Precinct Information Modelling

Position Paper

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This work has been undertaken in collaboration with both industry partners and other researchers with a focus on carbon management. The intention of that collaboration was to be bi-directional: the project team would learn from the collaboration to inform the structure of the proposed data model, while in return, there would be an opportunity to implement precinct models based on the proposed open standard that would support and facilitate the work of the CRCLCL.

The participation with the CRCLCL and endeavours to build partnerships with a wide range of both industry and research stakeholders, provided significant insights into the modelling needs for carbon management at the precinct scale. That has informed the development of the proposed schema, along with proposed deployment of related technologies (as detailed in the Technical Reports), strongly validating our primary deliverable.

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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

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Acronyms

ABAB	Australian BIM Advisory Board
BCA	Building Code of Australia
BIM	Building Information Modelling
bSDD	buildingSMART Data Dictionary
bSI	buildingSMART International
CEN	European Committee for Standardisation
CO2e	Embodied Carbon
COAG	Council of Australian Governments
DA	Development Application
EPD	Environment Product Descriptions
ETWW	Energy, Transport, Water and Waste
FESES	Floor Space and Employment Survey (City of Sydney)
GDP	Gross Domestic Product
GIS	Geographic Information System
GML	Graphics Mark-up Language
GNSS	Global Navigation Satellite System
GUID	Globally-Unique IDentifier
ICM	Integrated Carbon Metrics
IDBE	Integrated Digital Built Environment
IFC	Industry Foundation Classes
ISO	International Standards Organisation
LEP	Local Environment Planning
LGA	Local Government Area
LIDAR	Light Detection and Ranging
MVD	Model View Definition
NCOS	National Carbon Offset Standard
OGC	Open Geospatial Consortium
PIM	Precinct Information Modelling
SME	Small and Medium-sized Enterprises
UHI	Urban Heat Island
VANZI	Virtual Australia and New Zealand
W3C	World Wide Web Consortium

Executive Summary

Precinct Information Modelling (PIM) describes the process of creating a 3D digital model at the scale of a precinct, defined as any area of the built environment that is of interest for some practical purpose. As such, it describes an activity where all the information pertinent to that precinct is held in a digital form, defined in a way that supports the processes that are critical to that purpose. Some examples of precincts include brownfield or greyfield areas earmarked for redevelopment, a campus facility, a retail district that is being monitored for planning purposes, or a land reserve designated for the development of transport infrastructure such as a new road or railway.

PIM entails a process that is supported by a digital database technology that can be used by a wide range of industry practitioners who are responsible for the planning, design, delivery and operational management of the built environment. It goes further because the same information can then become a resource for the community who use and interact with the built environment, lending critical support for the smart cities and communities that are emerging in response to the challenges of rapid urban growth in Australia and urbanisation across the globe.

This position paper describes the development of an open data model for representing a precinct in a format that allows it to be shared across all application software tools that are used in the process of managing the built environment, with a focus on carbon management.

The discussion is grounded in the precinct planning and development context as the main use case, drawing on interactions with a range of CRCLCL projects from the Low Carbon Precincts Program. Reference is made to the broader applications of this work, especially in the geospatial domain.

The underlying concepts and principles that have driven this work are explained, addressing the technologies that are deployed and the precinct modelling objects that must be handled to support the identified use cases. Further details are addressed in a set of technical documents available through the CRCLCL.

This is followed by practical sections that describe how precinct models may be created and managed using available software tools in conjunction with purpose-designed tools. The aim is to demonstrate PIM processes based on the proposed open standard. Some prototype applications of PIM are then described, related to specific CRCLCL projects.

The final section discusses the prospects for PIM, its significance within the context of the challenges that face built environment professionals and the future directions that this work needs to take towards full utilisation and impact.

Introduction

Precinct Information Modelling (PIM) describes the process of creating a 3D digital model at the scale of a precinct, defined as any area of the built environment that is of interest for some practical purpose. As such, it describes an activity where all the information pertinent to that precinct is held in a digital form, defined in a way that supports the processes that are critical to that purpose. Some examples of precincts include brownfield or greyfield areas earmarked for redevelopment, a campus facility, a retail district that is being monitored for planning purposes, or a land reserve designated for the development of transport infrastructure such as a new road or railway.

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This introductory section will explain the genesis and underlying principles that have guided the development of the concept of PIM, not only within the context of the CRCLCL, but also within the wider national and international spatial information community.

PIM takes an object-based view of the built environment, focussing on the objects that we wish to "talk about" (at various levels of granularity) in any discourse about the physical environment we inhabit, generally within the context of a professional activity related to the management of the built environment at different stages during its life cycle, from early planning and design to end-of-life repurposing. As an example, Figure 1 - Common precinct entities, relevant to urban heat island analysis, that might be represented in the PIM data model (Source: Peter Newton, Swinburne University of Technology)

Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct managementFigure 1 - Common precinct entities, relevant to urban heat island analysis, that might be represented in the PIM data model (Source: Peter Newton, Swinburne University of Technology)

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Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct managementFigure 1 - Common precinct entities, relevant to urban heat island analysis, that might be represented in the PIM data model (Source: Peter Newton, Swinburne University of Technology)

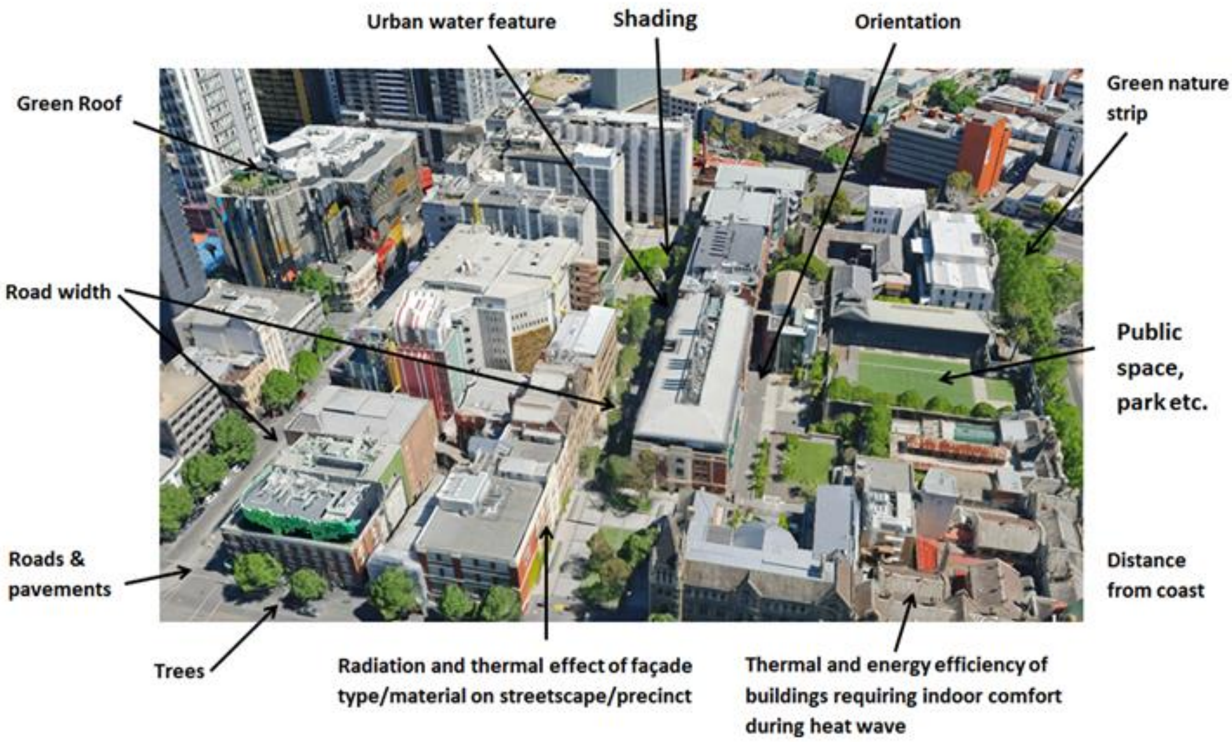

Figure 1 - Common precinct entities, relevant to urban heat island analysis, that might be represented in the PIM data model (Source: Peter Newton, Swinburne University of Technology)

Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct managementFigure 1 illustrates a range of built objects and concepts that might form part of an analysis of urban heat islands at the scale of a precinct.

Another simple use case would be holding information about the carbon load associated with a type of land use (say, residential housing) across a zone within an urban region, where the zone (a defined area of land) is the entity being discussed. Alternatively, at finer levels of granularity, we might wish to hold carbon data (embodied and /or operating) for a building or infrastructure type, or for a building component or material type. So, the objects in a precinct model are the things that we need to know about in any meaningful discourse related to our principal concern: delivering a built environment that is productive, liveable, resilient and environmentally sustainable.

In information modelling terms, it is not just the things and their properties that are important, but it is also the relationships between those things that help us to understand the built environment. Those relationships are explicitly represented within the models and may define concepts such as containment, adjacency, interdependence, connection and assemblage. As built environments become more complex, the needs for integrated modelling – in real time – become more critical.

In a precinct model, objects are typically represented as geometric forms that are spatially located, so it is often thought of as a 3D model (with the associated ability to visualise it).

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

Notably, while the 3D model itself is important, the processes that surround this new way of working provide an opportunity to use the model in a collaborative fashion among the many professional participants involved, based on shared information within the building model. The acronym BIM can be used to refer to the building information model itself, but it is more commonly used to refer to the process of building information modelling. The concept of PIM reflects this, as illustrated in Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct management

Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct

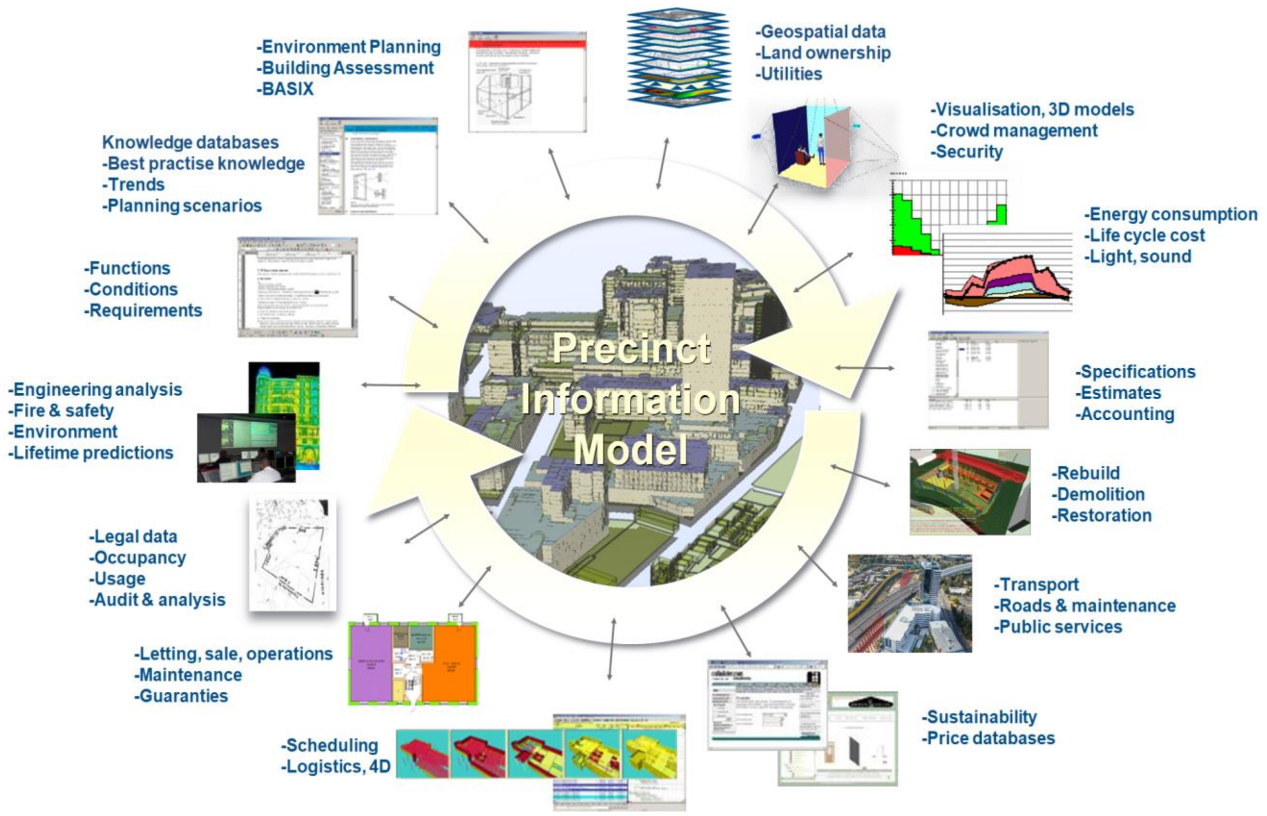

Figure 10 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct management

management

Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)

Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct management

Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)Figure 2, with the model being used by different professionals at all stages in the life of the precinct from pre-design, through planning, design and construction, and finally facility management.

This more effective way of collaborative working has led the infrastructure sector to become interested in the adoption of BIM techniques over recent years. Increasingly, both in Australia and across the world, the planning and design of linear transport infrastructure (roads, railways, bridges and tunnels) is now recognised as a strategic application of this digital engineering approach, not to mention the planning and management of utilities, urban space and key "gateway" infrastructure such as airports and seaports (Plume, et al. 2015; Borrmann, et al. 2017).

In scoping the proposal for the CRCLCL, where one of the three Research Programs proposed was *Low Carbon Precincts,* we foresaw an opportunity for the same processes that support the construction professions to be applied to the planning and design of urban precincts or districts. We realised that PIM could support collaborative decision-making at the scale of a precinct and, in that way, enable integrated solutions for urban management in the built environment. That strategy also sat well within the CRCLCL vision for addressing the complex issues of carbon management across the three CRCLCL streams of buildings, precincts and communities.

Digital modelling or prototyping is dependent on commercial software applications to support the creation and editing of the models by the various professional disciplines (each with specialised modelling requirements). In order to support collaborative work flows and decision-making, it is critical that the PIM data can be freely shared between those software tools, highlighting the need for agreed information modelling standards to support interoperability. The key to such a standard is to define an agreed common data model (or schema) that enables the representation of all the objects ("things") that constitute the precinct model, along with their defined properties and relationships.

There is an existing international standard for exchanging BIM data called IFC (Industry Foundation Classes). It was developed by an industry group called buildingSMART International (bSI) and adopted as an ISO standard (ISO 16739:2013). In developing the concept of PIM, we have adopted and extended IFC. This approach is ultimately contingent upon the PIM extensions being adopted by bSI and incorporated into international standards that software vendors are able to develop functionality against.

The PIM platform is designed to support the sharing of precinct information independently of any proprietary software application. It is not a software tool in its own right, and by its nature as an open, public information modelling standard; it cannot be commercialised. Within the context of the CRCLCL, this means that any research project or other activity that deals with precinct information can make use of the open PIM platform as a means of storing and sharing the information relevant to that project or activity. Such a capability would allow information to be used by other projects in a collaborative way, leading to efficiencies in the way precinct information is handled as well as the opportunity to develop integrated solutions to complex issues around carbon management and sustainable urban development more generally. It would also be a showcase for exactly the sort of collaborative working that PIM is promoting.

There have been some significant lessons learnt during the process of developing the PIM platform and associated open data model. One that stands out is a technical issue that is important to understand as background to the discussion that follows. As the PIM work has been focussed on the urban precinct scale, it inevitably intersected with the many geographic-scale modelling technologies (collectively described as GIS tools) that seek to represent and understand the physical world at a larger and more granular scale. While GIS can be viewed as a top-down approach, BIM is a bottom-up approach that describes the way the built environment is constructed, better to inform the processes of planning and design. The concept of PIM very neatly describes that common space or overlap between the building and geographic scales of information modelling for the built and natural environments (Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)

Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that

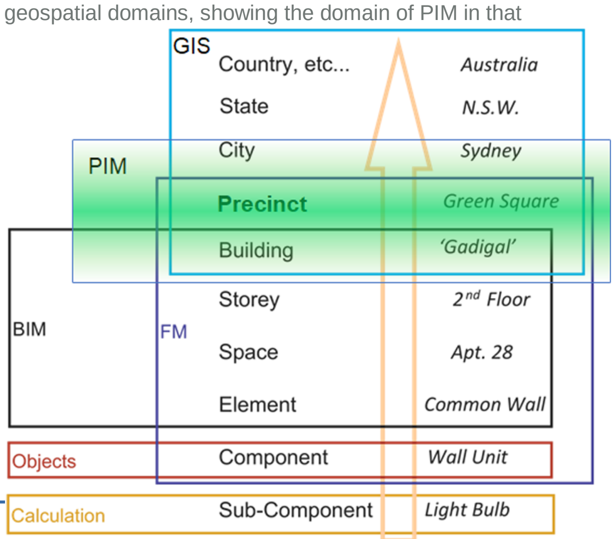

Figure 19 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)

context.Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)

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Figure 5 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)

Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.Figure 3).

Rather than duplicate standards, the PIM project has investigated and identified strategies that bring the standards in these two domains together while respecting the essential integrity of both approaches to the challenge of modelling the built and natural environments. This has led to the concept of the *Integrated Digital Built Environment* (IDBE) that refers to the integration, or federation, of all the data models and associated information that we have about the world we inhabit, allowing for that information to be held in an open and shareable format, with appropriate legal rights of access to ensure the integrity of the data. For a national approach to data access and security see VANZI.

Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.

Figure 5 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.

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Figure 6 - Common precinct objects with their representation in CityGML and the PIM data modelFigure 5 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.

Figure 5 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)Figure 4 illustrates the concept of the IDBE as the flow of information across the domains of BIM and GIS, with PIM positioned as an extension of the concept of BIM and merging the two domains.

The purpose of this Position Paper can be expressed as follows:

- to illustrate and explain how the PIM platform and associated data model can be used in a range of typical use cases;
- to explain the modelling concepts and principles that underlie the PIM data model;
- to outline the mechanisms that will lead to the full utilisation of the PIM project by industry;
- to identify opportunities to take the work forward beyond the life of the CRCLCL.

For readers who wish to explore these concepts in greater technical detail, there are a series of technical reports available, listed in the reference section at the end.

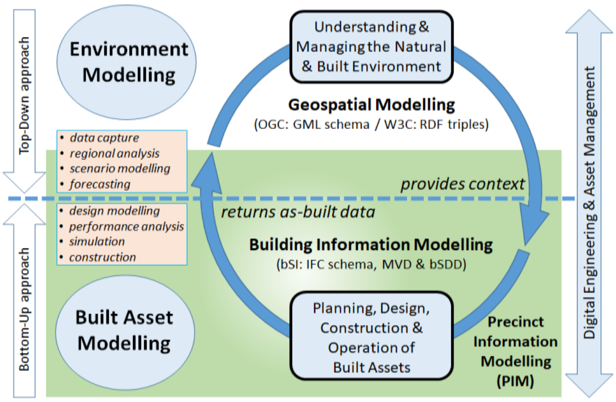

Figure 28 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.

Precinct Planning and Development

Effective precinct planning and development is critical as cities adapt to the global challenge of rapid urbanisation and resultant growth. Cities respond to this pressure by either allocating new subdivisions in greenfield areas on the urban fringe, or by identifying existing urban areas for redevelopment, either existing industrial precincts that may no longer be economically viable (known as brownfield developments) or areas that contain aging urban stock where densification can be achieved in an economic manner (known as greyfield developments). There are complex issues to be addressed in each of these urban fabrics such as available infrastructure, ecological impact, contextual appropriateness and housing mix. There are also opportunities to be considered, including achieving balanced resource consumption, implementing carbon reduction strategies, and developing more sustainable and resilient communities (Newton, et al. 2013; Newton 2017; Newton, et al. 2017)

This is the focus of the Precinct Program within the CRCLCL and is addressed in specific projects such as the ETWW Demand Forecasting (RP2002), Integrated Carbon Metrics (RP2007), Empowering Broadway (RP2018) and the Urban Heat Island Planning tool development (RP2005). It is also addressed in some of the Living Laboratories, as well as community engagement projects focussed on active transport (RP2021: Greening suburban transport) and healthy communities (RP2028: Development and trial of a co-benefits calculator).

All these activities that relate to the planning and design of urban precincts rely on some kind of model or representation that informs the decision-making. Traditionally, these models were in the form of drawings and physical models that could be appreciated and interpreted by people, but increasingly urban planners and designers use digital representations that support analytics, simulation and scenario testing. These models may be algorithmic, making use of the computational capability of computers, or they may be based on 3D digital prototypes. The models are computer-based and can be rapidly processed to provide support for informed and efficient decision-making. Figure 5 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)

Figure 6 - Common precinct objects with their representation in CityGML and the PIM data modelFigure 5 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)

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Figure 7 - Proposed spatial structure hierarchy for precinctsFigure 6 - Common precinct objects with their representation in CityGML and the PIM data modelFigure 5 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)

Figure 6 - Common precinct objects with their representation in CityGML and the PIM data modelFigure 5 shows an example of precinct assessment undertaken as part of the PIM project, associated with Fisherman's Bend (CRC for Water Sensitive Cities 2016).

The challenge with the digital models is that they are typically developed within a proprietary software

Figure 37 - Precinct assessment at the planning stage (Source: MUtopia Team, PIM Project Year 1)

environment and are very targeted in their application. They may perform one kind of analysis based on a bespoke model of the precinct unique to that application (and do it very well), but that model and the data it contains is not then available for other potential analysis applications. Furthermore, there is little opportunity to address the complex interactions between the factors that impact precinct performance more broadly and may be the subject of a separate precinct analysis tool that is based on its own precinct model.

The open PIM data model addresses this issue by providing a precinct modelling platform that is independent of the specific information needs of any one application, but is generally applicable across the range of tools that may be used in planning and development processes. In that way, information can be held in an open format and shared between proprietary analysis tools and management applications. This enables more comprehensive evidence-based planning and decision-making in an economically efficient and scientifically robust manner.

Precinct Modelling Concepts

This section of the paper reviews the underlying concepts and principles that have led to the development of the proposed PIM data exchange standard. It addresses these concepts under four broad headings: precinct models as an information repository linked to other representations of the built and natural environment; a description of the way information is organised within a precinct model based on the existing IFC data model; a discussion of the classes of objects that make up precincts; and concepts related to location and place, effectively addressing the issue of urban context.

Precinct Information Repository

A precinct model is best understood as a repository of information about a geographic area that is based on a 3D geometric object representation along with the properties and relationships of those objects: the geometry allows the precinct to be spatially visualised and navigated (but is not mandatory).

By their nature, precinct models can be very large and complex, so it is likely that the repository would be held in a database accessible through the Internet. There are both proprietary and open-source products that provide database technologies capable of handling PIM open data, providing different levels of functionality.

Much of the data needed for precinct analysis may be held in other databases or files, so an essential aspect of the PIM concept is to support access to multiple sources of information. It is for this reason that a precinct model repository may be held in a federated database environment, meaning that it is not a single massive database, but really a set of interlinked databases, often hosted by different organisations. That is important, because the PIM data standard should not replicate open data standards that already exist (or are under development) in other domains, but rather should provide support to link to such data sources at the object level. For example, Figure 6 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 7 - Proposed spatial structure hierarchy for precinctsFigure 6 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologiesFigure 7 - Proposed spatial structure hierarchy for precinctsFigure 6 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 7 - Proposed spatial structure hierarchy for precinctsFigure 6 below shows how some PIM concepts correspond to CityGML (a well-known geospatial industry standard) concepts for the object types depicted. As noted in Figure 1 - Common precinct entities, relevant to urban heat island analysis, that might be represented in the PIM data model (Source: Peter Newton, Swinburne University of Technology)

Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct managementFigure 1 - Common precinct entities, relevant to urban heat island analysis, that might be represented in the PIM data model (Source: Peter Newton, Swinburne University of Technology)

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Figure 2 - PIM as a life cycle process from pre-planning and design, through documentation, performance analysis, construction and ultimately precinct managementFigure 1, these particular objects are the types of concepts that may be relevant to urban heat island analysis, so it demonstrates that for a particular use case, either data standard may be applicable. This again illustrates the overlap described in Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)

Figure 4 - Cycle of information flow across the BIM and geospatial domains, showing the domain of PIM in that context.Figure 3 - The scale of things, with precinct modelling representing the intersection of BIM and GIS technologies (Source: Andreas Kohlhaas)

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Precinct Model Structure

The IFC schema uses the concept of a ***spatial hierarchy*** as an organising structure, allowing the physical elements used to construct the built environment to be associated with spatial entities as a way of locating them within the model. For buildings, that spatial structure is quite predictable: a project occurs on a site containing one or more buildings; each building can have several storeys, each made up of spaces. These spatial entities are significant precinct objects in their own right, in addition to providing spatial organisation. The physical components that form the fabric of the buildings are then associated with appropriate spatial entities, for example, walls are contained in building storeys and form the boundary of spaces, while landscape elements are associated with a site. Occupancy ("actors"), plant and equipment and service connections may all be associated with spatial entities.

When considering precincts, the question then arises, whether a similar spatial hierarchy can be defined on a precinct scale. The PIM project team have proposed a generalised extension to the standard building spatial hierarchy that can also accommodate linear infrastructure as well as urban space. This has been reviewed and refined within the international standards community, and is currently under discussion (Borrmann, et al. 2017).

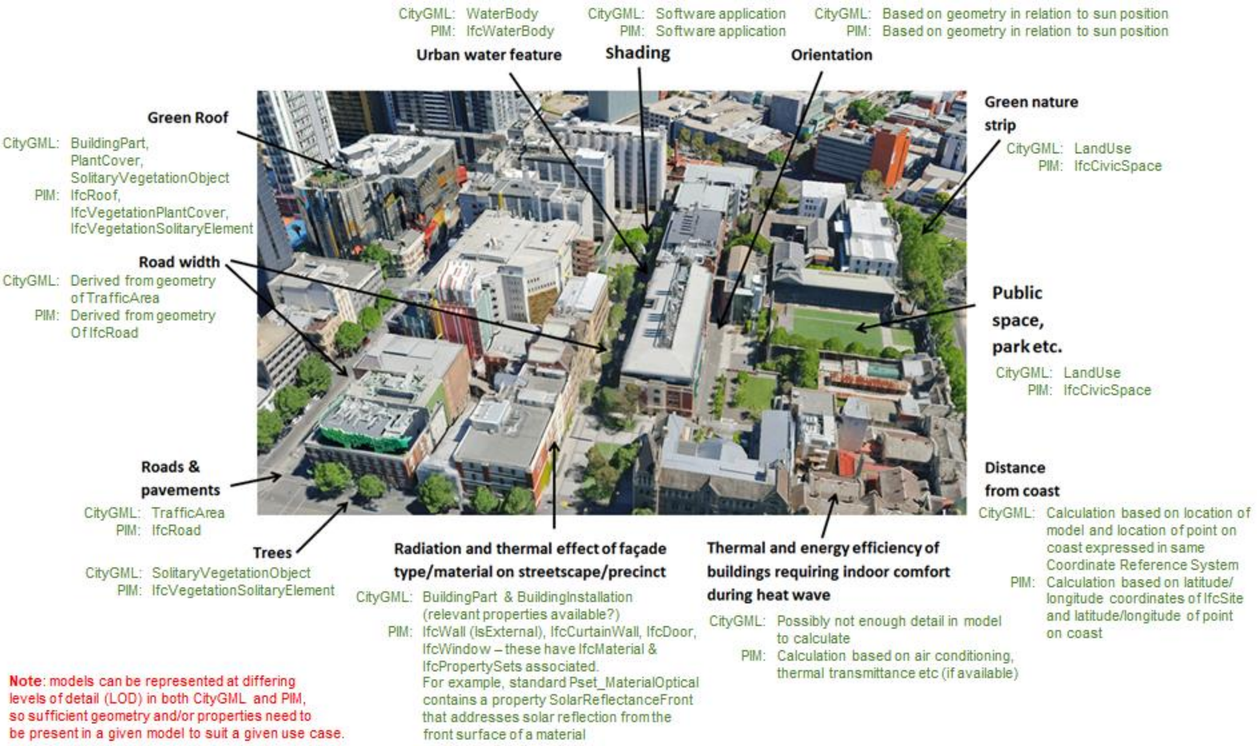

Figure 46 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 47 - Proposed spatial structure hierarchy for precinctsFigure 48 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 49 - Proposed spatial structure hierarchy for precincts

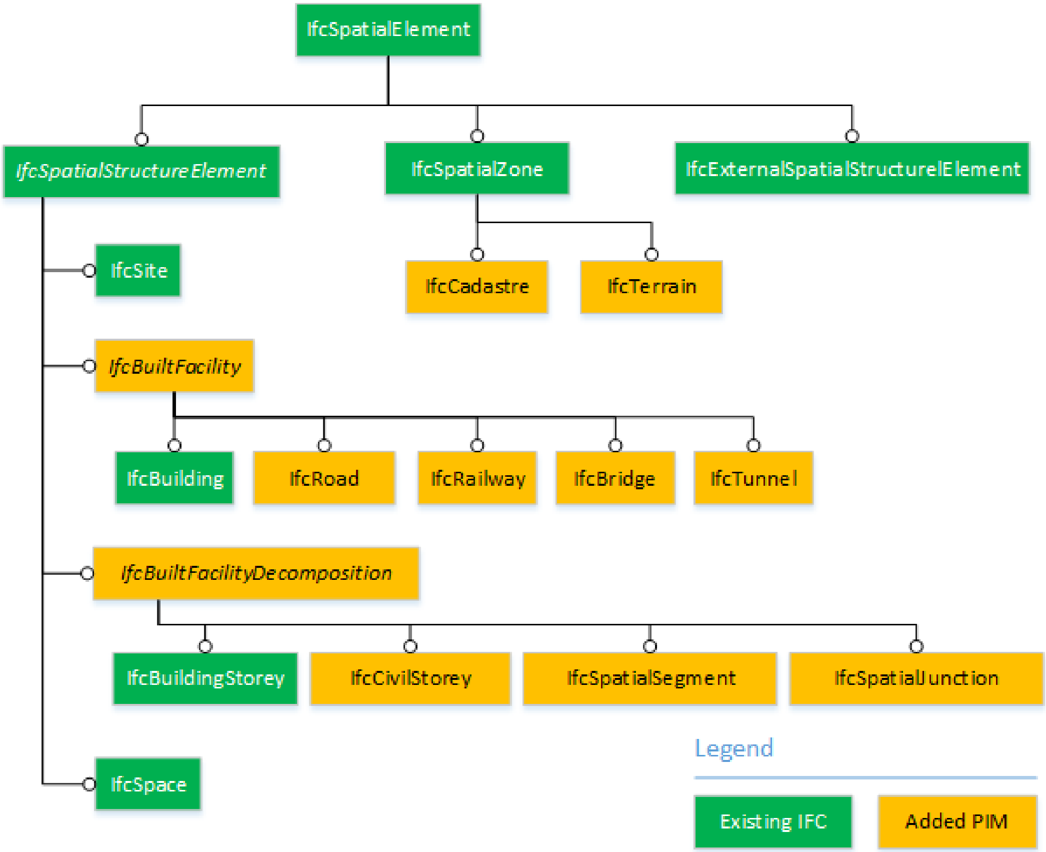

Figure 55 - Proposed spatial structure hierarchy for precincts

The proposed spatial hierarchy is shown in Figure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologiesFigure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologies

Figure 9 - Hierarchy of elemental entities in a precinctFigure 8 - PIM typologiesFigure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologiesFigure 7. Those entities shaded in yellow are the proposed new spatial structure elements for precincts, while those shaded green are the current IFC concepts, defining the spatial hierarchy for buildings (going from a broad to detailed level).

The notion of ***site*** is closely associated with the idea of a project: in the IFC schema, it is regarded as the area of land where a construction activity occurs. In many cases, that is a legally-identified land lot or cadastral unit, but that is not necessarily the case, especially when dealing with precincts. For example, a building construction project on a campus will occupy a fenced-off area within the land parcel(s) occupied by the campus facility.

In the proposed PIM schema, a distinction is drawn between the concept of a *site* and ***cadastre***. The latter is used to define legal ownership of land parcels and is critical to understanding the legal and spatial context of a project. At the same time, the site represents the place where a project activity is being carried out and therefore provides a different perspective on both location and context. Where the project activity relates to the entire precinct (such as a brownfield development precinct), the site would correspond to that entire area. A site may therefore consist of many cadastral lots, or may be a sub-divided part of only one.

Precinct Object Concepts

In addition to the spatial entities, there are many other precinct objects that make up the physical fabric of the built environment. Many of those are already defined in the IFC data model for buildings, but others need to be defined to support specific uses cases in PIM.

There are three principles that have driven the identification of appropriate object concepts when modelling at the precinct scale:

1. the first is to select the things that are important to any dialogue or analysis of the precinct throughout its life cycle from pre-planning (feasibility analysis) to management and operation;
2. the second is to identify concepts that support linkages to other information modelling standards

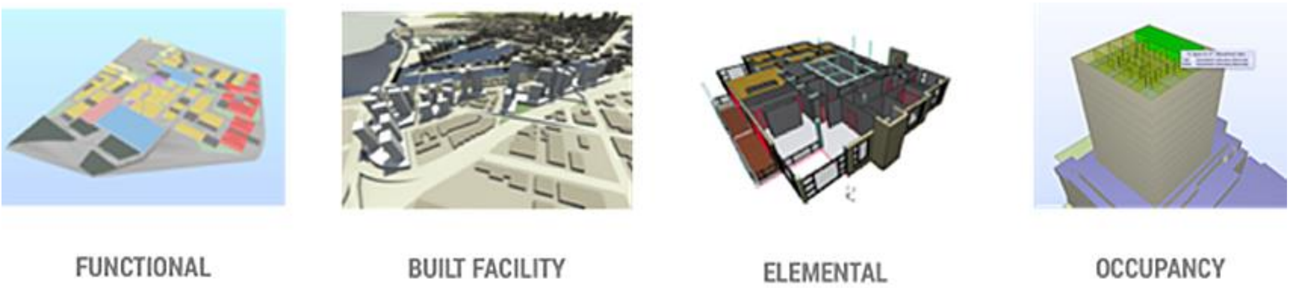

Figure 64 - PIM typologies

that already exist (or are under development) in the built environment or geospatial domains; this to avoid duplication wherever possible and take advantage of existing work;

3. thirdly, the focus must be on generic concepts to maintain the generality of the precinct model, allowing end users to identify specific types and properties appropriate to national, jurisdictional or organisational standards.

The application of these principles has led to the notion that precincts should be represented at four levels of granularity, generally corresponding to the issues that are considered as precincts go through various planning and design processes. Figure 8 - PIM typologies

Figure 9 - Hierarchy of elemental entities in a precinctFigure 8 - PIM typologies

Figure 9 - Hierarchy of elemental entities in a precinct

Figure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.Figure 9 - Hierarchy of elemental entities in a precinctFigure 8 - PIM typologies

Figure 9 - Hierarchy of elemental entities in a precinctFigure 8 illustrates those four broad categories of precinct objects, noting that this encompasses the spatial entities described in the previous section.

At The finest level of granularity is the ***elemental entities*** (elements in IFC) that are assembled to make or construct the fabric of built facilities. These can be prefabricated objects that are assembled on site during construction processes, or they may be objects that are created in situ, such as concrete slabs or railway track beds. Importantly, elemental entities may themselves be assembled from sub-components.

Figure 9 - Hierarchy of elemental entities in a precinct

Figure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.Figure 9 - Hierarchy of elemental entities in a precinct

Figure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

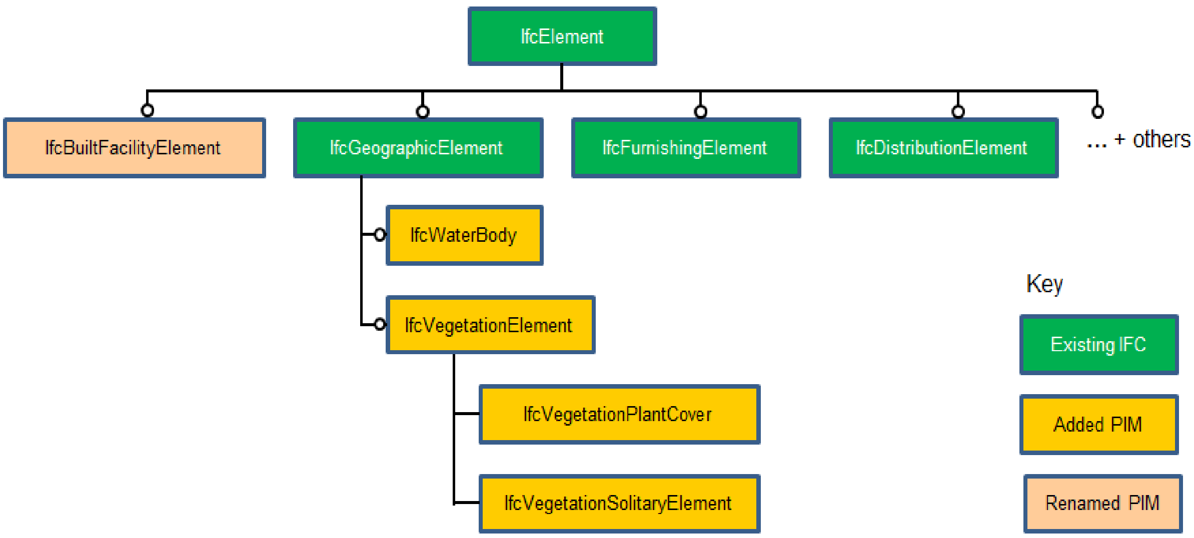

Figure 73 - Hierarchy of elemental entities in a precinct

Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM projectFigure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.Figure 9 - Hierarchy of elemental entities in a precinct

Figure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.Figure 9 illustrates a part of the elemental hierarchy for PIM, based on the IFC schema. The class called Built Facility Element is a renamed concept in PIM because in the current IFC standard it is called Building Element (reflecting the fact that it only includes elements for representing buildings). Precinct modelling use cases can often make use of those entity classes, but where the need arises, and following the principles just described, new precinct objects are added to this class. For example, an added precinct object is Vegetation, shown as a class under Geographic Element and having types as listed in parentheses).

Built facilities represent the constructed entities in the built environment, being anything that needs to be referenced as a single unit. Examples include all the high-level spatial concepts described previously (buildings, roads, bridges, civic space, etc.), but may also include any entity that has a functional purpose (transport access points such as bus stops, street furniture, utility structures, etc.). In the geo-spatial modelling domain, these are collectively referred to as features. The challenge in information modelling terms is to identify the most generic concepts that can then be sub-classed. For example, if we think of a road as an entity that defines a linear structure for the free flow of traffic, then that would include cycleways, pedestrian pathways and even trafficable waterways. It does seem appropriate to distinguish a road from a railway structure, where the rolling stock is constrained to follow tracks and subject to signalling and operational timetabling. As additional use cases are considered, there may be a need to expand this list (waterways or water bodies appears to be a useful candidate), but the principle should be to keep the defined hierarchy as simple as possible.

The decomposition of a built facility then extends the concept of a building storey (vertical subdivision), proposing that linear infrastructure is typically decomposed horizontally into linear segments and junctions. At the lowest level of the spatial hierarchy is the concept of space: this refers to any defined area within a precinct that is designated for a specific function. It could therefore refer to a room in a building, an area within a plaza or park, a traffic lane on a road or track on a railway, a safety zone in a tunnel, etc.

Functional entities provide the coarsest level of granularity, representing areas or regions (within a precinct) that are designated for a specific function or identified by some common set of properties. Examples include: designated land use zones within a precinct; jurisdictional regions within an urban context (local government or administrative units); census collection districts (associated with statistical data); flood, fire or water catchment zones (in general identified by a common characteristic); activity zones reserved for a specific purpose (e.g. a shared pedestrian and vehicle zone). These are generally defined geometrically by an enclosing geographic boundary, and may have height or clearance data associated with them. They may also be defined by ***aggregation*** of sub-zones, so for example, a census district could be defined as the aggregation of land parcels (if that were appropriate to the use case). Zones also correspond to the similar concept in geographic information systems.

In summary, therefore, the physical (fabric) entities that are assembled to create the built environment at any scale may be organised around this idea of a spatial structure, providing a way of understanding their relationships and locating them within the model. This is important not only for a user who may be interacting with the model, but is essential for any software application that is interpreting the model to support some analysis or operational process.

Precincts are also populated by people that interact with and manage those precincts, referred by others as the community service layer in a precinct representation (Ichikawa 2013, cited in Newton, et al. 2017). The concept of ***actor*** in PIM can be used to identify any kind of individual or group that is associated with a precinct. These may be end users, occupants, operators or managers. They may be part of a defined organisational structure, with reporting obligations and roles to play.

All precinct objects can have ***properties*** and performance characteristics that are measurable. This is handled by the use of ***property sets*** that are usually defined with respect to particular use case requirements.

Property sets consist of pre-defined sets of property-value pairs. PIM includes some standardised property sets, but also allows for any user-defined property sets to be associated with both types and instances of entities.

The buildingSMART Data Dictionary (bSDD) has been included in our PIM proposals as another means to extend IFC, while retaining only its generic entity definitions. bSDD is an on-line dictionary of concepts and the relationships between them. It is used to identify objects in the built environment and their specific properties regardless of language, so that for example "door" or "Embodied Carbon" means the same thing in New Zealand as it does in Australia or the UK. The data dictionary is open and international, allowing architects, engineers, consultants, owners and operators on one side, and product manufacturers and suppliers on the other side, to agree and share product definitions. When everyone shares the same concepts, the life cycle management of the built environment becomes more efficient.

The PIM project team have populated the bSDD with concepts derived from the New South Wales Department of Planning for land uses and development types. This allows for the functional/zonal PIM use case to use instances of the entity IfcSpatialZone named in a standardised manner e.g. "Residential Building", and to link embodied carbon property set definitions as defined in the bSDD, values for which can then be populated from an embodied carbon database such as an online version of the Accurate *Embodied CO2 Emissions Module*. This is explained in further detail in the PIM Project Technical Investigation Land Use (Mitchell, et al. 2016a).

Geospatial Context

The ability to tie any part of a precinct model to a precise ***geospatial location*** is critical (and supported in the PIM schema), both to provide the context of the precinct and a mechanism for using geospatial queries to interrogate external data sources that are geospatially referenced. This is a well-understood technology used commonly by mobile apps to locate services near the user's location, using GNSS technology. However, such geospatial queries provide many other opportunities, such as links to statistical data, local planning regulations, utility data, etc.

When working at the scale of a precinct, it is generally necessary to hold accurate information about the land parcels that make up the precinct. This requires not only information about the cadastral lot, but must also be able to record 3D cadastral entities such as aerial lots, rights of way and easements, as well as strata title for medium or high density residential developments (Aien, et al. 2013).

Any representation of the built environment at precinct scale requires that landform be explicitly modelled. This is adequately handled in the IFC4 standard (and therefore, PIM) as a land surface object. Where below ground or geotechnical information is required, there are existing standards in the geoscience disciplines that accurately map geology and can be referenced from PIM as part of the federated precinct model.

Creating, Editing and Viewing Precinct Models

The primary deliverable from the PIM Project is a standardised data model (or schema) to support the sharing of precinct model information. Demonstrator use cases have also been created.

Since a complete precinct model is an assembly of precinct objects as described in previous sections, the first step in creating a use-case model is to use available commercial software tools to build the component parts and export them in the available IFC formats. Although these export models cannot incorporate some of the proposed PIM extensions, they can make use of proxy objects or other structures and be manually edited to conform to the proposed standard. The separate models can then be merged to create a full precinct model.

Several types of existing software can be used in this process:

- Software packages that support the creation of building models for the architecture, engineering and construction sector. These are known collectively as BIM (building information modelling) authoring software applications. Most of those support the current release of IFC (IFC4) and can be used to create the geometry required and export those objects in IFC format for incorporation into a precinct model.
- Other commercial software products that are designed specifically to view, edit or analyse models exported in IFC format.
- BIM-style software products that support the modelling of civil works, allowing the user to shape land form and model infrastructure entities such as roads and bridges. Increasingly, these applications are adding support for exporting IFC models. The project team formed a collaborative relationship with one such Australian civil roads software vendor and has been able to experiment with the production of a road layout for the Tonsley precinct, represented in IFC/PIM. This is illustrated in Figure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM projectFigure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM projectFigure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

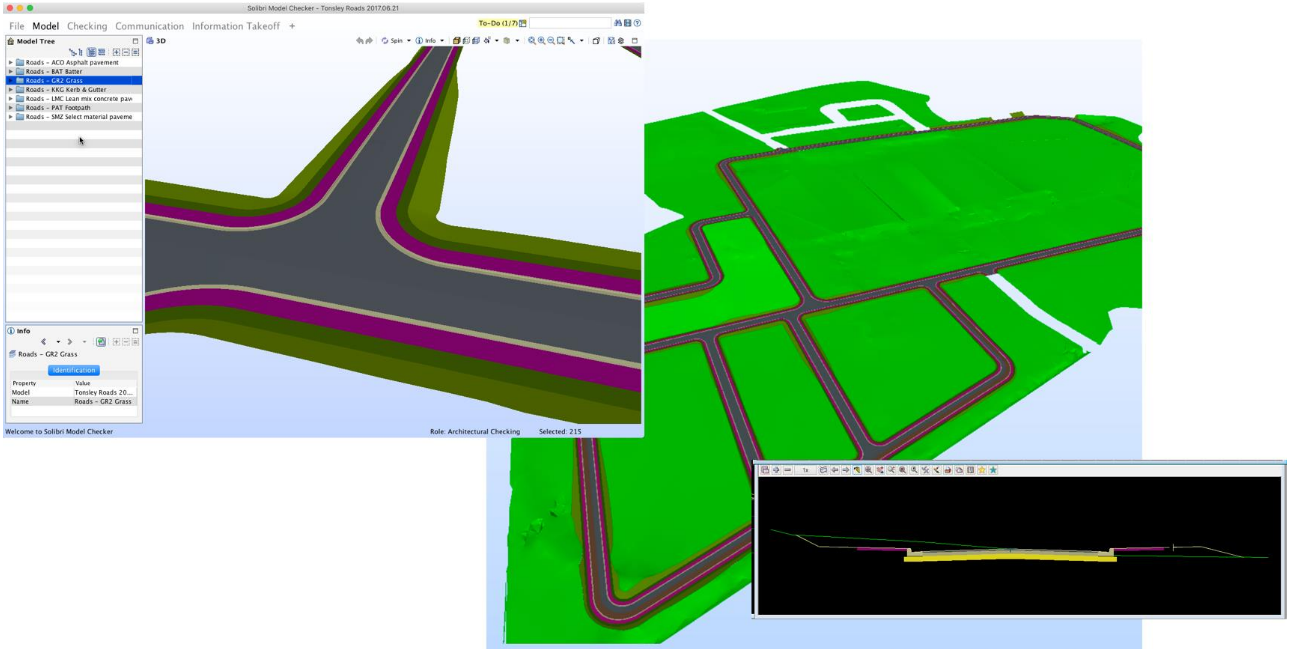

Figure 82 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

- Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM projectFigure 10.
- GIS (Geographic Information System) tools. These are widely used for modelling geographic regions. Though traditionally map-based, GIS tools now support 3D representations and make use of their own open standard formats, notably GML as the base standard with domain extensions such as CityGML (for city visualisations), IndoorGML (for interior fit outs) and InfraGML (for infrastructure).
- Though not actually tested in this project, it is important to recognise the existence of proprietary software tools and services designed to create and maintain 3D city models. These are traditionally focussed on creating visually accurate renditions of building form and the space and infrastructure around buildings. The data is typically created using flyover scanning techniques, employing both LIDAR and photogrammetry. Such models are becoming increasingly accurate, visually compelling and provide excellent urban planning and simulation opportunities. An important development in that field is the application of computer gaming technologies that facilitate real-time navigation of such models. These tools do meet a broad industry need and future work must explore how they can link into open built environment information standards.

Once the individual entities that make up a precinct model have been created, the challenge is to integrate those into a federated precinct model, based on the PIM schema. Since there is no software tool designed to do that, the PIM project team implemented two solutions.

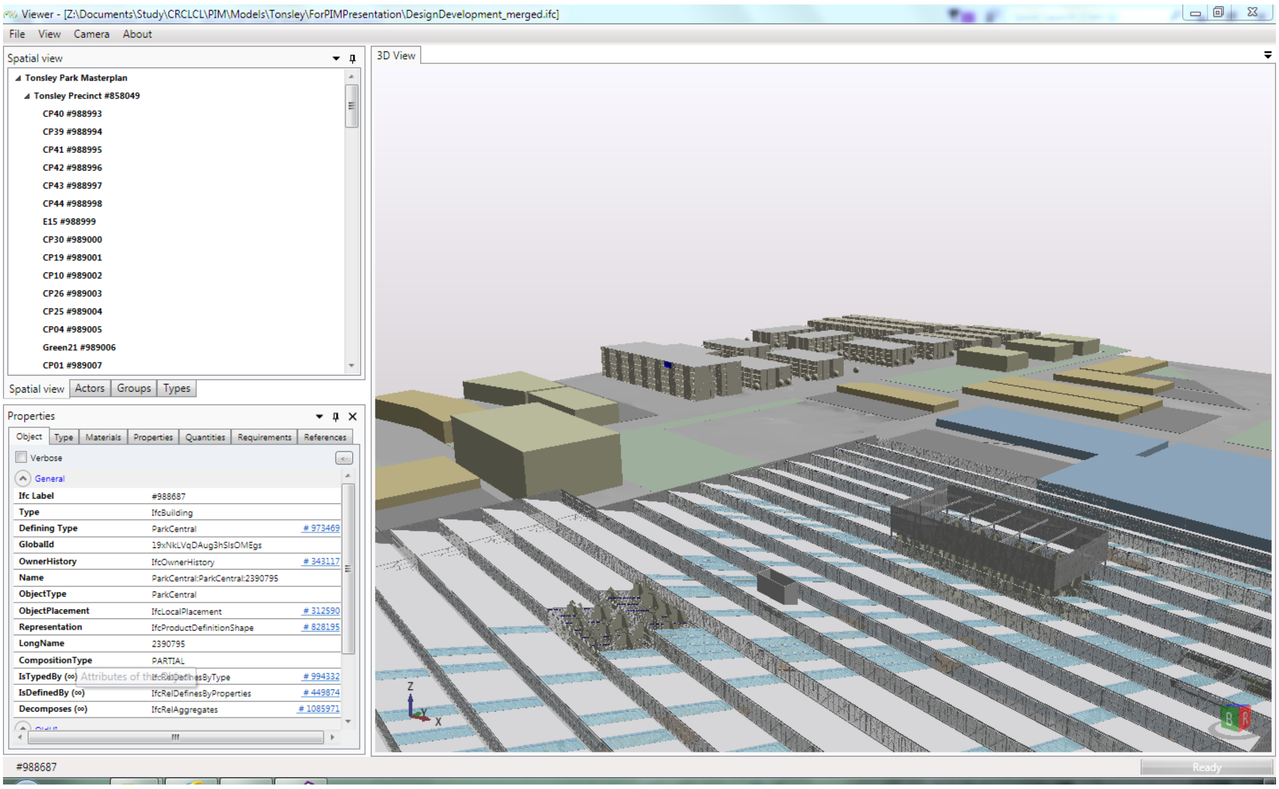

Figure 91 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

- The first makes use of a proprietary object database solution that is designed to handle large repositories of BIM data structured in IFC format. The advantage of that software platform is that it supports native IFC data, providing comprehensive tools for accessing, interrogating, merging and reporting. Since the database schema is defined in a transparent manner within the database platform, it has been possible to add the PIM extensions to that schema so that it becomes an internet-based repository for PIM models. It supports a standard object query language, allowing it to operate as a remote access repository of PIM data that can be interrogated from anywhere on the Internet. It comes with a standard client software tool that supports the management, navigation and visualisation of model data. The one limitation for our research on the PIM schema, is that the in-built visualisation software does not yet allow for the visualisation of precinct models held in PIM format.
- The second approach was to develop a new software tool designed specifically to provide functionality for viewing, navigating and interacting with a precinct model held in the PIM data format (and/or earlier versions of IFC). This is illustrated in Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.

Figure 13 - A portion of ETWW input data for TonsleyFigure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

- Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 and was implemented based on a set of open-source libraries with extensions written to fully support the proposed PIM entities. It can import PIM model data either by accessing a remote server database, or by reading a PIM model transfer file. It can also take from one source and export back to the other.

Prototype Applications of PIM

In this section, we briefly summarise work carried out as part of our collaboration with other CRC-LCL research projects. The material is reported in detail in a suite of Technical Investigations, listed in the References section.

Energy, Transport, Water and Waste (ETWW)

As a first step in collaboration between the PIM and the ETWW project, the PIM team reproduced the ETWW input and output data in PIM format, implementing a demonstrator model of the Tonsley brownfield precinct in Adelaide. The model includes 3D representations of the exemplar residential units to be developed on the site (arranged in background in Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.

Figure 13 - A portion of ETWW input data for TonsleyFigure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11). Each of the Tonsley scenarios is a separate PIM model, held on the PIM model server.

The Tonsley demonstrator model includes the original master plan for the site, as well as the demand forecasting analysis undertaken as part of the CRC LCL project ETWW (Taylor, et al. 2017). In addition, the proposed roadworks for the Residential Zone has been modelled in detail (Figure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM projectFigure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM projectFigure 10 - The Road sub-model for Tonsley merges with the site terrain model and comprises individual road elements such as pavements, kerb and guttering, etc.

Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM projectFigure 10) with road elements of pavement layers, kerb and gutters, batters etc. This is an example of the PIM extension for Road, a class of Built Facility (Figure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologiesFigure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologies

Figure 9 - Hierarchy of elemental entities in a precinctFigure 8 - PIM typologiesFigure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologiesFigure 7).

The ETWW research project addresses residential precincts in terms of the characteristics of household types. These household types are derived from Mosaic demographic data. Development assumptions in the ETWW Scenarios have been modelled with representative apartment types to assess the actual capacity of the sites and the urban environment impacts. The MAB (Multi-purpose Adaptive Building) – in the centre of the site is a detailed model of an existing building, while the other development zones are either modelled as development type zonal polygons, or as 3D block models to reflect a more detailed volume for planning or building consent assessment. This is illustrated in Figure 12 - Precinct model for the ETWW scenario A for Tonsley.

Figure 13 - A portion of ETWW input data for TonsleyFigure 12 - Precinct model for the ETWW scenario A for Tonsley.

Figure 13 - A portion of ETWW input data for Tonsley

Figure 14- Broadway Precinct Model, (including Ultimo extension)Figure 13 - A portion of ETWW input data for TonsleyFigure 12 - Precinct model for the ETWW scenario A for Tonsley.

Figure 13 - A portion of ETWW input data for TonsleyFigure 12.

ETWW data containing both inputs and output results for energy, transport, water and waste is held in an excel spreadsheet file. The spreadsheet data (Figure 13 - A portion of ETWW input data for Tonsley

Figure 14- Broadway Precinct Model, (including Ultimo extension)Figure 13 - A portion of ETWW input data for Tonsley

Figure 14- Broadway Precinct Model, (including Ultimo extension)

Figure 15 - Broadway Land Use Zoning for Sydney LEP 2012Figure 14- Broadway Precinct Model, (including Ultimo extension)Figure 13 - A portion of ETWW input data for Tonsley

Figure 14- Broadway Precinct Model, (including Ultimo extension)Figure 13) has been converted by the PIM team into IFC objects and defined by property sets replicating the ETWW detailed data. The model of this data (visualised in Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

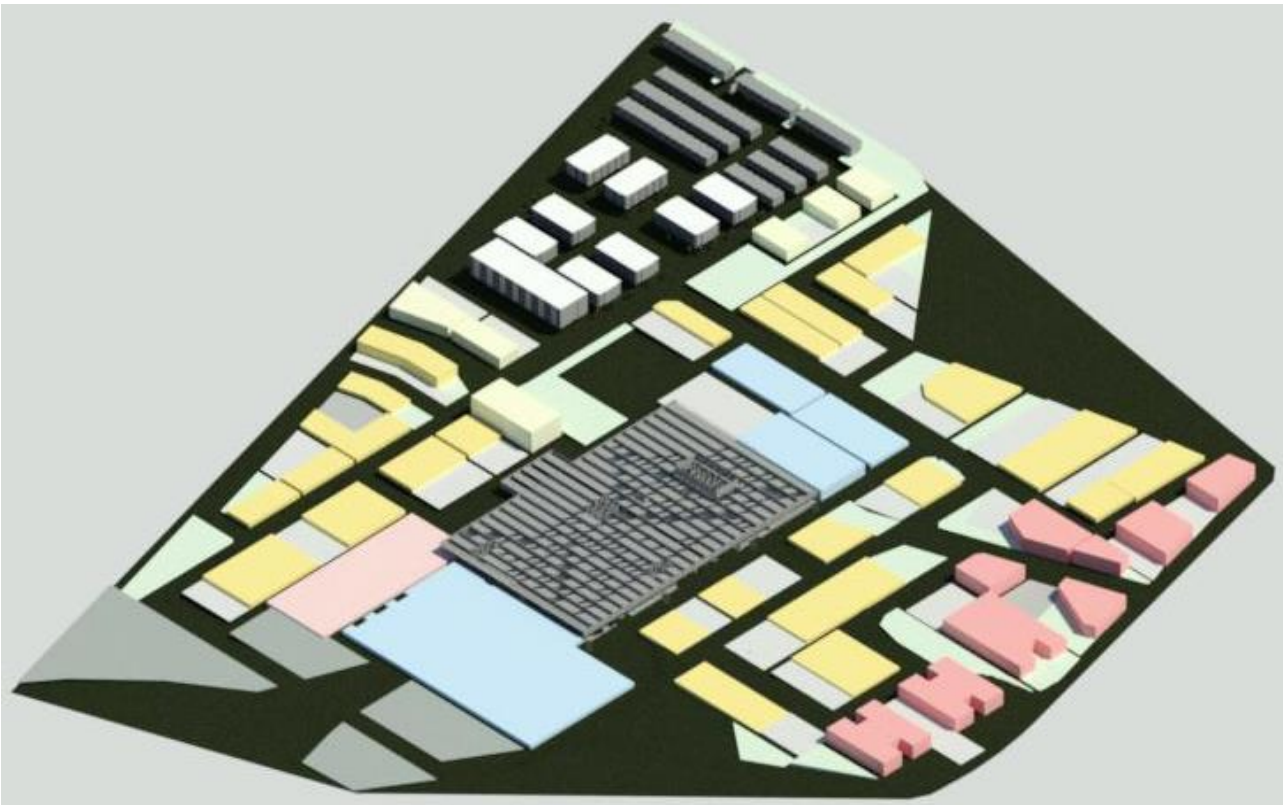

Figure 100 - Precinct model for the ETWW scenario A for Tonsley.

Figure 101 - A portion of ETWW input data for TonsleyFigure 102 - Precinct model for the ETWW scenario A for Tonsley.

Figure 103 - A portion of ETWW input data for Tonsley

Figure 104- Broadway Precinct Model, (including Ultimo extension)Figure 105 - A portion of ETWW input data for TonsleyFigure 106 -

	A	B	F	G	H	I
32			m2	10500		
33			size (kL)	0		
34						
35						
36		**Mosaic Code (2013)**		**B05**	**C13**	**D16**
37		**Residents**	Ave per hhold	**2.63**	**2.24**	**2.60**
38	**Household Typology**	**Workers**	Ave per hhold	**1.75**	**1.27**	**1.84**
39		**Dependants**	Ave per hhold	**0.89**	**0.97**	**0.75**
40		**Income**	Ave per hhold	$ 87,825	$ 79,371	$ 76,759
41		**Household Type**		3	1	2
42		**Description**	Type	Larger Detached	Apartment	Medium Size Detached
43			Proportion of total	9%	34%	57%
44			Households	10	36	60
45		**Bedrooms**	Ave per hhold	3.00	2.17	3.32
46				4.0	2.0	3.0
47		**Bathrooms**	Ave per hhold	1.47	1.22	1.79
48				2.0	1.0	2.0
49		**Parking allocation off-street**	Ave per hhold	2.0	1.0	2.0
50		**Parking allocation on-street**	Ave per hhold	1.0	0.5	1.0
51		**Plot Size**	m2	576	236	1069
52			m2	300	150	300
53		**Outdoor green space**	%	10%	0%	10%
54		**PEV**	Panels	15	12	10
55			Daily production (kW.hr)	12	10	8
56	**Household Structure**	**Rainwater Tanks**	size (kL)	4.5	1.0	3.0
57		**Vehicles**	total vehilces	**1.6**	**1.4**	**1.8**
58			electric vehicles	**0.0**	**0.0**	**0.0**
59			bicycles	2.0	2.0	2.0
60		**Appliances - Electric**	TV	2.5	1.0	2.0
61			Cooking	1.5	1.0	1.0

Figure 109 - A portion of ETWW input data for Tonsley

Figure 110- Broadway Precinct Model, (including Ultimo extension)Figure 111 - A portion of ETWW input data for Tonsley

Figure 112- Broadway Precinct Model, (including Ultimo extension)

Figure 113 - Broadway Land Use Zoning for Sydney LEP 2012Figure 114- Broadway Precinct Model, (including Ultimo extension)Figure 115 - A portion of ETWW input data for Tonsley

Figure 116- Broadway Precinct Model, (including Ultimo extension)Figure 117 - A portion of ETWW input data for Tonsley

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.

Figure 13 - A portion of ETWW input data for TonsleyFigure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11 - The PIM Viewer application, developed specifically for the CRCLCL PIM project

Figure 12 - Precinct model for the ETWW scenario A for Tonsley.Figure 11), demonstrates that all other concepts of the ETWW analysis requirements can be stored in a PIM repository

The Broadway Precinct – A Testbed for Precinct Concepts

To date the precinct model developed initially for the Empowering Broadway project (RP2018) has supported a number of key investigations and findings:

Creation of a large data set of building instances (over 400 in the immediate precinct of interest in Broadway, Sydney, and a further 200 in the Ultimo extension) derived from the City of Sydney's Floor Space and Employment Survey (FESES) data. The council's data was converted into PIM format using bespoke software developed by the MUtopia group at the University of Melbourne (early partner in the PIM project). The Broadway precinct model is essentially an aggregation of 3D space representations, organised into buildings and storeys across the precinct, with simple external wall and slab objects to enclose each building. The precinct model is shown in Figure 14- Broadway Precinct Model, (including Ultimo extension)

Figure 15 - Broadway Land Use Zoning for Sydney LEP 2012Figure 14- Broadway Precinct Model, (including Ultimo extension)

Figure 15 - Broadway Land Use Zoning for Sydney LEP 2012

Figure 16 - Development Planning using PIMFigure 15 - Broadway Land Use Zoning for Sydney LEP 2012Figure 14- Broadway Precinct Model, (including Ultimo extension)

- Figure 15 - Broadway Land Use Zoning for Sydney LEP 2012Figure 14 and comprises 379 sites (lots), 440 buildings and 16,000 rooms.
- Understanding in detail how Development Planning works under the NSW Local Environment Planning legislation (LEP) using the concepts of Land Use Zones and Development Types (see Mitchell, et al. 2016a)
- Understanding the role of cadastre – legal land ownership – in current surveying systems and the context for map-referencing and GNSS in precinct scale developments
- Understanding how Local Governments (represented by the City of Sydney) classify building assets and the organisations that use these facilities to understand changes in development activity within a local government area (LGA)
- Identifying the properties of precinct objects (at their differing levels of typology or detail) to capture environmental impacts and embodied carbon for comprehensive sustainability performance recording (Mitchell, et al. 2016b)
- A test bed for landscape planning and road modelling through contributions from two private organisations
- A platform for testing the requirements for an extended urban context to include built facility types other than buildings, such as roads, bridges utilities and civic space.

The Empowering Broadway Project

The CRC LCL Empowering Broadway project aimed "to identify and understand the economic, stakeholder, regulatory and technical barriers *to transitioning existing communities to low carbon energy and water solutions*...". (Swinbourne et. al. 2016). A key element of the project was "to empower stakeholders within communities to *drive transitions to low carbon energy and water use*, by providing them with the data and processes they need for change". The federal government's recent decision to expand the National Carbon Offset Standard (NCOS) to buildings, precincts and cities gives added impetus to precinct modelling such as this (Department of the Environment and Energy 2016)).

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

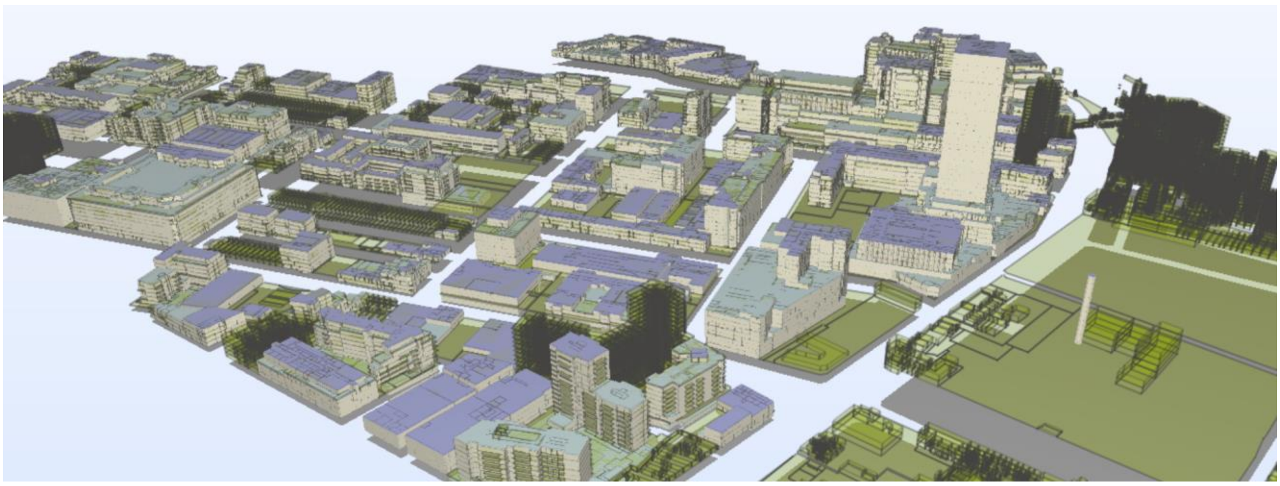

Figure 118- Broadway Precinct Model, (including Ultimo extension)

consumption, patterns of usage, etc.

It was noted at the outset, that the data necessary for the analyses does not necessarily require 3D modelling, but might require some spatial “connection“ data, electricity and water usage data, as well as location and the condition status of existing plant.

While the PIM team were able to demonstrate the capability to store the required data, the Empowering Broadway project was unable to proceed beyond its first year, so the goals was not fully realised.

Broadway in a Planning Context

Development of land in all Australian States follows Planning Department legislation that sets out the zones in which these developments may occur and what development types are allowed on that land. The discussion below examines the NSW Local Environment Planning (LEP) system in general and the specific LEP for the City of Sydney of which the Broadway Precinct in Sydney is a part. The PIM team have focussed on the early concept planning stages using functional and occupancy typologies where precinct sustainability assessment tools like Precinx and SSIM are used (Newton, et al. 2013). Figure 15 - Broadway Land Use Zoning for Sydney LEP 2012

Figure 16 - Development Planning using PIMFigure 15 - Broadway Land Use Zoning for Sydney LEP 2012

Figure 16 - Development Planning using PIM

Figure 17- Calculating embodied carbon using ICM metricsFigure 16 - Development Planning using PIMFigure 15 - Broadway Land Use Zoning for Sydney LEP 2012

Figure 16 - Development Planning using PIMFigure 15 below shows Land Use Zoning for the wider precinct surrounding the PIM Broadway site, in the Local Government Area (LGA) of Sydney.

Figure 127 - Broadway Land Use Zoning for Sydney LEP 2012

The permitted uses for this LGA are: R1 General Residential; B4 Mixed Use; B8 Metropolitan Centre; SP1 Special Activities (not in Broadway Precinct); SP2 Infrastructure; RE1 Public Recreation; UL Unzoned land.

Figure 16 - Development Planning using PIM

Figure 17- Calculating embodied carbon using ICM metricsFigure 16 - Development Planning using PIM

Figure 17- Calculating embodied carbon using ICM metrics

Figure 18 - Initial Project Framework as defined in the Urban Microclimate Project ProposalFigure 17- Calculating embodied carbon using ICM metricsFigure 16 - Development Planning using PIM

Figure 17- Calculating embodied carbon using ICM metricsFigure 16 (over page) illustrates a scenario whereby a designer is developing proposals for a Commercial Building, one of the permitted uses in Zone B4 in the Sydney LEP. The reference data is held in the cloud, allowing the designer to verify that such a usage is permitted in that zone. To support the designer’s sustainability assessment, carbon data would be available online in a national CO2e database, and indexed through the bSDD property definitions. The data is downloaded into the designer’s model. The DA proposal is uploaded to the Council DA repository, and assessed by the Council’s customised model auditing tools to verify compliance. The council officer checks that the submitted model data meets the LEP and Planning controls and is returned with compliance data added to the model.

To demonstrate this scenario, the PIM team have created two simple add-in tools for existing commercial BIM authoring software packages that allow a planner to reference permitted land use types while working on a development proposal that is compatible with the PIM format. The tools reference the land use development type data via the internet and present this to the planner as a simple drop-down list. The selection made from the list is incorporated into the model as properties of zonal entities (2D areas and/or 3D masses). In the case of referenced bSDD information, the globally-unique identifier (GUID) of the chosen concept is also stored as a property.

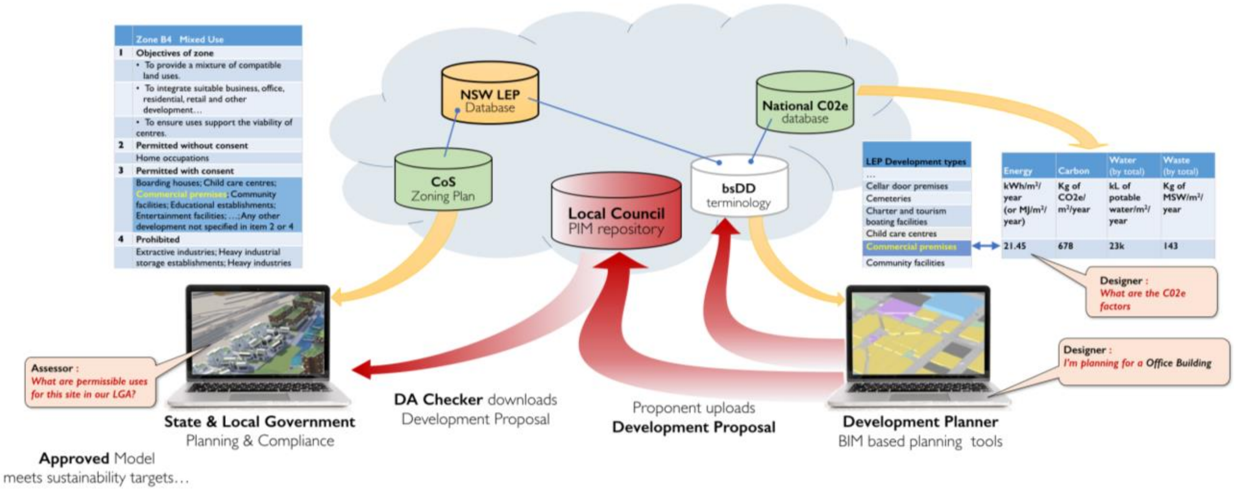

Figure 136 - Development Planning using PIM

Integrated Carbon Measurement

The Integrated Carbon Metrics (ICM) research project has taken a top-down approach to determining embodied carbon metrics based on national sector-based (input-output) economic data. The challenges encountered in applying all such data to precinct-level objects are: the comprehensiveness of the data (that is, are there available metrics for enough materials or elements of the built environment to allow for calculating a meaningful summation of the embodied carbon of a precinct); and, the level of detail at which the metrics are available (that is, can the metrics be applied at an aggregated level in the same way that building costs can be applied per square metre of functional area). Since ICM provides per dollar carbon metrics, for a precinct model it is first of all necessary to calculate the cost of each component of that precinct (entity or material of which it is composed) then multiply by the embodied carbon measure. For a precinct designer, for example, this requires the integration of the two sources of reference data (costs and embodied carbon) as shown in Figure 17- Calculating embodied carbon using ICM metrics

Figure 18 - Initial Project Framework as defined in the Urban Microclimate Project ProposalFigure 17- Calculating embodied carbon using ICM metrics

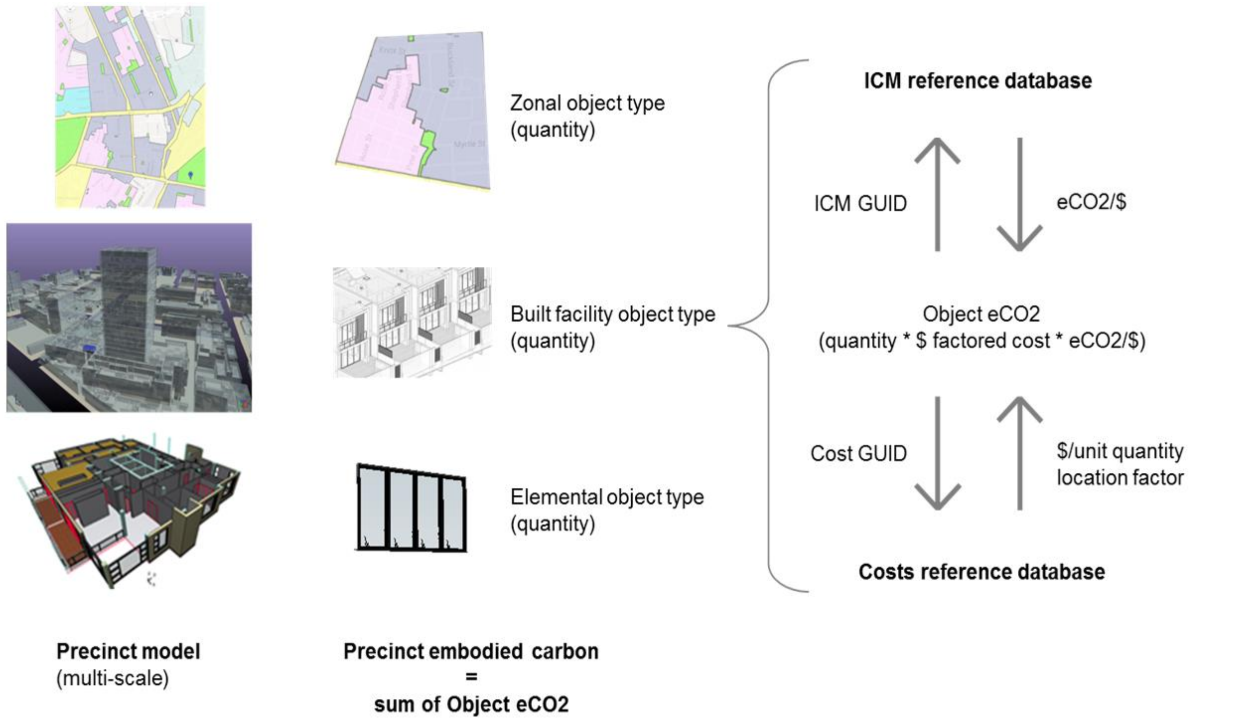

Figure 145- Calculating embodied carbon using ICM metrics

Figure 18 - Initial Project Framework as defined in the Urban Microclimate Project ProposalFigure 17- Calculating embodied carbon using ICM metrics

Figure 18 - Initial Project Framework as defined in the Urban Microclimate Project ProposalFigure 17, where the ICM GUID and Cost GUID labels in the diagram refer to globally unique identifiers (GUIDs) that allow particular entries in the respective databases to be unambiguously accessed.

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

Several areas of work are required to aggregate ICM data to make it applicable to actual precinct information models. For example, typical housing types (either as a whole or on some measurement basis such as per bedroom, or per number of occupants), per kilometre of typical roadway types, or per hectare of open space (parkland etc). This work has been hampered to date by an insufficient palette of available carbon metric data.

Urban Heat Islands

The “Microclimate and Urban Heat Island Decision-Support Tool” project (RP2023) aims to develop a microclimate and urban heat island mitigation decision-support tool to evaluate urban redevelopment proposals that increase density (and potentially temperatures) in built-up areas of Australian cities. The project framework is described in Figure 18.

The Urban Heat Island project commenced just as the PIM project was concluding, so the following are suggestions only on how PIM could be utilised (see also Figure 6 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 7 - Proposed spatial structure hierarchy for precinctsFigure 6 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 7 - Proposed spatial structure hierarchy for precincts

Figure 8 - PIM typologiesFigure 7 - Proposed spatial structure hierarchy for precinctsFigure 6 - Common precinct objects with their representation in CityGML and the PIM data model

Figure 7 - Proposed spatial structure hierarchy for precinctsFigure 6). Within the framework shown in Figure 18, the PIM project could contribute three essential components:

- An object-based model repository for exemplar precincts used to implement and test both the scenario analysis and the assessment of the predicted UHI mitigation outcomes. Importantly, these precinct models would be based on an open standard format (the PIM schema) so that the

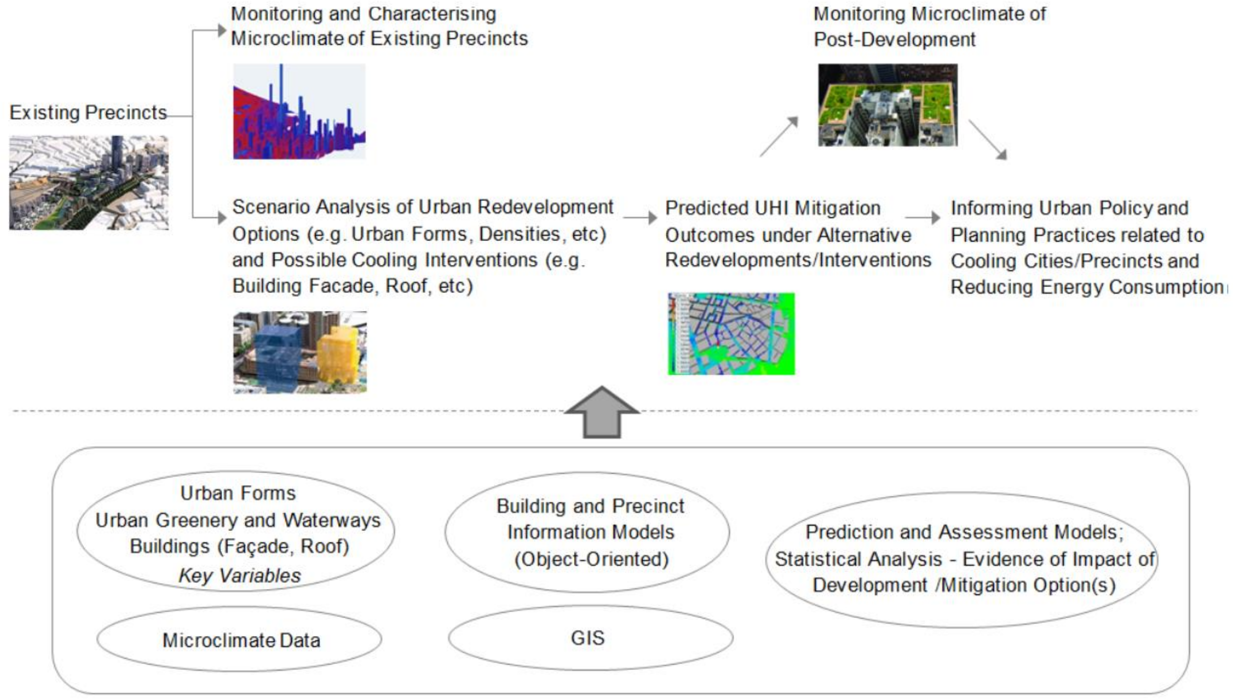

Figure 152 - Initial Project Framework as defined in the Urban Microclimate Project Proposal

information can be shared with other precinct analysis tools. The PIM project would provide an on-line portal that allows researchers and other stakeholders to access the precinct models database remotely.

- Support within the PIM concept model for the specific precinct entities (at appropriate levels of granularity) that are used to represent the physical environment for UHI analysis. The “key variables” identified as part of the project would be expressed as properties of those precinct entities, forming the basis for determining the UHI mitigation index. These entities fall broadly into two categories: built form and vegetation features that provide shading and localised microclimatic effects (air movement and humidity); and, the surfaces that radiate, absorb or disperse heat within the built environment.
- A repository for reference data that holds the relevant property values for precinct entity types. This would be accessed by the decision-support tool when performing the analysis.

A determinant of urban microclimate is the form, position and orientation of the urban fabric. This can be modelled at different levels of granularity. PIM would allow accurate representation of all the individual features that may have some impact on microclimate, including building form, street layout, vegetation (ranging from ground cover, shrubs and small tress, through to significant trees), water bodies, street furniture and other urban structures. This would allow for fine-grained analysis of localised conditions. At a coarser level of granularity, urban precincts could be organised into spatial zones that have particular characteristics, such as: open parkland; sparse bushland; dense canopied bushland; low-rise, sparse residential areas; compact, low-rise residential; high-rise commercial; etc. Such zones would be classified and could be treated as precinct objects for analysis purposes.

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

Prospects for PIM

Within Australia we are witnessing some significant implementations and adoption of digital modelling albeit with very limited national coordination at present, and we present below a hierarchy of systems that underpin representative efforts to enhance the built environment using digital models. These examples represent tangible activity that underpins or complements the PIM vision.

- In our creation of the Tonsley and Broadway precinct models, we have implemented the NSW and SA state versions of their planning systems. Both rely on a set of Zoning types, which specify permitted development types. The systems are very close in design, but not wholly so, and the remainder of the states have slightly different versions again. This is a situation that is similar to the case of the Building Code of Australia (BCA) when it adopted a national standard to replace each of the state's independent building ordinances. If there were a national adoption of a Land Environment Planning system that allowed for the integration of many GIS and legal aspects, this would provide a digital foundation for planning, and thereby urban and precinct modelling.
- The NSW BASIX system for environmental residential building performance assessment is an exemplary candidate for digital implementation. This vision was presented in the UrbanIT project with NSW Department of Planning as a major sponsor in 2010 (Plume and Mitchell 2011). Developments since then have seen a considerable maturity of authoring software and, for example, the availability from CSIRO of the AccuRate library of embodied carbon data for typical building elements (walls, roofs and floors). It is understood that the new versions of AccuRate will support IFC format residential models, which should lead to greatly improved, faster assessment and certification of compliant BASIX applications. If Local Government was to adopt this modelling practice, then a more reliable measurement of performance is possible.
- Safety and security have become a major concern (in particular since the Southbank fires in Melbourne or the Grenfell Tower fire in London). Managing the control of product quality and performance is a crucial role that regulations need to play for citizen's protection and well-being. The recent Queensland enquiry entitled, "Building and Construction Legislation (Non-conforming Building Products—Chain of Responsibility and Other Matters) Amendment Bill 2017" highlights the concern by Governments to enforce product compliance regulations. Product data libraries are a critical resource for designers who need accuracy about product geometry, performance attributes, compliance and related matters. In Europe, this has led to the adoption of digital product compliance certificates called Environment Product Descriptions (EPD). EPDs also address sustainability factors including embodied carbon.
- We note that BIM is not a static technology – significant resources are being applied to support the extension of BIM to include infrastructure (increasingly known as Digital Engineering) and PIM concepts are broadening that scope to encompass urban or city modelling. A handbook on BIM benefits published by EUBIM (EUBIM 2017), a task group established by the European Union, has identified that BIM "is the technology-led change most likely to deliver the highest impact to the construction sector. The prize is large: if the wider adoption of BIM across Europe delivered 10% savings to the construction sector then an additional €130 billion would be generated for the €1.3 trillion market. Even this impact could be small when compared with the potential social and environmental benefits that could be delivered to the climate change and resource efficiency agenda. The purpose of this handbook is to reach for this prize by encouraging the wider introduction of BIM by the European public sector as a strategic enabler; and to adopt an aligned framework for its introduction into the built environment and construction sector. This alignment brings clarity and repeatability to this digital innovation across Europe – reducing divergence, misunderstanding and waste. It will accelerate growth and encourage competitiveness of the construction sector, especially its SMEs." The same message comes through strongly in (Khanzode and Lamb 2017).

Future Directions

There is still much work that needs to be done in order to test (and refine) the proposed PIM schema, and so future work is focussed on participating in real-world precinct modelling projects to work toward that goal. The lessons learnt and ideas created in doing this work are also being fed back into the international standards development work to ensure that future releases of the IFC data model will be able to support precinct-scale modelling, and be taken up by commercial software developers in the future.

During the life of the PIM project and continuing beyond its completion, members of the project team have deliberately become engaged in the work of buildingSMART International (bSI), and its collaborative efforts with the Open Geospatial Consortium (OGC), in order to present the learnings from this work to that international community and thereby influence the ongoing development of IFC in particular, and its interface to corresponding OGC and related standards in the geospatial domain. Those engagement activities are more fully described in the Project Progress Report (Plume, et al. 2016) prepared in late 2016 for the PIM project review. The incorporation of our learnings into international standards and the ultimate implementation of those ideas in commercial software is a long-term endeavour, but once achieved, has the potential to reap very significant utilisation benefits.

The potential economic impact of the PIM project is possible to assess. The initial forecast of economic impact of this work (in the Impact Tool prepared for the CRC bidding process) was based on an economic study of BIM (Allen Consulting Group 2010) and its impact on the "buildings network", which was defined as, "those players and activities that relate to the whole life of a building and that generate large amounts of data that needs to be shared throughout a building's life, including architects, engineers, builders and contractors, as well as owners and facility managers." That study anticipated the monetary impact of an accelerated adoption of BIM in the building sector (in 2010) would be in order of $4.8 billion over 15 years in 2010 dollars (noting that they regarded that as a "very conservative" figure). Recognising that the urban planning sector is smaller, the Impact Tool estimated an increase in GDP of $1.75 billion over 15 years resulting from PIM adoption in that sector.

Since these forecasts were made, there have been some very significant shifts in both industry and government perceptions of BIM, both nationally and internationally. Those have directly influenced our PIM work, leading us in directions, with related conclusions, that we did not foresee in 2010. The main shifts are summarised below.

- There has been a rapid upsurge of interest within the linear infrastructure domain (mainly major transport authorities such as road and rail) in the adoption of BIM technologies and processes. This is apparent both nationally and internationally – particularly in the European Union where infrastructure developments by Governments must conform to CEN's adoption of the IFC open standards - and has driven a strong agenda to develop IFC extensions to support life cycle modelling of roads, railways, bridges and tunnels. This is increasingly referred to as digital engineering and forms a key aspect of PIM.
- At the same time, there is a growing recognition of the value of these techniques in the planning and design of precincts (extending to Smart Cities and more robust approaches to the management of the built environment), with expected eco-efficiency benefits (incorporating for both carbon management and productivity, both areas of CRCLCL focus). However, efforts to standardise that work typically takes second place to the demands of large-scale transport infrastructure where there is potential for very large productivity gains in construction (in the order of 14-15% estimated by McKinsey 2017).
- There has been a growing commitment to collaborate across three international standards organisations: buildingSMART International (bSI), the Open Geospatial Consortium (OGC) and the World Wide Web Consortium (W3C). This collaboration is to ensure that effort is not duplicated in the development of open modelling standards for the wider built environment in a period of rapid global urbanisation. The learnings from the PIM project have been inserted strongly into that discussion, providing a deeper understanding of the relationship between data standards for precincts and how they should complement each other (Plume, et al. 2016).
- Within the Australian context, there is a growing commitment to the adoption of BIM technology and processes, particularly in the infrastructure space. A significant starting point was Recommendation 10.4 from the Australian Infrastructure Plan (infrastructure Australia 2016), followed by the National Digital Engineering Policy Principles, endorsed by the Transport and Infrastructure Council in their Communique dated 4 Nov 16 (The Transport Infrastructure Council was established by COAG and includes Transport, Infrastructure and Planning Ministers from the Commonwealth, States and Territories, New Zealand and the Australian Local Government Association), the recent launch of the Australian BIM Advisory Board (ABAB), and most recently, the release of a BIM policy draft (DILGP 2017) by the Queensland Government that emphasises the importance of open BIM standards for infrastructure.

Though large-scale linear infrastructure projects go beyond the scope of PIM, infrastructure elements such as local roads and light rail are well within scope. We have made significant contributions to the international standards communities (both bSI and OGC), based on our work on PIM, and have participated strongly in dialogue on the coordination of BIM and spatial standards (Plume, et al. 2016).

The urban planning and property development sectors are lagging behind their counterparts in architecture, construction and BIM in this respect.

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PIM Project Reports

The following PIM Project Technical Reports are available at: http://lowcarbonlivingcrc.com.au/research/program-2-low-carbon-precincts/rp2011-pim-open-digital-information-standard-throughout

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