planning and realisation of infrastructure facilities, such as roads, bridges and tunnels (Borrmann 2013).

Another approach is to extract required subsets of data from GIS and BIM repositories using web technology and “mash” them together using a generic data exchange format. The data exchange, or transport format widely used for this purpose, is XML (eXtensible Markup Language). Demonstrations such as the Open Geospatial Consortium’s Phase 4 GIS/BIM demonstration use this approach to show that one interface can seamlessly correlate data drawn from the two disparate sources (OGC 2007). The web application reads and writes data via a middle tier which in turn interacts with the back-end data repositories. In this way, the web application does not need to directly know anything about the data storage formats, but rather just uses the Simple Object Access Protocol (SOAP) to get and put data. What this implies is that the BIM and GIS data is available on one or more database servers accessible by the middle tier. Relational databases in GIS have provided this capability for some time, but servers for BIM are comparatively recent. The Faculty of the Built Environment at University of NSW has been teaching with, and building applications using, the EDM Modelserver from EPM Technology. The EDM Modelserver is an object-based database server that can hold any data consistent with a schema defined using the Express data modelling language as defined in ISO standard ISO10303-11, IFC being one of these. Other work in this area has utilised an open-source BIM server developed from research at TNO in the Netherlands (Beetz et al. 2010).

This approach is useful and powerful in the context of precinct assessment being reviewed in this Scoping Study, as it provides a general-purpose mechanism to construct and execute queries (requests for data) from a range of different data sources and to collect that together to support an analysis process. However, that only addresses part of the issue: in order to construct the queries, a user must know the structure of the data being collected and those constructs must be purpose-built for each specific data retrieval task (at the “middle tier” described above). There is no agreed structure for the way a precinct is modelled that will allow the development of standardised data retrieval protocols that are able to be used across a range of precinct assessment tools.

One attempt from the GIS perspective to establish an agreed (standard) way of modelling a precinct is CityGML (Gröger et al. 2012). This is an XML schema defined for the exchange of 3D urban models including (simplified) buildings and infrastructure elements such as bridges and tunnels. From the BIM side, IFCXML is an XML schema which implements an exchange format based on the IFC standard for building modelling. Of relevance to precinct-level modelling, CityGML includes a level of detail (LOD) paradigm which allows for a level of visualisation of urban entities including buildings at differing scales of resolution:

LOD0 – regional, landscape

LOD1 – city, region

LOD2 – city districts, projects

LOD3 – building models (outside), landmarks

LOD4 – building models (interior)

De Laat and van Berlo (2011) have tested a proposed GeoBIM extension to the CityGML schema using their open BIMserver. In undertaking that work, they recognise that there are "two different worlds that both try to import the other world into their own". They argue a "need to develop technology to integrate both worlds and create a synergy between the strong (technology) parts of both worlds". The GeoBIM extension is an attempt to extend GIS-based CityGML with IFC semantics and relations. They take the Use Cases from the OGC's Phase 4 GIS/BIM demonstration, test, and report on the issues found in translating from IFC to GeoBIM-extended CityGML (LOD4 only) – they have not implemented a test in the other direction. Issues they report include:

- Some geometry incompatibilities between IFC and CityGML
- Surface textures are rarely incorporated into IFC models and therefore not transferred
- A suggestion that semantic information could remain separate from 3D geometry representation
- A suggestion that binary rather than human-readable text formats for data transfers may be required for performance reasons in web applications.

Again, this is useful in the context of this Scoping Study, as it recognises a need to develop a common representation that uses a semantically-strong, object-based paradigm as a basis for sharing precinct data across different tools and at different stages in the precinct development process.

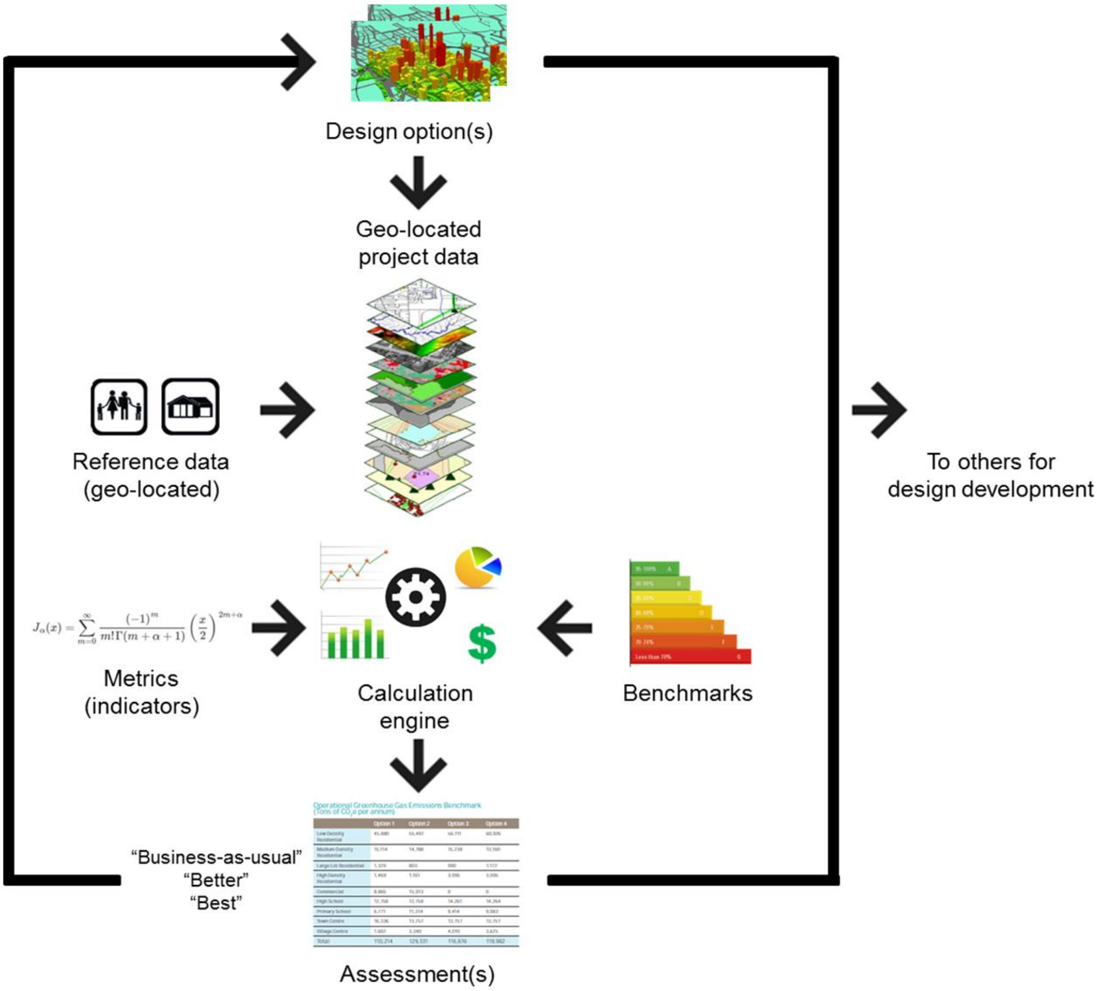
Other work related to precinct and larger urban scale data is not necessarily compatible with data formats useful for sustainability assessment. Alternative focus areas (and software) include visualisation and simulation, stakeholder engagement and parametric design. Exemplar research work in these areas includes the ETH Future City Simulation Platform (Halatsch et al. 2010); parametric shape grammars associated with the development of Masdar City in Abu Dhabi (Grêt-Regamey et al. 2013); urban data integration (Wang et al. 2007) and (Becker et al. 2011); parametric energy and resource flows in buildings and urban environments (Geyer and Buchholz 2012); ontologies as a means to provide a metadata layer on top of disparate urban datasets (Schevers et al. 2006 and Falquet 2011); gaming and virtual reality (Isaacs et al. 2011, Franklin et al. 2006, Phillips and Counsell 1996). There are also numerous commercial software applications in the urban simulation and visualisation area but these are not directly relevant to a low carbon agenda.

A list of research and other organisations associated with work in this domain is included in Appendix 4.

Operational Structure of the Current Assessment Tools

This section reviews the operational structure of the four precinct analysis tools developed in-house by the CRC partners and used to assess the sustainability aspects of proposed precinct designs. From an information and technical implementation viewpoint, there is much in common across all four software packages. It must be noted, however, that some partners prefer to view their tools as "a methodology for sustainable systems integration" rather than just software: the process of integrating technology-based assessment with design procedures is seen as the key strength of their approach, not just the tool itself. Figure 5.1 shows the conceptual structure of the process and operation of the four tools, inferred from our observation of each tool. The figure seeks to highlight the fact that each tool has essentially the same conceptual structure, though they may vary in the way that is implemented.

Figure 5.1: Operational structure of the existing precinct tools



At the core of each tool is a set of data for a given project which must be "geo-located". Since assessments of environmental factors are inherently local, they depend on a project being accurately located. PrecinX is based on Microsoft Excel, so its locational specifics are defined via a project location data field which is then used to populate the reference dataset against which the project model can be defined. The other three tools use GIS databases as their underlying data repositories. GIS is differentiated from standard relational databases in that it includes locational functionality natively.

The way in which that geo-located data is represented is discussed in greater detail in Section 5.3. For the purpose of this overview, it is sufficient to understand it as a traditional set of GIS overlays as suggested in Figure 5.1, where features of the design are geospatially located, allowing correlation of the project design with the required reference data using location and topological relations.

The project database will typically consist of one or more design options (or scenarios). A different option means a variation in some or all of the base data attributes. Commonly, there is a "business as usual" option ("reference" in PrecinX), one or more "better" options, and a "best" option. Since PrecinX does not include geometric design information, variations among its scenarios are solely based on numeric data entries, or choices made from pre-populated lookups. For the other three tools, the geometric data – the layout of the design scheme – can be varied among options. This provides for more exploration of innovative design options, where it has been established that 'design innovation' (alternative configuration of spaces, activities etc.) can deliver its own performance benefits in addition to those directly linked to material selection, building and infrastructure technologies etc. (Seo et al 2007).

In design firms, precinct-level tools such as these do not exist in isolation. Other software is used to develop various aspects of a scheme – financial and economic modelling, community interaction and issues tracking, physical design zoning and massing, etc. Similarly, there is handover of responsibility for ongoing design development to others, for example, from land auprecinx

thorities to developers, from developers to design and contracting organisations, and from assessors to designers and vice versa, even in the one organisation. In each case, to avoid excessive and wasteful rework, there is an apparent need for better interfaces between different forms of the data that are of common concern. In Figure 5.1, this issue is exhibited in the feedback loop between design options input and assessments output, as well as in the export to others where knowledge of design context and desired targets would be useful if transferred in usable digital format. This highlights the need for an agreed way of representing this data across all the different stages of the process.

All tools rely on available reference data for the locality in which the precinct is situated – both within and outside the immediate boundaries of the design area of interest. This data includes, but is not limited to, census statistics, services usage, transportation routes and usage, climatic data, financial and cost data such as house sale prices, construction costs, etc. This also applies to data tied to locational entities such as local government areas, or point features like schools, post offices, shopping centres and churches. It also includes data associated with “libraries of types”, for example residential (various standard house and apartment types) and non-residential (commercial, industrial, educational types) as well as construction assemblies and materials. For some precinct locations, there may be gaps in the available reference data. If these gaps need to be filled in order to inform the requirements of a calculation towards a particular decision, then data must be adapted from non-local sources and transformed to suit local conditions (leading to significant potential for inaccuracy).

As explained in earlier sections, each tool identifies a series of indicators (measured in terms of some metric, such as kilowatts per time period, CO2 emissions per dwelling or per time period, etc.). This is handled by the calculation engine component of all four tools. Benchmarks, determined from specific domain expertise, allow for a comparison of how a design option performs relative to business as usual/better/best target levels. In the large consulting firms, these benchmarks are determined as part of the overall service methodology, since those firms are large enough to include specialist expertise in-house who can investigate appropriate benchmarks for the project.

In one sense, the calculation methodology is the proprietary intellectual property component of each tool. Since there is a significant level of trust involved for the consumers of the output results, there is some onus on the tool developers to show that their results are verifiable. Although it can be argued that the “onus of proof” is similar to other forms of professional advice, model validation is of paramount importance and presents as a significant issue in the market (see Chapter 6). For software there are precedents for independent verification and certification: for example, for Building Information Model software, the independent buildingSMART organisation provides a test dataset against which each piece of software seeking certification on its ability to import/export IFC formatted data, can be tested. There are also precedents for the development of standardised algorithms for undertaking specific analysis computations: for example, the DOE2 or more recent Energy Plus algorithm for thermal analysis of buildings. The issue of certification is addressed in Chapter 6.

With that generic overview of the operational structure of the assessment tools, the next section examines in greater detail the specific data model adopted by the four partner tools.

Precinct Model Structure of the Four Exemplar Tools

The four tools reviewed approach precinct assessment in apparently similar ways but the indicators against which energy, water, carbon and other impacts are measured vary across the tools and even from project to project within a given tool. Partly this is due to the varied interests of the stakeholders for a particular precinct development project, and partly due to the availability or otherwise of relevant, appropriate reference data and benchmarks. One of the key statements made by a number of the people interviewed for this Scoping Study was that there is a need for transparency with regard to the way metrics are calculated, and the data which is the basis of those calculations. Additionally, precinct planning does not exist as a task in isolation. It is part of a continuum of urban development from economic modelling through master planning, detail design, construction and use/occupation. At all stages of this extended process, feedback on performance issues informing ongoing decisions should be seen as crucial to more sustainable forms of urban development.

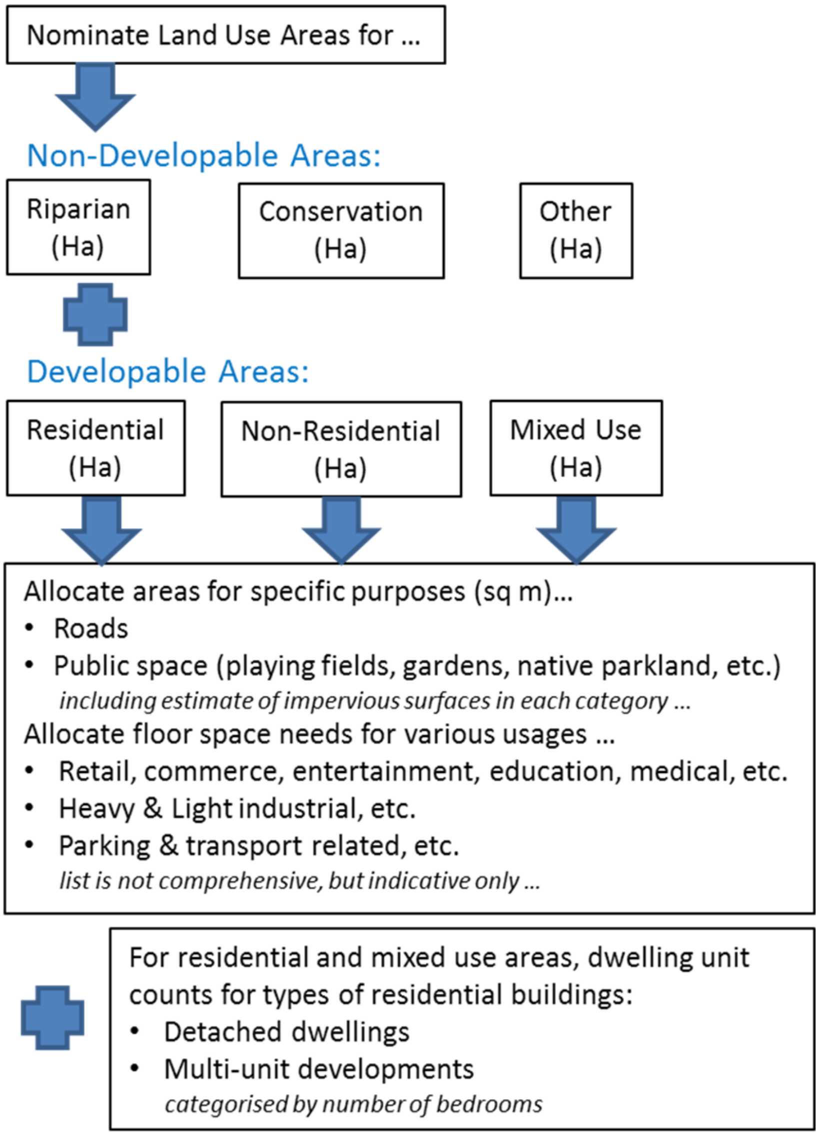
This section reviews the four tools with particular attention to the way they model an urban precinct in order to support their style of analysis. A key issue here is the manner by which the movement of planning and design information is supported through the progressive stages of the process. For example, as discussed in Section 5.2, there is a data re-entry stage when taking a proposed precinct design scheme (prepared by urban design professionals) into the tool, which typically requires the key parameters or features of the design to be translated into measurable parameters that form part of the modelling for performance assessment. Once modelled, those parameters may be able to be adjusted in value in order to test alternate scenarios, but there is no smooth path from design scheme to assessment tool. Similarly, once a preferred solution has been identified, there is no automated mechanism to take that information forward to the implementation phase in that precinct development. We refer to that imperative associated with PIM as information persistence.

The following analysis tracks this information migration process for the four tools reviewed.

PrecinX

PrecinX is essentially a spreadsheet-based, algorithm-rich, application where the model concepts that are used to represent the design are entered as "measurements" in a spreadsheet cell. A project can be entered with 15 to 20 inputs and refined as more detail becomes available over the life of project delivery. Figure 5.2 shows the steps required to build the information model from a design proposal, beginning with the nomination of the major land use areas, and then breaking down the area requirements for the various usage categories within the developable regions. Most of the values are estimated by the tool and pre-populated with default values, allowing the user to overwrite them as needed. The example items listed in the figure are indicative only, not comprehensive.

Figure 5.2: Process steps for creating PrecinX information model



Based on the spatial location of the project, the tool then collects data in relation to a range of “themes” such as transport, embodied CO2, energy and water, as well as local climate, ABS demographics, local tariffs, transport mode split and metropolitan benchmarks. Most of that data comes from reference sources, but the precinct-specific data is either derived from the data described above or entered based on knowledge of the precinct (e.g. under transport, values are entered for distance to nearest regional centre or transport node, local employment, etc.).

It is clear that a user of PrecinX needs to approach the tool with a clear idea in their mind about the mix of development types. That would generally be sketched up in a schematic plan, but no doubt refined as the values are entered in the spreadsheet. If one had a modelling application that allowed a user to develop the schematic plan as a 3D object model, then an automated process could populate the spreadsheet directly. In terms of precinct objects required for that process, it would include:

- Geographic regions to represent each of the categories of land use: each would be defined as a spatially-located closed boundary and tagged with the land use type and other required data (e.g. roads and public spaces need a measure of impervious surface area; areas assigned for residential development need number of dwellings and bedroom count).

- Constructed facilities with floor space requirements: at this stage in the urban development cycle, these only need to be placeholders (spatially located) with an allocated floor space requirement.
- The road network is required to calculate length of roads and some distance measures: this would be modelled as nodes and links (overlaid on the roadready to goway reserves).

A PIM could be constructed that contains a precinct model represented using those three entity types. The output from PrecinX is a set of graphs and calculated indicators. In information modelling terms, that could simply be attached as a report document to the proposed precinct design model. More usefully, the calculated performance indicators could be attached as performance requirements to specific entities in the PIM and then taken forward to the design development phase. In that way, as those precinct entities (represented in the schematic design as placeholders only) are instantiated with design solutions, those can be analysed and tested against the planning intent for that particular facility.

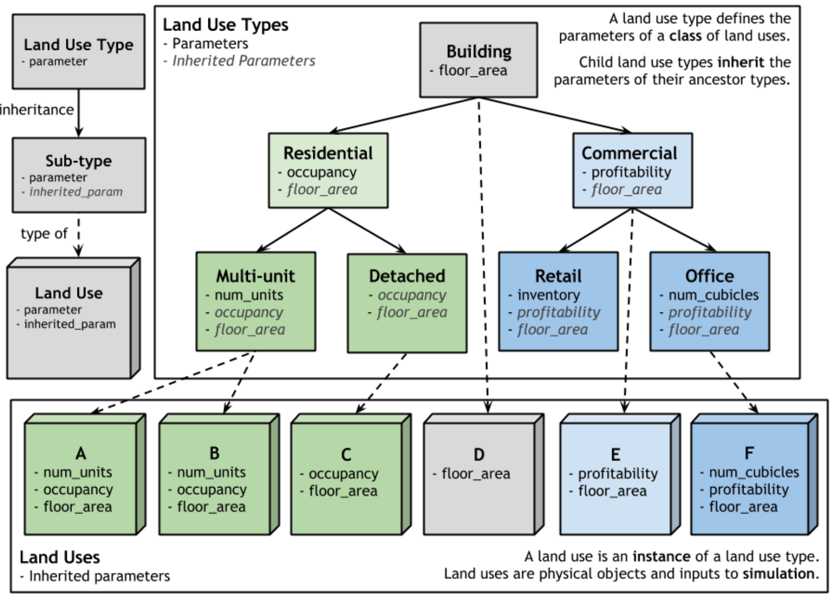
MUtopia

MUtopia is a custom-built web application utilising Google Earth and WebGL platforms for 3D rendering, and is capable of importing spatially-located design entities from a variety of file formats. Importing is made relatively easy because the internal model structure is based on a single geometric entity construct (termed *Land Use*) that is used to represent (visually) any one of a long list of precinct objects. Each geometric entity has a name, description, footprint (polygon or list of X-Y points), elevation, height, colour properties, number of storeys and a *Land Use Type*. A *Land Use Type* represents a collection of additional Parameters that form the mathematical model. New land use types can be created as needed and organised by the user into a hierarchical semantic structure. For example, the user might create a broad category of *Land Use Type* such as *Building*, and then break it down further to *Residential* and *Commercial*, and so on as needed, adding more specific *Parameters* along the way.

Figure 5.3 shows part of a typical MUtopia precinct model, with a small hierarchy of *Land Use Types* and some examples of *Land Use* entities of those types. The arrows illustrate the flow of *Parameter* inheritance.

In order to carry out the analysis related to precinct components such as transport, waste and energy demand, MUtopia allows the user to provide input values for each *Parameter*. *Land Use Type* inputs apply to all *Land Uses* of that *Type*, but may be overridden by more specific *Land Use* inputs. These input values may be plain numbers or mathematical expressions that reference other parameter values (similar to an Excel spreadsheet). The *Parameters* provide a very flexible way to associate reference data drawn from other data sources with a *Land Use Type*. In one example provided, each residential type (detached, attached and multi-unit) had two parameters for the number of that type across the precinct and the average GFA, depending on the number of bedrooms. That data could be entered by the user from an external source and used in metrics for transport, waste, energy (supply and demand) and water. Since the entire precinct can be treated as a *Land Use* entity, with an associated *Land Use Type*, parameters can be created to capture precinct-specific data (e.g. under the transport theme, parameters were created for indicators like distance to job hub or transport node, walkability score, etc.).

Figure 5.3: Example of a typical MUtopia Information Structure



Source: MUtopia Presentation

As with PrecinX, a user approaches the tool with a design proposal in mind, imports the geometry of required precinct features, and then is able to adjust parameters (such as elevation and height) within the tool. The flexibility of the tool allows MUtopia to be customised by the user to support a very broad range of assessments and provide many types of reports. For example, one assessment undertaken displayed the proposed buildings (represented only by their footprints and height) by adjusting their height and colour to visually highlight energy use.

In terms of precinct information modelling, the requirement for importing and exporting the 3D model data is very straightforward because it works with only one geometric form. On the other hand, the very flexible internal mechanism to create a unique semantic hierarchy for each project could conflict with a standardised approach to share the design model using an open PIM standard since every project may have its own unique semantic hierarchy created at the whim of the application user. Standardised hierarchy templates could thus be adopted to facilitate compatibility between projects.

SSIM (Stage 1) and LESS

For the purposes of this discussion, both these tools may be treated together. Though they each have their own distinctive (proprietary) methodology for analysing precinct performance, the underlying modelling is based on standard GIS database technology and concepts. Precincts are represented using a well-defined set of high-level entities:

- Geographic regions are represented as spatially-located polygons with a defined set of properties, including a name and description.
- Precinct features, such as buildings or points of interest (post office, school, etc.) are represented as geospatially located points, again tagged with a name and other properties. For visualisation purposes, 3D GIS technologies allow such features to be rendered as 3D forms.
- Precinct network systems, such as road networks or the route of a natural waterway, are represented as nodes and links, again with names and other properties attached.

These entities are typically organised into thematic layers that can be selectively manipulated. For example, all post offices may be held on a single layer or, more generally, all community service entities (schools, hospitals, police stations, etc.) may be collected on to a single layer.

The way each tool classifies the entity types varies enormously, not only across tools, but even across projects using the same tool. For example, on a specific housing precinct master plan provided as an example for one of the tools, dwelling types were classified as: Low/Med/High density, large lot, rural or mixed use. There are two issues here: the first is the lack of an agreed way of classifying precinct objects in order to capture semantics in a more effective and consistent manner (e.g. when classifying buildings by type, is it more meaningful to distinguish between multi-occupancy and single-occupancy buildings, rather than focus on usage classifications like residential and commercial); the second issue revolves around the terms used to describe building types in an unambiguous way in order to achieve greater consistency in the analysis process (developing an ontology that defines more precisely how we maintain a meaningful discourse on precinct performance, particularly important when establishing shared LCI reference data as discussed in Chapter 4).

The GIS applications tools (like ArcGIS) provide facilities for importing and spatially locating design information from other applications such as AutoCAD or SketchUp, so those are the tools generally used by designers for creating a proposed design solution. Reference data is typically held in formats that can be pulled into a GIS information model, so as long as appropriate raw data is available. An analysis expert can assemble the information and negotiate with the design team (plus the client and other stakeholders, where appropriate) to establish indicators and metrics to be used in the analysis. The output from these analysis processes are typically reports, graphs and precinct visualisations.

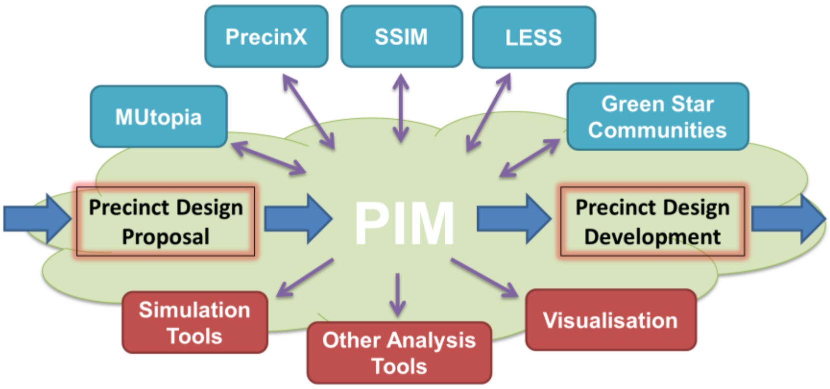
Developing A Shared PIM Schema

The view emerging from this Scoping Study is that all the reviewed tools/methodologies (and any future ones which may emerge) could benefit greatly from a common, and open, object model – not a new piece of software developed from within the CRC, but an information “standard” that establishes the way precincts are modelled for the purpose of assessment at whatever stage of development. This is what we refer to as a Precinct Information Model (PIM). The PIM includes urban-level entities and features as well as infrastructure and services, buildings, landscapes, including the materials from which all of these entities are composed. Furthermore, the PIM needs to include abstract conceptual entities that relate to the way precincts are managed in the analysis process: examples might be “projects”, “scenarios”, “targets”, “requirements”, “benchmarks”, “formulae” and “ownership”. Finally, it must also encompass the set of possible “relationships” and “properties” commonly associated with precinct entities.

Figure 5.4 illustrates the context of PIM, providing a modelling schema that can take a precinct design proposal coming from an urban designer, make it available for input into a variety of precinct assessment tools and then, once agreed, move forward into the precinct development phase.

The PIM is a formal definition of information constructs. As already discussed, there are existing standard information models that address aspects of the envisaged scope of the PIM – CityGML for urban visualisation, BIM for buildings, and other GIS standards endorsed by the Open Geospatial Consortium (OGC). The research required to develop a shared PIM schema involves integrating and extending these, particularly from the additional perspective of “low carbon”; to test and validate the PIM protocol from all angles and via as much relevant software within its scope as possible.

Figure 5.4: Precinct information model context

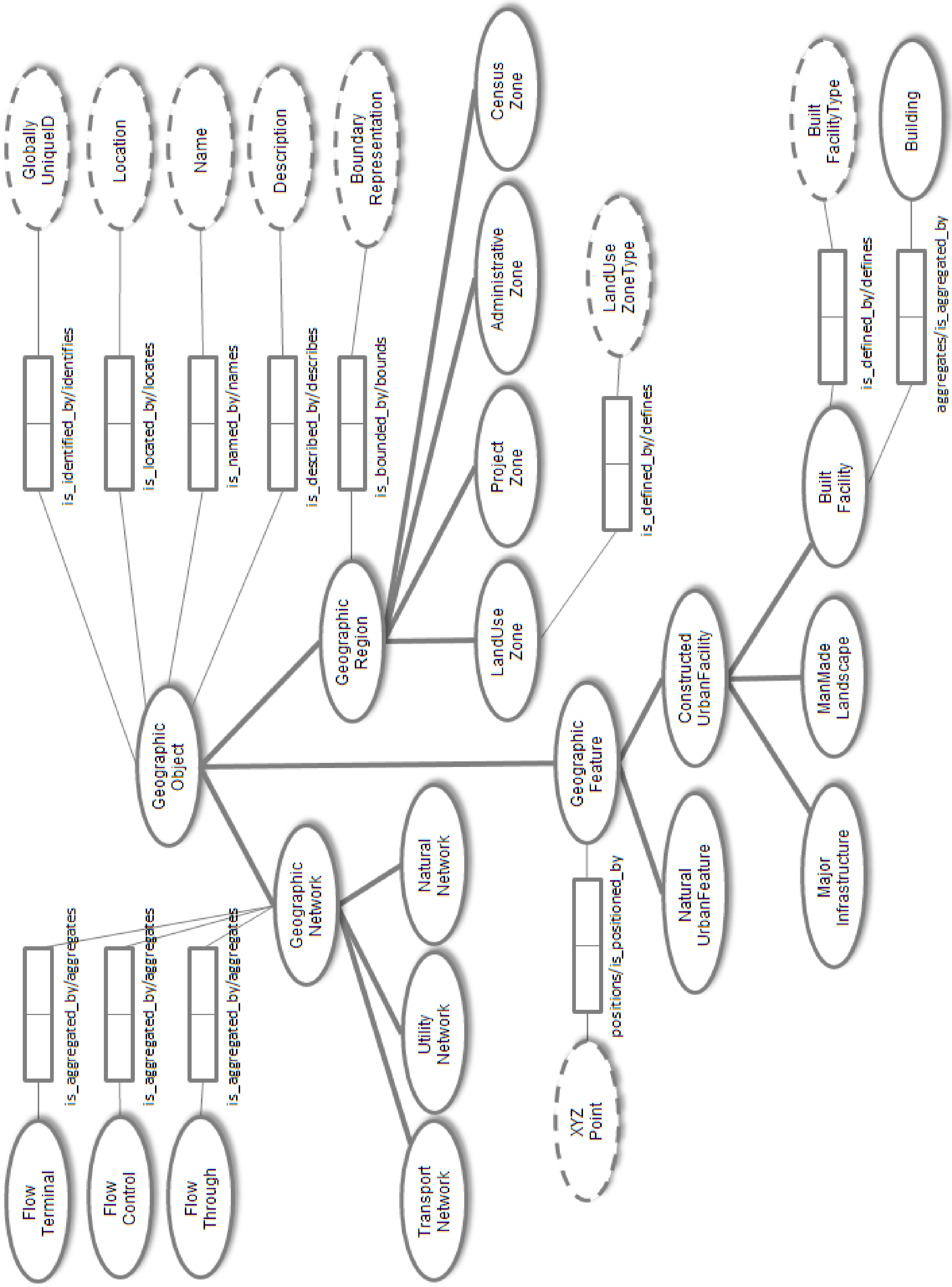


A partial PIM schema that would encompass the four exemplar tools described above is illustrated in Figure 5.5. What is proposed here is a preliminary model used to illustrate the range of concepts that a PIM schema might encompass. A fully-agreed schema would require rigorous discussion and testing, involving many stakeholders and several iterations of the schema design to ensure that it was conceptually correct and useful. That is why a longer-term PIM project is recommended (see Chapter 7).

Physical Precinct Objects

The concept of Precinct captures the entirety of a locality that is subject to analysis and would be represented by a Geographic Region (giving it inherited attributes such as name, description, location and geometric form). It would have additional attributes that relate to its function as a development region, such as client name, administering authority, list of statutory authorities with oversight of the precinct. This has been shown in Figure 5.5 as a type of Geographic Region called ProjectZone, depicting an urban precinct that is being developed as a project.

Figure 5.5: Partial PIM schema suitable for precinct assessment



There are three primary physical precinct object concepts, Geographic Objects, that encapsulate the way precincts are modelled or represented in the four tools reviewed.

- LandUseZone – this concept captures the need to define various types of sub-regions that have a common set of characteristics, again represented by a Geographic Region. Attributes might include name, description, etc. It would be linked to a LandUseZoneType object, with an enumerated list of types such as natural landscape, public open space, residential zone, commercial, industrial. Other classes of Geographic Region that capture different ways of viewing urban regions would include AdministrativeZone (an urban zone defined by a governance structure) or CensusZone, particularly given the need to link these tools to external sources of reference data.
- ConstructedUrbanFacility – this concept captures the need to identify proposed constructed precinct objects that must be provided in the precinct and have location and property values associated with them that are necessary to support precinct assessment. There is such a complex set of urban entities that this is likely to be part of a class hierarchy of concepts. For example, it may sit alongside an object class called NaturalUrbanFeature, belonging to a super-class of GeographicFeature. Similarly, it may be broken down into sub-classes to distinguish entities such as MajorInfrastructure (bridges, tunnels, etc.), ManMadeLandscape (constructed parklands) and BuiltFacility to represent all types of buildings, both institutional and privately owned. This latter concept would be linked to a BuiltFacilityType object to provide an enumerated list of types such as Residential Dwelling, Office, Hospital, School, etc. A BuiltFacility would be an aggregation of one or more objects of type Building.
- GeographicNetwork – this concept captures the need to model connected service networks that involve flows of some kind, perhaps classified into TransportNetwork, UtilityNetwork and NaturalNetwork (plus others), each represented as connected nodes that are spatially located. Though the information needs here to support the four precinct assessment tools are fairly modest, there is considerable complexity required to cover the full range of possible urban systems. There would, for example, be different node component types depending on their function (FlowControl, FlowThrough, FlowTermination) and the same applies to the links. The main use of these information structures in the context of the four tools under discussion is to provide more accuracy when assessing some types of indicators (e.g. travel time and distance measures).

It must be emphasised that the schema described above is very tentative and included here only to provide a sense of how a PIM schema may be constructed. This schema is generally focused on supporting the analysis needs for precinct assessment at a particular stage in the design and development of a precinct, but would need to be elaborated in order to really capture the breadth of concepts required. For example, a fundamental urban spatial concept that relates to land ownership, the cadastral lot, would have to be integrated into this schema for it to be of any use in downstream processes.

Abstract Precinct Entities, Relationships and Properties

The requirement for identifying specific abstract concepts to support precinct analysis was mentioned above. The criteria for determining the need for such concepts in the PIM exchange schema is whether they are required to be transferred to a downstream or parallel process. For example, concepts such as Project or Scenario may not be required if the information model only needs to represent a specific project or scenario as opposed to holding several in one data model. Concepts such as Target, Requirement and Benchmark would be needed in order to facilitate performance checking as the precinct plan moves into the detailed design and delivery phases. The concept of capturing Metric or Calculation as part of a shared PIM raises interesting issues: the MUtopia system has developed their internal information model so that it treats formulae as user-definable and nestable objects used for calculating indicators that may be defined for a specific project. Conceptually, the same is true of all the tools where the formulae are transparently held in spreadsheet-style models. The question for the PIM schema is whether it is important to hold those formulae for some downstream process and therefore include them as part of the PIM schema.

In general, we distinguish between "product" concepts that deal with the physical objects that make up precincts (as discussed in the previous section), "control/ performance" concepts that encompass ideas to do with target, requirements and benchmarks, and "process" concepts that include anything to do with the way projects are managed, so that would encompass ideas to do with scenarios and extend to professional roles involved in processes.

Another broad set of concepts needed to capture the semantics of a PIM are relationships. There are some examples of those shown in the partial PIM schema diagram (Figure 5.5): *defined_by, aggregates, is_bounded_by*, etc. The existing open BIM standard, known as IFC, has several defined relationship types that capture generalised concepts including "assignment", "association", "connection", "declaration" and "aggregation, nesting and decomposition". Most of these have more specific subtypes, for example, a sub-type of the "connects" relationship deals with "spatial containment". It is likely that those existing relationship object definitions cover most of the precinct assessment concepts required, but that would be a matter of further investigation.

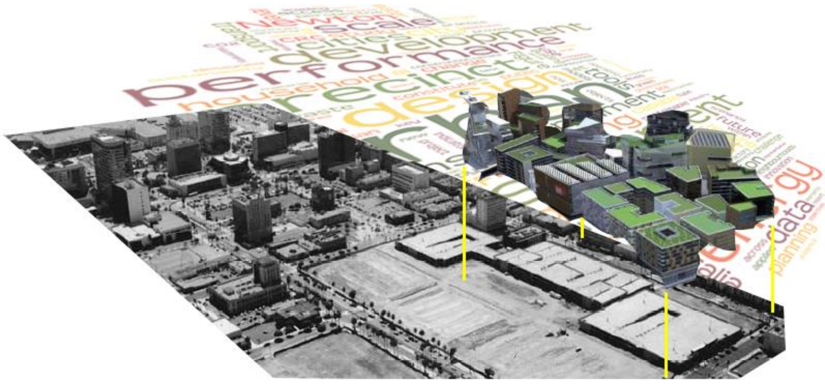
It is envisaged that the PIM schema would use the concept of a "property set" to provide the ability to associate one or more defined sets of properties with any given precinct object. This allows the definition of agreed standard property sets that are required by a domain of interest (in this case, precinct master planning) as well as the inclusion of custom property sets to accommodate information capture to support a very specific application.

Hypothetical Example Of A Greyfield Precinct Development

This section provides a specific, hypothetical example of how the partial schema described in the previous section would contribute to the development of a greyfield precinct. The PIM, based on an open data model, is a formal definition of the information content for a precinct-level model. As such a PIM aggregates, as well as is inclusive of, the detailed constituent entities that make up a precinct.

Figure 5.6 is a diagrammatic representation of a greyfield redevelopment. The base layer shows an out-dated shopping mall surrounded by a sea of grey asphalt (the car park) on the southern edge of a town centre. In this example, a mixed use redevelopment of this precinct is proposed. An information model of the precinct should include everything relevant to its planning, operation and maintenance – if not as one integrated model, at least in parts that potentially can be read together since each is constructed against a common information schema (data definition).

Figure 5.6: A hypothetical greyfield development



For the proposed infill development, there is an existing context made up of objects about which much is known. There are physical entities – buildings, car parking, streets, and landscape elements. These can be deconstructed in information terms into their component assemblies, made up of manufactured products, and ultimately composed from quantities of various materials. In the case where some of these entities are to be removed to make way for the new infill development, the quantity and composition of waste created can be accurately calculated. With reference to the partial PIM shown in Figure 5.5, the buildings are *BuiltFacility* entities, the streets are *TransportNetwork* entities, the carparking and landscape elements are *ManMadeLandscape* entities, and the existing services (energy and water reticulation) are *UtilityNetwork* entities. The identified precinct to be developed is a *ProjectZone* – note that in this sense, a precinct is an arbitrary designated area on which to carry out the proposed project. The *ProjectZone* may be contained wholly within another type of zone (for example a *CensusZone* or an *AdministrativeZone* such as a local government area), or it may overlap several of these. Where reference data is only available relative to local government areas, and the *ProjectZone* overlaps more than one of those areas, an approximation will be required to calculate an appropriate proportion of the reference value from each reference source to be the value for the *ProjectZone* for that characteristic.

Properties of these entities, including geometric representation, may be attached at this gross level (the definition of a core set of relevant properties should be an integral part of the ongoing detailed definition of the PIM). For some levels of analysis (and simulation) this level of information granularity may be sufficient. For example, the “look” of a building can be achieved by attaching a picture (texture map) to a simple geometric mass – a technique used by some existing urban simulation software, particularly where movement through the urban precinct is part of the user interface (and therefore, restricting the number of geometric primitives is important for efficient scene rendering performance). However, in a situation where one or more of the existing buildings has previously been modelled using BIM, or there is an identified need to more closely integrate the new buildings with the existing, and therefore it is decided to create a BIM model for part or all of that existing building, these more detailed entities can be aggregated against the broad PIM entities. Entities at the detail building level include walls, slabs, roofs, doors, windows, spaces. Again, these entities may have geometric representations and other properties. Especially for the low carbon precinct-level assessment agenda, it will be important to define a common set of properties against these entities from which the sustainability metrics can be consistently derived and aggregated. As discussed in Chapter 4, LCI data could be organised to be referenced in a bottom-up fashion – in this example, that would be applicable where detailed material/product/assembly information is available such as for one or more of the existing buildings against which to aggregate quantities of materials used times relevant index value for each material. Or, for the proposed development, that data could be applied as an approximated (aggregated) index value times the quantity (square metres) of a given usage type (residential, retail etc.) or, alternatively, times the quantity of the proposed construction type(s).

Since a greyfield development of this type could have ongoing socio-political ramifications, when communicating with the affected stakeholders in the project – owners, existing tenants, neighbours and municipal authorities – the proponents of the infill development need to be careful to present their analyses and findings in a transparent and verifiable manner. This transparency has a number of implications for a proposed PIM. Is the reference data used applicable in this situation? And, are the calculations made using that data based on formulae which are certified or independently provable? One of the tasks for the development of the PIM schema is to assess the need to provide an entity to contain such a formula within the formal schema (as MUtopia have done in their data model).

There are also virtual entities interwoven in this precinct information model. The shopping mall contains tenancies (both in a legal and a geometrically bounded sense) and these are contained within one or more cadastral lots. A history of energy and water use for these tenancies exists. A history of rental returns exists. A history of changes in occupancy and usage exists. Before any planning redevelopment starts, there are existing planning controls in place – land use zones, and planning envelopes (floor space ratios, building heights and setbacks).

Furthermore, for the proposal, there are stages in its planning containing entities at different levels of resolution. The planning starts with usage layouts (zones), then indicative 3D urban form (block masses). From there it progresses through detailed design (product assemblies), construction (schedules), etc. At each stage, carbon and other assessments are possible only if appropriately granular reference data and benchmarks are available relative to the quantification of entities at the same level of detail (that is, "trustworthiness"). In information modelling terms, there is a progression from existing entities with attributes indicating their current and required states, through entity types, to individual entity instances. For example, a planning zone entity with attributes for land usage (residential) and proposed population (2000 persons), in a next design iteration develops to the instantiation of residential dwelling typologies (attached, detached, multi-dwelling) with quantities for each, and then to the placement of all the individual instances of those dwellings onto cadastral lots. These instances at this stage are still "fuzzily-defined placeholders" for the subsequent individual dwelling designs which follow. In addition, planning and design is not a linear process. Early in the proposal, there may be a number of competing options (or scenarios). Unlike IFC, which currently only has the capability to "snapshot" a single design at a point in time, it is important for the PIM to include the concept of a *scenario*, since very early in the planning of the proposed infill development the design is fluid and we may simultaneously be carrying multiple design versions to be assessed and communicated in parallel for a period of time.

The planning and development and construction process can be lengthy, particularly for greyfield sites where financial investment and returns are often tied to incremental staging, and over this whole period there can be many handovers of responsibility for the ongoing information "bank" associated with that development. This means that it is important to include another type of virtual entity in the consideration of an overall PIM. These entities are those concerned with "intent" and include such concepts as "targets" and "constraints" which act as indicators of design and performance intent for subsequent participants in the development chain. For example, the mixed-use proposal is flagged to achieve a 6-star sustainability rating. At the broad masterplanning level the scheme has been assessed as meeting this target, but this will need to be revisited as more is progressively decided regarding the characteristics of the scheme, and ultimately tested five or ten years after occupation. The target remains as an integral part of the information model, not as an ephemeral by-product. These "intent" entities are instantiated around, and linked into, the contextual physical and virtual entities which exist in the model at a given point in time. They inform the "process" of the development.

What this example tries to show is that the conceptual model (the PIM) is an open data definition, independent of the software tools used to create, manipulate, and utilise/view the entities modelled. The intention of a PIM is that there is a seamless integration of relevant information (conceptually integrated even if physically disaggregated) across all the various scales and viewpoints – there is a place and a semantic context for each piece of information against which a whole range of general purpose, as well as specialised, software can interoperate.

Summary of PIM Development Imperatives and Opportunities

Coming out of the preceding discussion, we can identify several key imperatives and opportunities that will drive the development of the PIM schema to support precinct planning and design that achieves sustainable, resilient, low carbon outcomes. These generally arise directly from the above analysis of the four precinct assessment tools, but are discussed here in the broader context of where those tools are deployed in the design, delivery and management of the built environment.

- Life Cycle Modelling. The focus of the Scoping Study has been on one specific stage in the life cycle of an urban precinct, but there is an identified disjunction as information comes from the previous urban design stage (generally in the form of a CAD drawing) and passes from the precinct assessment phase on to detailed design and implementation. The PIM data model should be developed to facilitate the management of information throughout all stages in the life of the urban precinct, including operation and use and ultimate redevelopment as the cycle continues.
- Geo-Location and Urban Context. In the same way that precinct assessment lies within the life cycle context of an urban precinct, so too in geospatial terms it lies within a wider urban context. This raises several issues. The first concerns the way reference data, which is generally location-dependent, is linked to the precinct. The geospatial entities that are commonly associated with reference data include local government area, census district, planning zone, flood zone, etc. The *LandUseZone* entities that have been postulated in the partial PIM schema defined in Section 5.4 will intersect these spatial entities in complex ways. Similarly, as discussed at the end of Chapter 4, there will be a need to consider how LCI data is associated with the *ConstructedUrbanFacility* entities defined in the PIM. Another issue is managing indicators that relate to urban features that lie outside the precinct, particularly when considering access to service entities like hospitals, transport hubs, centres of employment etc. Most cities have existing network descriptions and databases, with efforts to standardise these to facilitate access. At present, reference data is drawn from these sources to measure access distances in somewhat rudimentary ways in the current tools, relying on the knowledge of the user to select the appropriate reference data. If the PIM data model interoperates with those existing network models, then an opportunity exists to capture the urban context of a precinct as part of a wider urban information model.
- Data Retrieval Protocols. A key aspect of the PIM will be the development of standards that define the way that information is retrieved during any given process. In technical terms, these are referred to as “model view definitions” and are used to manage common information exchange scenarios. A good example of that would be the challenge identified in the previous point, to develop standard protocols for linking to common geo-located reference datasets.
- Alternate Scenarios. A primary feature of all the precinct analysis tools reviewed is the ability to manage different scenarios, or alternate design solutions, each with a measured performance across a set of indicators. The question arises as to how these should be managed. A simple approach would be to treat each as a separate static model (based on the same standard PIM data model), but given the importance of the scenarios to downstream decision making during the development of a precinct, there needs to be some consideration given to more effective ways of managing model versions.
- Transparency and Certification. There are a number of issues that arise around validation of both the data used in precinct assessment and the calculation algorithms employed. This has several implications for the PIM data model, such as establishing a dictionary of agreed terms, especially when linking to reference datasets (as discussed in Chapter 4) to remove ambiguity and increase the comparability of different assessment approaches. A shared, common PIM data model would allow a proposed precinct design to be assessed by a range of tools, permitting a comparative assessment or even certification of the performance of different tools.
- Capturing Design Intent. There is a clear need to develop mechanisms to carry design intentions and requirements forward from the planning and

assessments stages. The goal of precinct planning is to establish carbon performance expectations or targets. A potential benefit of a PIM is the ability to embed those intentions within the model as it progresses to the implementation phase so that there can be a continuous performance assessment undertaken as the design is realised through successive stages of refinement and ultimate construction. This leads to the notion of design auditing and post-construction performance monitoring against the established targets.

- Degree of Granularity. The modelling required to support the four precinct tools discussed in this chapter is quite coarse, but other types of precinct analysis may require more precise modelling of some precinct objects. For example, it may be sufficient to represent a precinct zone tagged for "light industrial" land use simply as a 2D polygon region on a "map", while for more detailed microclimate analysis it may be necessary to model it with building block forms and vegetation objects.
- Visualisation. An issue that surfaced frequently through the discussions with tool developers was visualisation. This is a key issue for precinct modelling, but is seen as a relatively small component of a PIM. There are many city modelling technologies that permit powerful visualisation techniques, including dynamic movement of people or vehicles within a simulated and realistic environment. Such tools play an important role in precinct design, particularly in terms of communication, and those technologies are well developed. The PIM schema needs to support and interoperate with such technologies.
- PIM Scope. The final imperative that has been identified is the need to identify the scope of PIM. To what extent should a PIM support economic modelling, spatial data, building-level details, parametric data or embedded algorithmic models? These are issues that will need to be explored, but really address the boundary between information modelling to support data exchange and persistence and the embedded intelligence within software tools that make use of that information to support precinct analysis.

Conclusion

If we understand that development/exploitation of land is always about change, then at any slice of time taken through that process, there is always a "context" (that is, the known facts, the existing objects, the trail of decisions already taken, and the intentions/requirements/targets informing subsequent stages). The PIM is about defining holistic digital information semantics that provides coherence to the various interests, to eliminate where possible the gaps that exist at handover from one stage of design to the next, thus providing a common level of understanding between software used, and to facilitate transparency. For example, all of the assessment tools in one way or another produce sets of targets (usually in the form of reports) to inform future decision making. These targets ideally should become direct digital inputs to other design and analysis software without the need for manual re-entry (and costly, mistake-prone, double-handling). The PIM is a mechanism to facilitate that sharing and efficiency.

The PIM schema will provide a comprehensive open-source knowledge framework – embracing the whole of the built environment – allowing existing and new technologies to understand, plan and manage sustainable built developments across the diverse users and organisations in communities.

Integrated digital modelling based on PIM will enable innovative solutions to flourish, based on a new integration of the geospatial and building views of the built environment. Core tools can provide access to government and private distributed data repositories, intelligent urban database models, enhanced technologies for 3D visualisation, and new understanding of sustainable urban development. A by-product will be a new capacity for urban portfolio strategic asset management, and a definitive technology for performance measurement and analysis.

Market Perspectives on Precinct Assessment

6. Market Perspectives on Precinct Assessment

Introduction

The five precinct assessment and rating tools that form the focus of this report are part of a larger group of precinct tools that are now being applied in the Australian market. All could still be classed as in their infancy, i.e. development or pilot phase or subject to further review and development.

Building scale assessment tools have won a clear place in the market, after a generation of R&D activity, which continues to the present. In the context of testing the level of interest in the market for precinct tools, and where the CRC for Low Carbon Living should be focusing its attention, 21 senior executives from Australia's leading built environment industry associations, professional associations, government agencies and private companies were surveyed.

Survey

A limited email survey (see Table 6.1 and Appendix 5) was undertaken to complement the interviews with the toolmakers and is summarised in Table 6.2. Its purpose was to use the CRC partners and associated experts linked with larger (precinct) scale property development in a preliminary evaluation of the usage and benefits of assessment and rating tools.

Table 6.1: Profile of organisations surveyed

Organisation type	Number of respondents
Consultant	1
Developer	4
Government Land Organisation	2
Government	5
Industry Association	4
Local Government	1
Tool developer	4
Total	21

Table 6.2: Synthesis of survey responses

Question	Summary
Importance of precinct/neighbourhood design rating/ assessment tools?	Capacity to make a positive impact by: • driving performance • identifying a target • providing a consistent national language – a language known to its audience • assisting tendering, specifying – leads to more efficient process • establishing better precincts by incremental improvement • enabling an integrated approach to precinct planning Limiting factor: • the availability of a rating that is not linked with any mandatory requirement will be limited in its scope. • the resale value of a rating in the residential market is significantly less than other building sectors due to the much smaller returns that are realised by a home owner Demonstrating leadership: • as a voluntary option, a tool can provide those who wish to lead the market.
Who would use?	Planners • developers and planning applicants provide council with (transparent) assessment of applications against benchmarks. • relevant for any agency, utility, council for infrastructure planning purposes Local government • Sees local governments as the logical main user; whoever pays gets the benefits. Community • value should be in the hands of the user. Most users are the community, through local government, poorly resourced and poorly skilled at present. • and to engage the end users on various development options
Are there any tools ready to go?	Rating • GBCA Green Star Communities rating tool best known (being applied to approximately 20 projects in pilot phase) • UDIA EnviroDevelopment less well known but has been applied on over 50 developments, primarily in Queensland • One Planet Living (UK BioRegional) has just arrived in Australia and needs to be tested in local context Assessment • PrecinX was the only tool referenced by the market: used by several state government land organisations (GLOs) and by developers on over 100 projects nationally.
Voluntary or mandated tools?	Voluntary • most respondents indicated this route was preferable • allow the developers (in consultation with agencies, utilities) more flexibility/creativity in determining what outcome they want to achieve for their end users in a particular development • currently no argument by governments being put that there is a market failure. Alignment with government policy

Question	Summary
	• any voluntary tool needs to align with government policy for example if carbon (CO_2e) is used as the metric, aligning it as closely as possible to other government schemes with this metric would provide greater consistency. Mandate • forced adoption does provide role models and case studies.
Necessity of certification and standards?	Standard setting • strong consensus that government and industry see the need for standards • standards unify industry, and make processes simpler. Certification • independent certification is important for credibility • certification can be both informal and formal, but formal certification with 3rd party assessors needed and valued by industry. • there is an attraction – business value to be seen to be certified. • certification drives industry-wide knowledge
GIS+BIM Integration?	BIM & GIS • both BIM and GIS approaches are recognised in the market (if incompletely understood). PIM • how the two interrelate was unclear from the market and was not something that any had a view on Future development • only with significant development/adoption will biggest gains be found
One tool or many in the market?	Market Driven • multiple tools confusing, but currently no endorsement of one particular tool; most respondents thought market will sort this out Next Steps • build on existing tools rather than develop one 'new' tool. It's more about looking at functionality of current tools and where each would be best applied and improved.
Life cycle approach?	Endorsement • widespread endorsement, e.g. full life cycle would be truly useful and revolutionary Qualification • lies in what is measurable or provable.
Basis for endorsement by industry and government?	Demonstrated Need? • from a government perspective, a demonstrated need/lacking in the market; providing an overall net benefit to the community; and being targeted at the right level of government. End user involvement • buy-in from key stakeholders and potential users is crucial Transparency • if metrics are established you can set the benchmark but need to have transparent calculations.
What is missing?	Purpose driven data collection

Question	Summary
	• the tool should be the medium for data improvement, industry-wide.
How to audit carbon?	Reference/benchmarks • starting point should be a BAU or a reference; needs practical benchmarks to compare performance Data availability • embodied plus operating • quality current data Alignment with Global Greenhouse Accounting protocols • Scope 1-3 • lack of greenhouse credits from built environment sector innovations
What opportunities to improve access to precinct information?	Collaboration • working more collaboratively on development planning and understanding options available and things like implications/trade-offs etc. • doing this early in the planning process and in a more integrated fashion. • PIM export could be a control model; PIM instance could be a submission Information/Education • a better understanding of how precincts work to inform future policy development • education for the whole assessment team – local government, planners, designers, developers, residents and users is vital
Role for government?	Responsibility • there is a mixed response as to where responsibility lies between the three tiers of government in relation to urban development assessment • general lack of vision and leadership in relation to government role in urban development Consistency • there needs to be a whole of government approach with national urban policy and high level buy in (COAG?). • aligning existing data of various forms into a consistent output at a precinct level (AURIN?).

The Role of Precinct Tools

Importance

The development of the PrecinX assessment and Green Star Communities ratings tools has created a new awareness across government and industry of the potentials of precinct assessment tools. Amongst those surveyed there was widespread awareness – over 70% of all respondents identified both Green Star Communities and an appreciation of the GBCA work and were also aware of PrecinX. The situation amongst the state government land organisations (GLOs) is unique and advancing rapidly with their adoption of PrecinX and their collaboration across all states (except the Northern Territory). The private sector tool developers have created their software as an extension of their consultancy services, offering to their clients an innovative service, and as a consequence are leaders in the market. Design proposals can be visualised, scenarios modelled and compared, whilst also providing an analysis of planning scheme performance to support more sustainable urban development.

Common benefits identified across both groups are:

- Opportunity to compare different scenarios, promoting discussion and highlighting cost/benefits
- Providing clear performance measures, leading to a defendable position and a common language that promotes an integrated approach to precinct design
- Leads to more efficient processes and incremental improvement of precincts by explicit specification of targets before work proceeds
- Can be used as a community education tool.

However, these benefits will be limited if the availability of a rating mechanism is not linked with any *mandatory requirements*. As a *voluntary* option, a tool can provide those who wish to lead the market with a mechanism to show these benefits, which is appropriate and already being sought by some in the residential development sector.

These potentials do not apply consistently over all sectors. An appreciation by the built environment industry of the availability of precinct tools is quite weak especially at the local government level where resources are stretched and budgets limited.

Who Will Be the Main Users?

Almost all groups surveyed expected to be using such tools, or expected that their use would deliver a benefit once they could overcome access, training and the funding of the integrated studies. There is an uneven uptake at present, but this is very likely to change as these tools become more accessible.

Government Planning

The GBCA Green Star Communities rating project has established a national framework to address development at the precinct (or community) level. In combination with precinct assessment tools, there is now an emerging capability to model multiple scenarios, and also provide a mechanism to engage the end users on various planning and development options.

Local Government

Some municipalities anticipate that developers and planning applicants will in future provide council with (transparent) assessment of applications against benchmarks in a fashion similar to the already feasible method of getting council approval for a planning or building development by using a BIM model. With an explicitly modelled land and planning context, performance assessments could be submitted as an integrated model (as outlined in Chapter 5). Such processes reduce bureaucracy, allow independent verification and augment local councils' portfolio asset models.

Community

The community as a likely user group is not evident at present but provides a significant opportunity. 3D visualisation tools are emerging alongside sustainability assessment,demonstrating the capacity for powerful community engagement. Most community engagement is via local government, but they are currently poorly resourced and poorly skilled and this represents a significant barrier to wider adoption independent of any technical limitations or challenges with the tools.

Developers

As a tool for developers, it can address land acquisition, planning, design, build and potentially operations. Large developer organisations have been examining tools in the market place for sustainability assessment and one developer is known to be using PrecinX on a project in Western Australia and SSIM is involved in a Victorian project. Within the much larger detached housing construction sub-sector, however, knowledge of the tools is very weak, and compliance with BCA is the only driver, an attitude that also occurs in some of the larger developer/contractors.

Voluntary or Mandated Tools

The most common response on this topic was that the voluntary route was the most preferable. Currently, no argument by governments was being put that there is a market failure. Government policy should allow all developers in consultation with agencies, utilities etc. more flexibility and creativity in determining what outcome they want to achieve for their end users in a particular development.

However, in the context of alignment with government policy to meet sustainability objectives, any voluntary tool needs to align with specific policies that may emerge, such as the metrics for carbon (CO2e). This would ensure greater consistency across agencies and users.

Alternate views have been put. Setting benchmarks is an alternative method to drive innovation and achieve low carbon outcomes in the built environment. In the UK CO2 benchmarks have been set and buildings must demonstrate their performance. A certifiable assessment process would be required prior to the date at which targets need to be met.

Key Issues For Existing Tools

What Is Ready to Go?

PrecinX was the principal assessment tool referenced by most respondents in the survey, as was Green Star Communities as rating tool. *EnviroDevelopment* was less well-known but referred to as being used on several developments. It is very strong in Queensland and WA, and almost entirely absent in NSW, reflecting the role of the UDIA in the former and the position of PrecinX in the latter. Some local government councils appear to be following the *One Planet Living* protocol developed by the UK Bio Regional group, but it has had limited application to date, and needs to be tested, in the Australian context.

The survey identified many detailed issues with existing tools that are probably symptomatic of a market undergoing significant change with few mature assessment systems accessible and reflected in work practice. For example, one respondent observed that in the residential sector – which accounts for approximately 10% of the nation's carbon challenge – current sustainability (energy) assessment tools address perhaps 1.5% of that market, and only in the new buildings category. A much wider penetration is needed to influence outcomes.

An important lesson to be learnt from the *LCAdesign* building analysis tool developed by the CRC for Construction Information (CRC-CI 2007) is that, to be successful, the whole 'infrastructure' for a tool has to be in place. A barrier to major commercial success was in large part due to the lack of adequate building product/LCI data. Building product manufacturers in Australia are currently not required to be responsive to the need for object based product data, not only for building and precinct sustainability performance calculations but more widely to support the full range of structural, acoustic, thermal, energy performance assessments. (Chapter 4 highlights the crucial role of LCI data in all built environment assessment tools.

Certification and Standards

Across all of the surveyed participants there was a common concern that government and industry have to improve the standards being used for data and dissemination.

A key issue is an absence of a national or state strategy in place for standardisation, collection and organisation of built environment related data. Current assessment work relies on information much of which is patchy from both a spatial and temporal perspective and often requires some form of extrapolation or estimation. This is unreliable evidence and a poor foundation for decision making.

There is a current imbalance in access to data. Private tool developers do not have the same access as those in government. Considerable effort is needed from private tool developers to source public data.

Government utilities consider robust, standardised datasets should be provided by 'expert' sources (whether that is government, utility data, climate data from CSIRO/BOM/OEH, etc.). Performance metrics should be based on industry standards where available. Data needs to be updated at regular intervals, with more granular data where available and where able to be shared, e.g. through programs like BASIX, so tools do incorporate real lessons learned once precincts are developed.

Life Cycle Approach

There was widespread endorsement that the consideration of the full life cycle was an important strategy. By considering the different phases of development, many issues related to the handover to the next party, the scope of information at each stage, design vs operations, and the current roles of government and industry are challenged and many opportunities highlighted. These included:

- How to bind compliance at each stage of precinct development;
- Measurement of operating performance over a series of out-years, raising the issue of how the data is to be reviewed at each milestone, how it should be collected over such future time periods, and how the information can be used to support better evidence for sustainability, design and operations.
- Calculating life cycle costs, but recognising that purchasers have limits for up-front costs where an extra premium that would make for substantive life cycle improvements becomes a barrier.
- Changing roles for local government in relation to housing intensification, infrastructure capacity assessment and climate change adaptation planning all imply greater need for precinct scale assessment models

Basis for Endorsement by Industry and Government

For *government*, requirements were a demonstrated industry need or lacking in the market, providing an overall net benefit to the community and being targeted at the right level of government.

From a state agency perspective the GLOs were committed to PrecinX as an *open-source application* to underpin a transparent data platform for whole of government dialogue. Further, they consider PrecinX to have huge potential, but validation is important for data and assessment methods.

For *local government*, where a key issue is communicating to their citizens, community engagement is vital, so tools should reliably create confidence about development and get rid of 'developer tricks' (viz. 3D models that are unlikely to be implemented). *Education* based on a clear business case is required to influence the audience(e.g. *Green Star Communities* have put in place a very substantial engagement process).

What is Missing – Gaps

Data Improvement

All respondents referred directly or indirectly to critical issues about data, clearly one of the most important topics raised in the survey as well as partner discussions. Currently, some data is sourced from GIS software vendors, while much of the key GIS data that forms the basis of decision making comes from multiple state government agencies, for example, in South Australia the Departments of Planning and Housing, South Australian Water, and Energy and Power SA. This situation is most likely to be typical of all states, and demonstrates both the difficulties of accessing so many independent sources and the likelihood that data standards and collection methods will vary considerably. BASIX data, originating in NSW, has been central in the PrecinX tool underpinning information that allows strategic assessment of sustainability measures. BASIX data is extensive and reconciled with end use consumption data for electricity, water and gas.

Several respondents identified the need for a *National database* that would provide custodianship of data, a single source of information, and nationally consistent datasets. Who would hold this? The *Spotlight on Australian Capital Cities* report (KPMG 2010) has highlighted this issue. The Australian Urban Research Infrastructure Network (AURIN) was established in 2010 with a mandate to improve data access across multiple data 'lenses', several of which are relevant to precinct design assessment.

A common theme in the survey was that several groups are developing, or requiring the use of, LCI data. This is a crucial enabling dataset that needs a nationally validated approach. There are many waiting for government to demand it. Embodied carbon could well be the first priority. There are particular weaknesses and gaps in precinct information, e.g. on green space and green infrastructures. Urban 'landscape' typologies needed to be better represented.

GIS and BIM Integration

Many respondents knew one or the other of these technologies but few had a clear idea about the potential of the integration of BIM and GIS at precinct scale(PIM). Terminology for this is still evolving as noted by the respondents.

While GIS is the common tool in local and state governments for representing their portfolios, GIS data nationally is still uncoordinated, although there are many activities such as VANZI (see http://www.vanzi.com.au/) developing an Australian digital access protocol to national datasets.

A group of respondents very supportive of the potential of PIM are those that note the task of planning has turned from greenfield to brownfield, and now greyfield. Redevelopment of existing infrastructure has become more crucial, with infill as the big opportunity/challenge. It is important to determine location-specific opportunities and impacts. BIM and GIS were considered by some as good ideas, but will only be successful if useful (to their users), low cost, open-source, and have standards that are compatible with existing tools.

Reference was made to Green Infrastructure Modelling (GIM being a subset of PIM). The US SITES tool quantifies these GIM measures and is to be integrated into LEED. Local government appreciate PIM is an area for growth, where a significant gap exists, but at present adoption of new solutions is seen to be a burden for training, lack of time and additional work load, greater data storage and software purchasing restrictions.

It was suggested by the tool developers that a common Built Environment Model (note in this context BEM=PIM) dataset would be very useful. Future scenarios need assumptions based on building typologies, models and attributes, with the state GIS domain providing access to existing, updates and new developments, and should support retrofitting.

Challenges and Opportunities

How to Audit Carbon

Suggestions included a need for baseline carbon performance; carbon targets; pathways to low carbon design, low carbon exemplars; benchmarks to compare performance; accessible data relating to embodied energy (carbon) as well as operating energy (carbon).This data should be aligned with the Global Greenhouse Accounting protocols scope 1-3.

Embodied energy (carbon) is not implemented in some of the private sector tools and while recognising its significance, is not being sought by key decision makers. However, this is likely to become important when attempting to achieve future higher level project ratings on carbon performance: The property sector needs real and binding carbon targets for both new and existing buildings, and badly needs commercial incentives for rapid and significant change to occur.

The Role of Government

There was a mixed response as to where responsibility lies between the three tiers of government, made more difficult by lack of vision and leadership by government in urban development. *Nationally* there needs to be a whole of government approach setting national urban policy and high level buy-in through COAG. Industry representatives reinforced the need for *key policy discussion with government*. Their position is that government must lead.

At the *local government level* planning schemes can affect change. Local government regulations need to move beyond minimum compliance and there needs to be more capacity in local government to more creatively plan and manage neighbourhood change. Currently local government lacks capacity, yet it is the level of government where development takes place.

Future Development of Assessment Tools

The key findings from the survey can be summarised as follows:

A strong opinion that a new tool is unnecessary. In the state government sector PrecinX has a definitive adoption and project feedback is very positive. The collaboration amongst the state GLOs has been a major step in developing a national approach by the state government agencies, and sharing of expertise, identification of weaknesses and priorities is already informing shared strategic directions.

In the private sector, several tools already exist and there is no business benefit to develop *ab initio* competing tools for a market as small as Australia or a new tool for the international market. A common view that improving data quality, data access and creating new data types, and setting data standards in an open format is essential to increase accuracy and utility of the tools, and provide a robust base for evidence based precinct design assessment.

Metrics are a concern for both regulators (governments at all tiers) as well as software tool-makers seeking to align with appropriate settings for assessment. Common metrics ensure transparency and build reliability of assessments and decision making based on them. Nationally there is a lack of consistency across responsible jurisdictions that will ensure an effective response by industry.

The emergence of technologies for representing built environment developments as object-based digital models was not clear among all groups surveyed. Many current software solutions are based on conventional formats, incorporate only partial aspects of the built environment and are constrained by the absence of a *life cycle capacity* to model and maintain precinct data, hindering scenario building, milestone reporting, access for design and construction, monitoring of post-occupancy reporting and strategic planning. There is also lack of an *open industry standard for built environment objects*, data classes and precinct representation (PIM) that would assist all types of users, to carry out modelling and to manage assets.

Recommendations For Further Research

7. Recommendations For Further Research

As a result of this study, several key areas have been identified for further research that has the capacity for significantly advancing the current performance of precinct assessment tools.

Precinct Assessment and Rating in Living Laboratories

Precinct assessment and rating in a Living laboratories context is proposed as a project for CRC LCL capable of advancing the development of tools in this area. In its 2011 proposal to the Australian government for funding, the CRC LCL committed to developing a minimum of nine Living Laboratories over the seven year course of its operation. A Living Laboratory has been defined as ' an organisational arrangement, where the impact of introducing a change process or a new product/service (intervention) can be monitored and observed in a real world community with diverse stakeholders' (CRC LCL RP 3005 CRC Living Laboratories Framework: Final Report, p. 2).

This study has confirmed the need for further R&D to advance the scope and performance of all precinct design assessment tools. It is proposed that two CRC Living Laboratory (LL) projects be established to enable a co-operative study involving all four assessment tools (LESS, MUtopia, PrecinX and SSIM) to be applied to the same precinct, to explore a common set of development scenarios and supply side options for delivering evaluations against an agreed set of benchmarks (via involvement with the Green Star Communities rating system). The most prospective LLs capable of supporting research aligned to extending precinct design assessment capability are Lochiel Park (Adelaide) and Green Square (Sydney). There are several research issues capable of being examined in either or both LL settings:

- Defining and calculating 'core' *indicators* of performance assessment capable of replication across all classes of urban development where assessment against criteria of sustainability, resilience and low carbon built environment design outcomes is required. There are likely to be additional 'key' indicators established for specific projects or jurisdictions. Currently there are a wide spectrum of indicators in play (e.g. ASBEC's Cities Task Group indicators study), but little or no consensus on their relative importance – especially with the more recent emergence of carbon and resilience as new arenas for demonstrating performance. Nor is there transparency in the methods by which indicators are derived: a basic requirement for scientific validation.
- *Data* availability and adequacy (spatial, temporal, quality) for a range of precinct assessment tasks, including baseline information for precinct indicators, modelling and inputs to BAU benchmark calculations. This is a common problem that requires better documentation and a strategy to resolve that involves CRC partners who are principal data custodians in a number of critical areas (e.g. utilities). Embodied energy/carbon data was identified as the most critical data deficiency of direct relevance to the CRC LCL. It is in the process of responding via Research Project 2007 Integrated Carbon Metrics, which needs a Precinct Objects Library (see Section 7.3) in order to package/supply data of relevance to precinct design assessment. Utilities and major infrastructure providers are key players here in relation to ground-testing demand and supply side precinct forecasting, provision of baseline data and directing extension of precinct tools to a wider (urban context) consideration of project impact assessment.
- *Benchmarks* are critical for guiding decision-making in project design and project rating. There was no commonality across assessment tools for this process. There are benefits to be derived from a standard methodology and nomenclature, given the desirability of communicating performance to the marketplace and the prospect of meshing with precinct rating tools to achieve this. Establishing carbon benchmarks for built environment

precinct objects (embodied carbon) and precinct-based activities (operating carbon) and their joint place-based interactions (e.g. neighbourhoods with detached housing and car dependency as compared to medium density neighbourhoods with good public transport access) are critical performance metrics related to designing a low carbon built environment.

- The range of precinct *development* scenarios that local and state governments and developers need to consider in precinct planning and design. A principal example is the forecasting of future demand emanating from a precinct. Here the CRC LCL's RP 2002 Integrated Energy, Transport, Water and Waste Demand Forecasting study needs to be linked to both potential LLs as a test-bed for its algorithms, and a migration path to the existing precinct assessment tools where comparative assessment of their respective projections can be made and end-user take-up stimulated. Other scenarios of interest include: future demographics on a small area basis, climate change vulnerability, energy costs, economic development etc.
- *Costing* alternative design options to reflect, at minimum, capital vs. life cycle cost; allocation of costs and benefits between the principal stakeholders of precinct development; examining critical trade-offs, e.g. capital vs. lifecycle costs vs carbon emissions from alternative energy technologies. Estimates of costs associated with undertaking a range of assessments for a project (viz. linked to required performance indicators in a rating scheme) constitute important LL outputs of value to industry and government.
- Examining the most effective modes of *representing the performance* output measures of a particular precinct design (e.g. high rise vs low rise medium density) and/or future development scenario (e.g. urban heat island under BAU, +2°C, + 4°C): 2D (spider diagrams, pie charts, histograms, maps etc.), 3D viewer images, fly throughs, immersive environment.
- Establishing the degree to which the precinct assessment tools are aligned to rating tools such as GBCA's Green Star Communities, as well as other rating systems operating in Australia.
- Providing local government and the design professions with exemplars of leading precinct design assessment tools and their application to high profile planning projects

Each Living Laboratory provides a combination of common and uniquely different 'environments' for examining the respective capabilities of each precinct assessment tool – outlined in Table 7.1.

Table 7.1: Attributes of Lochiel Park and Green Square Living Laboratories

Lochiel Park (Adelaide, SA)	Green Square (Sydney, NSW)
Representative of greenfield development	Representative of an urban redevelopment (infill) project
A final precinct design that has subsequently been developed	Has been in planning and preliminary design stage for several years
Provides background data, precinct designs etc.	Provides a range of background data, designs
UniSA monitoring of energy usage that will enable comparison of 'as designed' versus 'as operated' (a critical link between CRC Programs 1,2 and 3); plus potential for survey-based LL studies linked to RP 3008 Transformation to Low carbon Living: Social Psychology of Low Carbon Behavioural Practice	Completed UNSW ARC Linkage Project (Urban IT) that attempted a digital representation of aspects of Green Square to demonstrate the ability to integrate BIM and GIS data (i.e. PIM)

Lochiel Park (Adelaide, SA)	Green Square (Sydney, NSW)
Ability to examine a range of scenarios not previously considered	Ability to explore a range of scenarios currently being developed that involve City of Sydney (focus on public domain issues), AECOM (built environment assessments and trade-offs) and others
Ability to experiment more broadly with alternative precinct design (e.g. density) and/or technology (e.g. distributed generation) options, and compare to a 'base case'	Engagement with evaluation of alternative designs and technologies (e.g. in particular DG systems for delivering low carbon energy – such as trigeneration)
Renewal SA and UniSA have an ability to co-host the LL project	City of Sydney, Urban Growth NSW and UNSW have an ability to co-host the LL Project

Overall, the LL studies would deliver a legacy of value to the built environment professions:

- *Reference sites* where future assessment tools (related to buildings, precincts and infrastructure) could be applied to specific, representative precinct designs, using established datasets, with well-defined scenarios and target performance levels etc. to be compared against the spectrum of 'benchmark' outputs generated in the LLs by the current set of cross-validated assessment tools
- *Scientifically validated* sets of indicators, calculators, CRC models (e.g. demand forecasting) related to precinct performance
- A *reference work* on best practice for precinct design performance assessment (a bookend for the 2011 federal government Urban Design Protocol – see Executive Summary) across a range of design options and future scenarios (e.g. linked to climate change, demographics and a range of economic futures).
- A value proposition for local councils, private developers and government land organisations associated with developing more sustainable, resilient, low carbon communities.

Precinct Information Modelling (PIM)

PIM has been identified as the key digital information platform for advancing precinct design assessment – a key Workpackage of Program 2 in the CRC LCL (see Figure 1.2). Consultations with industry partners during the Scoping Study identified a number of specific opportunities for direct deliverables from the PIM project. These deliverables included:

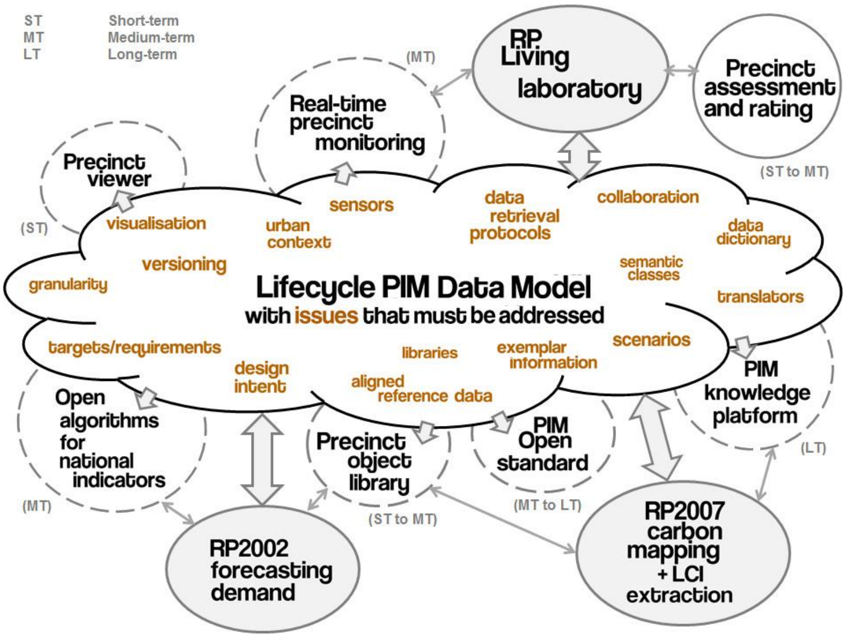
- support for a PIM object library that would provide a common mechanism for locating and linking to reference data;
- a precinct viewer based on a common model format and accessed from any precinct assessment tool;
- a precinct object ontological dictionary that matches common precinct concepts to the variety of terms used in the marketplace in order to facilitate effective accessing and sharing of reference data;
- support for the establishment of shared PIM databases for Living Laboratories.

The vision for PIM project is to provide a definitive modelling platform that will support interoperability between existing and future precinct assessment tools, allowing the market to develop and deliver robust software applications to predict, monitor and manage carbon load throughout the lifecycle of an urban precinct. At its core, the project will deliver an open, standardised model schema that will permit precincts to be represented at appropriate levels of granularity to support design, visualisation, performance measurement, monitoring and facilities management, starting at the initial master planning stage and continuing through design, delivery and operation of precincts. The CRC research partners are well placed to undertake this work, but it will involve very broad collaboration both nationally through the CRC's industry and government's networks and internationally with other research groups undertaking related work.

The key benefit of developing an open PIM standard within the context of precinct master planning is that it encourages market-driven development of accurate and innovative assessment tools rather than the CRC developing a new tool. This responds to a strong message from industry partners that a new tool is not needed. It also provides a platform for access to accurate reference data and shared access to utility applications such as visualisation and interoperability with commonly-used CAD design tools.

The relationship between the PIM project and related work of the CRC is illustrated in Figure 7.1.

Figure 7.1: PIM research issues with short, medium and long-term deliverables and other project links



The PIM data model has been shown symbolically within a cloud in Figure 7.1 as an underlying information model to support lifecycle management of information that is held efficiently within a cloud-based information repository capable of handling the vast amount of information required for urban-scale low carbon management. The dashed-line bubbles clustered around the cloud indicate the types of tangible deliverables that will flow from the PIM project (and there will be many more than shown). Each is driven by the specific needs of partners and end users to deliver benefit from the underlying research and implementation. Importantly, the PIM project will have a two-way relationship with other research projects within the CRC such as the three shown. These will provide essential insights that inform the development of the PIM schema, while also benefitting from the PIM work and potentially leading to specific PIM outputs. The current CRC project RP2002 on demand forecasting is a clear example of how that can work: the forecasting models that are developed will be based on a specific precinct model that will inform the design of the PIM schema, while also benefitting from the linkages that the schema provides in sourcing data and capturing the results to feed into downstream processes that make use of the demand data.

Precinct Objects Library

Another of the recurring opportunities identified in the partner consultations was the need for a shared library of common precinct objects, often quite generic in nature, which can be pulled into a precinct design proposal along with accurate predicted performance data. These could range in type from typical building or infrastructure objects (such as, residential towers, a range of detached dwelling types, school or other institutional building, etc.), to land use zones, open space and network infrastructure entities. In each case, the objects should be parametric, so a multi-storey building type would have parametric values for footprint size and number of storeys, or a land use zone would have variable area or density value. Each such object would be linked to up-to-date reference data to enhance the reliability of data sources.

A project of this kind would link to other projects being undertaken or proposed within the CRC. It would constitute a key deliverable within the proposed PIM project. Another important link would be with the proposed "carbon mapping" project (RP 2007) that draws from the repository of embedded carbon footprint data held in the Industrial Ecology Virtual Laboratory currently under development (see https://nectar.org.au/industrial-ecology-virtual-laboratory) as well as the LCI data described in Chapter 4.

Decision Support Tool for Distributed Energy Generation Technology Options

A decision support tool and databases to enable the eco-efficiency assessment (life cycle costing + environmental impact) of distributed energy generation technology options capable of being applied at scales ranging from building to precinct/district was identified as an important objective for CRC LCL research. Issues of storage and grid are clearly integral. What is initially sought is the development of specifications for a tool capable of application to prospective development sites across Australian cities, which can assess the economic and technical feasibility of a large number of technology options and account for variations in technology costs and energy resource availability. At minimum it should provide an important overview that compares the cost and feasibility of different configurations. Designers can then use more specialised software to model the technical performance. The tool should be accessible to a large set of users, including non-technical decision makers. It should also model both conventional and renewable energy technologies; for example: solar photovoltaic (PV); ground source heat pump; wind turbine; hydro power; biomass power; microturbine (co-gen/trigen); fuel cell, etc. This is indicative of a number of specialist, carbon-focused databases and decision support tools that the CRC for Low Carbon Living is well positioned to deliver into the marketplace.

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Appendices

Appendix 1 Precinct Assessment Tools Example Metrics

LESS Indicative only – customised to each project, according to client priorities and available data

Theme	Indicator	Units
Environment	Mitigation of heat island effect with shading	Shade and built up area (m2 or %)
	Air quality	Suspended particles matter parts per million
	Native vegetation/habitat	Area (m2 or %)
	Rain water harvested	kL/annum
	Solar energy harvested	kWh/sqm/day or % of available
	Flood prone land	Area (m2 or %)
	GHG emissions	T/Co2e/annum
Governance	Trees planted	Trees/ha
	Hospital services availability	Beds/1000 people
	Education services availability	Schools/1000 people
	Unemployment	% of population
	Investment in sustainability education	$/annum
Social	Property crime intensity	Incidents/1000 people
	Socio economic disadvantage	SEIFA index
	Public open space	Area (m2 or %)
	Secure pedestrian only public domain	Area (m2 or %)
	Dwelling density	Dwellings/ha
	Space for public events (markets/cultural events)	Area (m2 or %)
Economic	New residential development	Approvals/annum
	Household income	$/household
	Night time/day time land use	% or ratio
	Average capital growth	% per annum
	Job density	Jobs/ha
	Expected population growth	% per annum
	Rental return	$/m2
	Retail services ratio	Retail floor space (m2) /1000 people
Infrastructure	Total road length	Kms/ha

Theme	Indicator	Units
	Cycle path length	Kms/ha
	Waste water treatment catchment	% area connected to treatment plant
	Journey by public transport	% trips taken
	Distance of dwelling to bus stop	Metres

MUtopia Indicative only – customised to each project

Theme	Indicator	Units
Transport	Household Vehicle km travelled	km/dwelling/year
	Household PT use	km/dwelling/year
	Household walking and cycling use	km/dwelling/year
	Household other modes	km/dwelling/year
	Residential transport emissions	broken down in terms of mode and building source
	Mode Share weekday	% for Car, PT, walk /cycle, other
	Mode Share weekend	% for Car, PT, walk /cycle, other
	No. Trips weekday	number for Car, PT, walk /cycle, other
	No. Trips weekend	km for Car, PT, walk /cycle, other
	Distance Split weekday	% for Car, PT, walk /cycle, other
	Distance Weekday (km)	km for Car, PT, walk /cycle, other
	Distance Split Weekend	% for Car, PT, walk /cycle, other
	Distance Weekend (km)	km for Car, PT, walk /cycle, other
	Total Dist Weekday (km)	km for Car, PT, walk /cycle, other
	Total Dist Weekend (km)	km for Car, PT, walk /cycle, other
	Emission Factor (kg CO2eq/km)	for Car, PT, walk /cycle, other
	Weekday Emissions (tonnes CO2eq)	tonnes for Car, PT, walk /cycle, other
	Weekend Emissions (tonnes CO2eq)	tonnes for Car, PT, walk /cycle, other
	No. Trips	TOTAL for precinct

Theme	Indicator	Units
	Distance (km)	TOTAL for precinct
	Tonnes CO2eq emissions	TOTAL for precinct
Waste	Waste quantities	
	Generation	Tonnes
	Collection	Tonnes
	Transfer station	Tonnes
	Initial treatment	Tonnes
	Final treatment	Tonnes
	Transportation – Automated	Tonnes
	Transportation – Road	Tonnes
	GHG emissions	
	Generation	Tonnes CO2
	Collection	Tonnes CO2
	Transfer station	Tonnes CO2
	Initial treatment	Tonnes CO2
	Final treatment	Tonnes CO2
	Transportation – Automated	Tonnes CO2
	Transportation – Road	Tonnes CO2
	Costs	
	Generation	$
	Collection	$
	Transfer station	$
	Initial treatment	$
	Final treatment	$
	Transportation – Automated	$
	Transportation – Road	$
	Other KPIs	
	Diversion rate %	%
	Quantity of landfill waste avoided	tonnes
Energy	Energy Supply	
	Percentage (%) of renewable energy generated on site	%
	Cost $ /kWh	$
	kg of GHG /kWh	Kg/kWh
	Solar inputs and outputs	

Theme	Indicator	Units
	Global Horizontal Irradiance	GJ/m2
	Mean Annual Temperature	degrees C
	Annual Slope Irradiance	GJ/m2
	Performance Ratio	%
	AC Power Output	KW
	Capacity Factor	%
	Array Size	
	kWp	KW
	Panel Area	m2
	kWhr/year	kWhr/year
	Basic cost estimation	$
	Wind Outputs	
	Wind Velocity at height of 10m at turbine location	m/s
	Average Wind velocity at turbine location	m/s
	Peak Rated Power	kWp
	Estimated turbine roof area	m^2
	Electricity generated	kWh/year
	Basic cost estimation (including installation)	$
	Raw Electricity generated per kWp	kWh/kWp/yr
	De-rated electricity generated per kWp	kWh/kWp/yr
	Capacity Factor	%
	Performance Ratio	%
	Co/Trigeneratinon (or biomass) output	
	Plant sizing	
	Plant Size	kW
	Electricity generation	kWhr/yr
	Electricity Generated	MJ/yr
	Primary energy used in electricity production	MJ/yr
	Thermal energy produced	MJ/yr
	Harnessable heat	MJ/yr
	Shortfall in required primary heat	MJ/yr Surplus
	Hot thermal load that can be supplied	MJ/year

Theme	Indicator	Units
	Remaining primary heat after hot thermal supplied	MJ/year
	Cold Thermal load that can be supplied	MJ/year
	Remaining primary heat after cold thermal	MJ/year surplus
	Shortfall makeup	
	Heating Backup source	Electricity or gas
	Heating efficiency	%
	Cooling backup source	Electricity or gas
	Cooling efficiency	%
	Electricity consumption for shortfall	kWh
	Gas consumption for shortfall	MJ
	Electricity consumption (positive) or Generation (negative)	kWh
	Gas consumption (positive) or Generation (negative)	MJ/year
	Electricity Emissions	kg/kwhr
	CO2 emissions	
	$ Emissions	kg/year
	Shortfall Gas Emissions	kg/year
	Electricity Shortfall/generation emissions (+ve)/offset (-ve)	kg/year
	NET EMISSIONS including generation offsets	kg/year
	TOTAL EMISSIONS	kg/year
	Energy Supply simplified	
	GHG emission per kWh	kg of CO2/KWh
	Percentage of Grid	%
	Power provided for development	MWhr
	Tonnes of CO2 produced	Tones
	Power Cost per year	$
	Net present cost of power over lifetime	$
	Tonnes of CO2 emitted in first year	Tonnes of CO2
	Tonnes of CO2 emitted over project life	Tonnes of CO2
	Average current grams of CO2/kWh	g/kWh
	Predicted 2030 grams of CO2/kWh	g/kWh
	Energy Demand	

Theme	Indicator	Units
	Heating and Cooling Annual Demand	
	Heating Emissions	tonnes CO2eq/yr
	Cooling Emissions	tonnes CO2eq/yr
	Heating Load	GJ/yr
	Cooling Load	GJ/yr
	Total Electrical Load	GJ/yr
	Total Gas Load	GJ/yr
	Hot Water Annual Demand	
	Emissions	tonnes CO2eq/yr
	Gas Usage	GJ/yr
	Electricity Usage	GJ/yr
	Cooking and Appliances	
	Emissions	tonnes CO2eq/yr
	Gas Usage	GJ/yr
	Electricity Usage	GJ/yr
	Lighting	
	Emissions	tonnes CO2eq/yr
	Electricity Usage	GJ/yr
	Total	
	Total annual electrical	GJ
	Total annual gas usage	GL
	Total CO2 emissions from elev	Tonnes
	Total CO2 emissions from gas	Tonnes
Water	Water includes far more detailed usage stats, only summaries are shown here	
	Total Water used within the precinct	Non residential, SD, AD, MD, Total – kL/yr
	Total hot water used within the precinct – kL/yr:	Non residential, SD, AD, MD, Total – kL/yr
	Total cold water used within the precinct – kL/yr:	Non residential, SD, AD, MD, Total – kL/yr
	Rainwater harvesting potential	Non residential, SD, AD, MD, Total
	Recycling potential (Grey water)	Non residential, SD, AD, MD, Total
	Imported water needed	Non residential, SD, AD, MD, Total
	Energy use for water supply	Non residential, SD, AD,

Theme	Indicator	Units
		MD, Total
	Energy use for heating the water	Non residential, SD, AD, MD, Total
	Energy use for recycling the water	Non residential, SD, AD, MD, Total
	Total Energy use for water provision	Non residential, SD, AD, MD, Total
	Total GHG emissions	Non residential, SD, AD, MD, Total – tonnes(CO2)/yr
Economics	Employment	No of local jobs
	Access to jobs	Km (distance to job hub)
Liveability	Housing affordability	Several e.g. Mean years pay back
	Walkability	Walk score index mapping
	Access to services: (retail, community, schools, open space, health)	Distances to amenities
	Access to public transport	km
	Provision of open space within precinct	Spatial analysis of open space
	Security/Safety	Crime rates
Resilience	Vulnerability index to climate change	
Financial	Net present value	$
	rate of return	1/years
	mean payback period	years
	variance of rate of return	none
	Sortino Ratio (it measures the risk-adjusted return of an investment asset, portfolio or strategy. It is a modification of the Sharpe ratio but penalises only those returns falling below a user-specified target, or required rate of return, while the Sharpe ratio penalises both upside and downside volatility equally. Though both ratios measure an investment's risk-adjusted returns, they do so in significantly different ways that will frequently lead to differing conclusions as the true nature of the investment's return-generating efficiency)	none

PrecinX (compares project model against reference)

Theme	Indicator	Units
Transport	Total Travel GHG Emissions	t(CO2-e)/yr

Theme	Indicator	Units
	Total Travel GHG Emissions	t(CO2-e)/person/yr
	% reduction against reference	percent
	VKT	vehicle km/(person. day)
	VHT	vehicle hrs/(person. week)
	Reduction against Metro average VKT	percent
	Travel Distances	
	Conventional Car driver	km/day
	EV driver	km/day
	Car Passenger	km/day
	Train	km/day
	Bus	km/day
	Ferry/Light Rail	km/day
	Walk	km/day
	Bicycle	km/day
	Other	km/day
	Travel Times	
	Conventional Car driver	hours/week
	EV driver	hours/week
	Car Passenger	hours/week
	Train	hours/week
	Bus	hours/week
	Ferry/Light Rail	hours/week
	Walk	hours/week
	Bicycle	hours/week
	Other	hours/week
Embodied Greenhouse Gas	Total – t(CO2-e)	
	Total Embodied GHG Emissions	calc number
	per Occupant	calc number
	Detached Dwellings	calc number
	Attached Dwellings	calc number
	Multi-Apartments	calc number
	Precinct Infrastructure	calc number

Theme	Indicator	Units
	Per Dwelling – t(CO2-e)/dwelling	
	Detached Dwellings	calc number
	Attached Dwellings	calc number
	Multi-Apartments	calc number
	Precinct Infrastructure	calc number
	Per Capita – t(CO2-e)/person	
	Detached Dwellings	calc number
	Attached Dwellings	calc number
	Multi-Apartments	calc number
	Precinct Infrastructure	calc number
	% reduction against reference	percent
Operational Energy	Annual Precinct Energy Import	calc number (Elec – MWH / Gas – GJ)
	Annual Precinct Energy Export	calc number (Elec – MWH / Gas – GJ)
	Net Annual Precinct Energy Demand	calc number (Elec – MWH / Gas – GJ)
	Operational Energy GHG Emissions	
	Electricity and Gas GHG Emissions	calc t(CO2)/yr
	Water supply, treatment and pumping	calc t(CO2)/yr
	Total Precinct GHG Emissions	calc t(CO2)/yr
	% reduction against reference	percent
	Peak Demand	
	Peak electrical demand	calc number kW
	Peak residential electricity demand	calc number (kW peak / kW/dwelling)
	Peak residential grid electricity demand	calc number (kW peak / kW/dwelling)
	Non-residential peak energy demand	calc number (kW peak / W/m2)
	Residential Results	
	Net Residential Energy Consumption	calc number (Elec – MWH / Gas – GJ)
	Annual Residential GHG Emissions	calc number t(CO2)/yr
		kg(CO2)/(person.yr)
	Reduction against metropolitan average	percent

Theme	Indicator	Units
	Non-Residential Results	
	Non-residential annual energy demand	calc number (Elec – MWH / Gas – GJ)
	Annual Non-Residential GHG Emissions	calc number t(CO2)/yr
	Annual Non-Residential GHG Emissions	kg(CO2)/(person.yr)
Water	Total Mains Water	calc ML/yr
	% reduction against reference	calc percent
	Indoor demand	calc ML/yr
	Heat Rejection demand	calc ML/yr
	Outdoor demand	calc ML/yr
	Rainwater	calc ML/yr
	Recycled water	calc ML/yr
	Residential Results	
	Residential Mains Water – ML/yr	calc ML/yr
	per resident	calc kL/(pers.yr)
	Reduction against metropolitan average	calc percent
	Per Household	
	Mains Water	calc kL/household/year
	Recycled Water – kL/household/year	calc kL/household/year
	Private Rainwater – kL/household/year	calc kL/household/year
	Non-Residential Results	
	Non-Residential Mains Water	calc ML/yr
	Recycled Water	calc ML/yr
	Open space irrigation demand	calc ML/yr
	Open space irrigation demand per m2	calc L/(m2.yr)
	Precinct Discharge Results	
	Stormwater	
	Discharge quantities	calc ML/yr
	Stormwater Pollutants	calc kg/yr
	concentration	calc mg/L
	Sewer	calc ML/yr
	Other Results	

Theme	Indicator	Units
	Water supply electricity demand	
	Total	calc MWh/yr
Housing	Dwellings that are MIH (Moderate Income Housing) for Submarket	calc number
	Dwellings that are MIH (Moderate Income Housing) for GMR	calc number
	% improvement against existing housing	calc percent
	Results By Family Type	
	Family Type	lookup

SSIM (customisable per project – example based on a SSIM Stage 1 residential precinct in NSW shown here)

Theme (Principle)	Indicator	Units
Liveability	Access to Amenities	
	Access to Retail Centre	Population within 3 km of a commercial or retail centre
	Access to Village Retail Centre	Population within 500m of a village centre
	Access to Town Centre	Population within 800m of a town centre
	Access to Community Facility	Population within 500m of a community facility
	Local Food Production	Area identified for potentially productive land
	Access to Schools	
	Access to Primary Schools	Population within 500m walk of a primary school
	Access to Secondary Schools	Population within 1.6km of a secondary school
	Access to Open Space	
	Access to Neighbourhood Park	Population within 500m walking distance of a local park or sports field (with park facilities)
	Access to Sporting Fields	Population within 800m walking distance of a sports field
	Provision of Open Space	
	Provision of Neighbourhood Park	Total area of publicly accessible open space indicated as ha/1,000 people
	Provision of Sporting Fields	Number of sporting fields per 10,000 people

Theme (Principle)	Indicator	Units
	Provision of Parks	Number of Neighbourhood Parks benchmark 2,000 people
Environmental Responsibility	Energy Consumption	Land Use Energy Consumption (MWh/yr) benchmark
	Greenhouse Gas Emissions	Operational carbon emissions (Metric tons of CO2e) benchmark
	Potable Water Consumption	Land use water consumption benchmark (kl/yr)
		Wastewater generation benchmark (kl/yr)
	Access to Public Transport	Population within walking distance of a Bus Stop. A distinction and priority weighting is made between:
	Access to All Bus Services	District bus network (500m)
	Access to Regional Bus Services	Regional bus network (800m)
	Access to Shared Paths	Map of dwellings within 500 metres (~5min) of a shared cycling/pedestrian path
	Ecological Value	Existing biodiversity assets and impacts of proposed plan
Economic Prosperity	Employment and Economic Resilience	
	Employment land per person	Area per person
	Access to employment lands	Population within 2km of employment lands
	Affordability	
	Lot Size Diversity	An assessment of diversity of product and price
	Development Investment per person	An assessment of overall average per capita investment
	Development Yield	Estimated amount of dwellings and the mix of housing types.
	Estimate of Key Infrastructure Cost	Estimated commercial and retail GFA
		Estimated social and community facility GFA
		Proposed open space
		Estimate of infrastructure cost will include:
		• Public Open Space (Land and infrastructure works)
		• Water Management (Land and infrastructure works)

Theme (Principle)	Indicator	Units
		• Restoration of riparian corridors (where applicable)
		• Road construction (Infrastructure cost – cost of land covered in residential area)
		• Bridges (Infrastructure cost)
		• Culverts (Infrastructure cost)
		• Other identi ed key infrastructure items
Design Excellence	Design principles about place: productivity + sustainability	
	Enhancing – Enhances local economy, environment and community	qualitative based on Australian Government's Urban Design Protocol for Australian Cities
	Connected – Connects physically and socially	ditto
	Diverse – Diversity of options and experiences	ditto
	Enduring – Sustainable, enduring and resilient	ditto
	Design principles about people: liveability	
	Comfortable – Comfortable and welcoming	ditto
	Vibrant – Vibrant, with people around	ditto
	Safe – Feels safe	ditto
	Walkable – Enjoyable and easy to walk and bicycle around	ditto
	Principles about leadership and governance	
	Context – Works within the planning, physical and social context	ditto
Governance and Engagement	Traffic and Transport	Comments via consultant/stakeholder workshop
	Landscape and Visual Assessment	ditto
	Schools	ditto
	Biodiversity, Riparian and Bushfire	ditto
	Heritage	
	European Heritage	ditto
	Aboriginal Heritage	ditto

Theme (Principle)	Indicator	Units
	Retail and Employment	ditto
	Watercourses, Riparian Corridors and Floods	ditto
	Energy	ditto
	General Comments	ditto

Appendix 2 Australian LCI Databases

AusLCI

Overview

AusLCI is an Australian national LCI database. Initiated by CSIRO along with ALCAS, it was officially launched as AusLCI in November 2006. Since then, AusLCI has been adding to its inventories of Australian products.

AusLCI enables viewing and downloading high quality LCI core datasets. These datasets are structured by major sector, sub-sectors and categories.

Availability

Publicly available but requires registration on the website (www.auslci.com.au)

Australasian **LCI**

Overview

The Australasian LCI database has been developed for use with life cycle assessment(LCA) work over the past 12 years, initially as part of a national project (with state and commonwealth governments and the CRC for Waste Management and Pollution control as key partners).

Availability

The data is available on the Life Cycle Strategy website (www.lifecycles.com.au) with SimaPro format or csv format.

BP LCI data

Overview

In 2011, the Building Products Innovation Council (BPIC) developed the Building Products Life Cycle Inventory (BP LCI) to provide the Australian building industry with a database for measuring the environmental impact of building products over their life cycle. Its coverage comprises mostly building products (less than 50 items), e.g. concrete, masonry, tile, steel, gypsum board, cement, insulation material, windows, reinforce, brick and timber.

Availability

Data can be accessed through the BP LCI website (http://www.bpic.asn.au/LCI) and it is being integrated into Australian national LCI data (AusLCI).

CRC CI LCI

Overview

The CRC for Construction Innovation (CRCCI) developed a LCI database for building materials and products between 2001and 2005 for use with *LCADesign*, a software tool for automated environmental assessment of commercial buildings from BIM. To enable more rapid development of LCI datasets for building and construction industry applications, the CRC CI database was based upon an existing global database, the Boustead Company Limited (BCL) Model, originally developed in Great Britain. Using Boustead global database, CRC CI developed LCI dataset for a set of the most common Australian building and construction materials (less than 100 product items).

Availability
A consulting firm, *Equate*, has the licence of the tool (*LCADesign*) and thus it is possible to access data via that company (www.equate.com).

FWPA Embodied carbon

Overview
In 2009, an embodied CO2 (ECO2) module was developed and integrated into the housing energy rating tool AccuRate, with co-investment from Forest and Wood Products Australia Ltd (FWPA) and CSIRO's National Climate Adaptation Flagship. The module was to be used to calculate the ECO2 emissions for those materials used in the construction of new homes in Australia. Emissions occurring during the construction phase, those caused by maintenance and repair during the use phase and those occurring at the end of life of the building were not considered. These emissions are generally smaller than the embodied building materials emissions in residential construction. Also, the uncertainties associated with the construction, maintenance/repair and end of life emissions are much greater. Further significant effort would therefore be required to obtain good definition for the emissions associated with these phases before they could be included.

Embodied carbon data for common building materials used in Australian construction was calculated using SimaPro. For some parameters which are very difficult to obtain or unavailable in Australia, the LCI data available in SimaPro (e.g. European databases such as Ecoinvent, ETH etc.) were used. These parameters can be updated in future when Australian data become available. The data covers <100 items assessed from cradle to factory gate.

An example of this data is:

Materials	Unit	Embodied CO2 (kg CO2 eq./unit)	Comments
Ceramic tile	M3	1920	Adopt European data from Ecoinvent (2003,ceramic tiles, at regional storage/ kg/CH) Assumed raw material are transported within 100km
Concrete block 90 light-weight (solid)	M3	375	Adopt Boustead data (UK lightweight concrete block) Thickness 90mm Density 1800 kg/m3
Steel	M3	12,207	Australian LCI database in SimaPro (2004, Steel, Bluescope Port Kembla, 20% recycled content/AU U)

Availability
The embodied carbon data can be downloaded from the Hearne Scientific site (www.hearne.com.au/) with the AccuRate software. A detailed technical report can be downloaded from FWPA website (www.fwpa.org.au).

FWPA timber LCI

Overview
FWPA (Forest and Wood Products Association) developed the first national rigorous LCI data of Australian wood and timber products in 2009. FWPA timber LCI data covers the following categories of forestry and wood products:

Category	Products	Unit

Category	Products	Unit
Logs – Softwood	Peeler log, High quality saw log, Low quality saw log, Pulp log, Chips	Per m3
Logs – Hardwood	Peeler log, Saw log, Pulp log	Per m3
Sawn timber – Softwood and Hardwood	Rough sawn green timber, Rough sawn kiln dried timber, Planed kiln dried timber, Bark, Chips (as sawmill co product)	Per m3
Veneer	Veneer, Interior Plywood, Exterior Plywood, Formply, T&G Flooring, Structural Plywood (each 3 thicknesses)	Per m^2
LVL	LVL (3 thicknesses)	Per m^2
Particleboard	Raw and Decorated (each 3 thicknesses)	Per m^2
MDF	Raw and Decorated (each 3 thicknesses)	Per m^2
Glulam	Pine	Per m^3
I-beams	OSB web and pine flanges, Plywood web and LVL flanges	Per Lm

Data is developed by a process approach covering cradle-to-manufacturing factory gate. It provides industry with a reference of production practices and the ability to benchmark and monitor performance over time.

Availability
LCI data is available through the AusLCI website (www.auslci.com.au). A detailed technical report is available from the FWPA website (http://www.fwpa.com.au/).

RAIA embodied energy

Overview
Dr Bill Lawson was an Australian pioneer in the calculation of embodied energy for building materials and assemblies commonly used in construction. In 1996 RAIA (Royal Australian Institute of Architects) published "*Building Materials Energy and the Environment*" which contains Lawson's embodied energy data at that time.

The data is quantified based on the process approach and the data collection is representative of the 1990s. Data covers common building products and assemblies (floors, walls, roofs etc.). The data is represented as energy consumption per common SI unit (MJ/kg of building products, MJ/m^2 of assembly area)., for example:

Data example of RAIA embodied energy

Material	Unit	Example
Building product	MJ/kg	Cement – 5.6MJ/kg
Building assembly	MJ/m^2	Cavity clay brick wall 860MJ/m^2

Availability
The data is available from RAIA's bookstore (Lawson 1996).

I/O Embodied Energy/Carbon data

Overview

Embodied energy and carbon data for Australian products has also been developed using economic input and output (I/O) analyses. Compared to the process approach which quantifies *direct* input and output, the I/O method *indirectly* quantifies energy requirements or carbon emissions for Australian products from national economic accounts. Key Research Centres generating this type of data are Melbourne University (Robert Crawford) and University of South Australia (Stephen Pullen), and University of Sydney (Manfred Lenzen).

Some data is provided with a monetary base (MJ/$) and others are shown with a mass base (MJ/kg).

Availability

Most data is available through the university based researchers.

Appendix 3 International LCI Databases

3EID (Embodied Energy and Emission intensity Data for Japan)

Overview

Developed by NIES (National Institute for Environmental Studies) in Japan, embodied energy and emissions data for Japanese commodities is quantified using economic input output analysis

Availability

The data can be downloaded from:
(http://www.cger.nies.go.jp/publications/report/d031/eng/datafile/index.htm)
with html or xls files.

ELCD (European reference Life Cycle Database)

Overview

ELCD is the European reference Life Cycle Database for LCA. Its data is based on process approach in European context and covers more than 300 datasets which are mainly “End-of life treatment”, “Energy carriers and technologies”, “Materials production”, Transport services etc. from cradle-to-gate level.

Availability

Data is available from: (http://elcd.jrc.ec.europa.eu/ELCD3/sourceList.xhtml).
Data can be downloaded in both “html” or “xml” file from the website.

ICE database

Overview

ICE (Inventory of Carbon & Energy) is an inventory data originally developed by Hammond & Jones, University of Bath, UK. for building materials. Hammond and Jones created inventory of embodied energy and carbon coefficients for building materials, which classify 34 main material groups. The data has been mostly collected from secondary sources (e.g. journal articles, LCA books, conference papers) and is European (boundary) based. To make consistency of data, there are five selection criteria considered in ICE database: approved methodology (compliance standards), system boundary (as cradle-to-gate), data origin (UK based), age of data source (modern sources of data) and representative of embodied carbon.

Construction material groups in ICE database

Groups	Materials	Unit
Aggregates	General, recycled, virgin etc.	MJ/kg and kg CO2/kg
Aluminium	General, cast product, extruded, rolled etc.	MJ/kg and kg CO2/kg
Asphalt	General, roads & pavements, recycled, virgin etc.	MJ/kg and kg CO2/kg
Bitumen	General, virgin	MJ/kg and kg CO2/kg
Brass	General, recycled, virgin etc.	MJ/kg and kg CO2/kg
Bronze	General, virgin	MJ/kg and kg CO2/kg
Carpets	General, felt, Nylon, PET, plypropylene, rubber, wool etc.	MJ/kg and kg CO2/kg
Cement	Mortar, Fibre cement, General, soil cement etc.	MJ/kg and kg CO2/kg

Groups	Materials	Unit
Ceramics	General, fittings, refractory products, sanitary products, tile	MJ/kg and kg CO2/kg
Clay and Bricks	General, tile, clay pipe, clay brick, facing brick, limestone bricks etc.	MJ/kg and kg CO2/kg
Concrete	General, block, prefabricated concrete, fibre reinforced, concrete road & pavement, wood-wool reinforced.	MJ/kg and kg CO2/kg
Copper	General, primary copper, secondary from low grade scrap, secondary from high grade scrap	MJ/kg and kg CO2/kg
Glass	General, fibreglass, toughened glass	MJ/kg and kg CO2/kg
Insulation	General, cellular glass, cellulose, cork, fibreglass, flax, mineral wool, rockwool, paper wool, polystyrene, woodwool, recycled wool	MJ/kg and kg CO2/kg
Iron	Virgin iron	MJ/kg and kg CO2/kg
Lead	General, primary lead, secondary lead, primary lead with zinc	MJ/kg and kg CO2/kg
Lime	General	MJ/kg and kg CO2/kg
Linoleum	General	MJ/kg and kg CO2/kg
Paint	General, single coat, double coat, triple coat	MJ/m^2 and kg $CO2/m^2$
Paper	Fine paper, wall paper	MJ/kg and kg CO2/kg
Plaster	General plaster, plasterboard	MJ/kg and kg CO2/kg
Plastics	ABS, acrylic, general, Nylon, polyester, PET etc.	MJ/kg and kg CO2/kg
Rubber	General, synthetic rubber, natural rubber	MJ/kg and kg CO2/kg
Sand	General	MJ/kg and kg CO2/kg
Sealants and adhesives	Epoxide resin, general, mastic sealant, phenol formaldehyde	MJ/kg and kg CO2/kg
Soil	General	MJ/kg and kg CO2/kg
Steel	General, bar & rod, engineering steel, pipe, plate, section, sheet, wire, stainless	MJ/kg and kg CO2/kg
Stone	General, gravel, granite, limestone, marble, marble tile, shale, slate	MJ/kg and kg CO2/kg
Timber	General, glulam, hardboard, LVL, MDF, particle board, sawn hardwood, sawn softwood, Veneer particleboard	MJ/kg and kg CO2/kg
Tin	Tin coated (steel)	MJ/kg and kg CO2/kg
Titanium	General primary titanium, general recycled titanium	MJ/kg and kg CO2/kg
Vinyl flooring	General vinyl flooring, VCT	MJ/kg and kg CO2/kg
Zinc	General, primary zinc, secondary zinc	MJ/kg and kg CO2/kg
Miscellaneous	Carpet underlay, cork, cotton, asbestos, nickel, silicon, etc.	MJ/kg and kg CO2/kg

Availability

Data is available from http://www.constructionstudies.ie/modules/wt4106-materials-tech-/inventory_of_carbon_and.pdf

SimaPro database

Overview

Pre Consultants, LCA and sustainability consulting firm based in the Netherlands, created SimaPro LCI database for use with their LCA software, SimaPro tool.

SimaPro database includes inputs from broad set of international database providers, for example:

LCI databases in SimaPro data	Description
ecoinvent	More than 4000 industry processes including energy, building materials, chemicals etc. Data shows in both “unit process” and “calculated results”.
US LCI	More than 400 processes covering energy, transport and material production in North America
ELCD	More than 300 processes for EU based processes and materials etc.
IDEMAT	500 processes of materials provided by Delft University
US input & output	Based on 2002 US commodity matrix. The data represented as monetary base unit (e.g. CO_2eq/$)
EU & Danish input & output	More than 750 commodities covering Danish economy.
Swiss input & output	More than 150 processes for Swiss based boundary.
LCA food	500 food products and processes
Industry data	More than 70 processes of industrial data

Source: Pre (2013)

Availability

Data is available from Pre (www.pre-sustainability.com) with licence.

US LCI database

Overview

The US Life Cycle Inventory Database collects information on the environmental impact of commonly used materials, products, and processes. and is maintained by the National Renewable Energy Laboratory with partners DoE and Athena Institute. It is freely available through the project website at. One of the major objectives of this project is to keep the process and data transparent. Users can access project documentation via the website. The LCI data is available in different formats to fit different user needs. There is a streamlined spreadsheet, EcoSpold format spreadsheet, EcoSpold XML file, and a detailed spreadsheet with all the calculation details. The data can be imported into major LCA tools. The current database provides all of the energy and material flows into the environment in the US in the three different boundaries: cradle-to-gate, gate-to-gate and cradle-to-grave)

Availability

The LCI Database is freely available at www.nrel.gov/lci. The LCI data is provided in the form of modules that quantify the environmental input and output of unit processes. US LCI database can be downloaded with different formats to fit different user needs such as streamlined spreadsheet, EcoSpold format, EcoSpold XML file, and a detailed spreadsheet with all the calculation details. The data can be imported into major LCA tools.

Appendix 4 Research Organisations

Research and other organisations associated with work in the area of precinct information modelling include:

CityGML

Eindhoven University of Technology, Eindhoven, The Netherlands

Institute for Applied Computer Science, Karlsruhe Institute of Technology

Open Geospatial Consortium 3D Information Management (3DIM) Working Group

Institute for Geodesy and Geoinformation Science, Technical University Berlin

Urban Information Integration

Research Institute for the Built and Human Environment, Technology House, University of Salford

Chair of Information Architecture, ETH Zurich

Energy and Urban Models

Department of Architectural Engineering, Dong-A University, Republic of Korea

Department of Architecture, Pusan National University, Republic of Korea

Sustainable Cities Division, TNO Built Environment and Geosciences, Delft, The Netherlands

GIS and Extensions

ESRI

BIM and Extensions

buildingSMART

EPM Technology, Norway

Bimserver.org, The Netherlands

Appendix 5: MARKET Survey Respondents

Contact	Role	Organisation
Adam Beck	Tool Developer	Green Building Council of Australia
Kristin Brookfield	Industry Organisation	Housing Industry Association
Felicity Calvert	Government Land Organisation	Urban Growth NSW
Clare Culross	Government	Australian Building Codes Board
Bernardo Cuter	Local Government	Manningham City Council
Troy Daly	Developer	Bovis Lend Lease Design Group
Beck Dawson	Developer	Investa Property Group
Phil Donaldson	Government Land Organisation	SA Urban Renewal Authority
Rob Enker	Government	Building Commission
Marlon Kobacher	Consultant	Edge Environment
Catherine Neilson	Industry Association	Australian Institute of Landscape Architects
Nicola Nelson	Industry Association	Sydney Water
Brett Pollard	Tool Developer	Hassell
Sara Stace	Government	Department of Infrastructure and Transport
Roger Swinbourne	Tool Developer	AECOM
Sonia Thompson	Developer	Bovis Lend Lease Design Group
Rick Walters	Industry Association	Infrastructure Sustainability Council of Australia
Wayne Wescott	Industry Association	Local to Global: the Sustainability Connection