Precinct Information Modelling

A new digital platform for integrated design, assessment and management of the built environment

Peter Newton, Jim Plume, David Marchant, John Mitchell and Tuan Ngo

Introduction

Cities are among the most complex systems on earth and for most nations their largest national assets and economic engines. In the twenty-first century, they are expected to be home to approximately two-thirds of a forecast nine billion people. Planning and managing the built environments of large, rapidly growing cities in a manner that delivers sustainable, liveable, resilient and equitable urban development constitutes one of the grand challenges facing contemporary societies. There are many critical transitions required for the creation of sustainable built environments (Newton, 2008; Newton et al., 2009; Newton, 2012). *Digital transformation* is one such transition; including the manner in which it can deliver the innovation required across all sectors of industry, including the built environment sector.

Much has been written about the capacity of information and communications technologies (ICT) to radically improve the performance and productivity of built environments, practitioners and their outputs. Over 20 years ago, it centred on capitalising on the emergence of high-speed digital broadband networks to enable real-time design collaboration and closing the information loop across the supply chain (Newton et al., 1993; Newton, 1995); and more recently creating a new platform for information modelling at building scale through Building Information Modelling (BIM) (Newton et al., 2009), with the Cooperative Research Centre (CRC) for Construction Innovation playing a catalytic role in Australia. Focus is now shifting to Precinct Information Modelling (PIM) and in a more general sense to urban information modelling. As focus for a 2013 scoping study by the Australian CRC for Low Carbon Living (Newton et al., 2013), PIM was conceived as a digitally enabled information platform comprising a set of standards and protocols that could harmonise and direct the fragmented activity involving urban modelling of big spatial datasets at precinct scale. Conceptualisations by the International Organization for Standardization (ISO) in relation to urban sustainability (Figure 7.1) and smart infrastructure frameworks (Figure 7.2) highlight the complexity and dimensionality of the challenge.

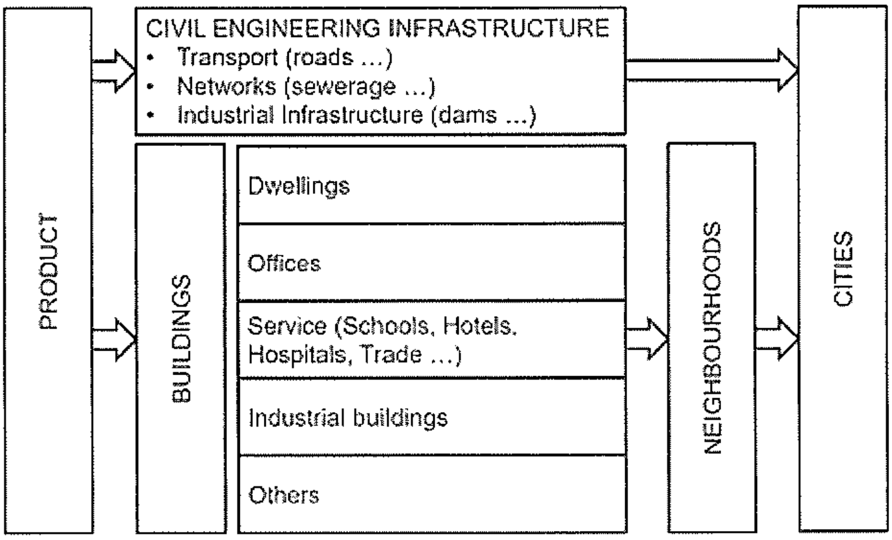

Figure 7.1 The urban sustainability framework: products, buildings, infrastructure, neighbourhoods and cities.

Source: Newton et al. (2009), used with permission.

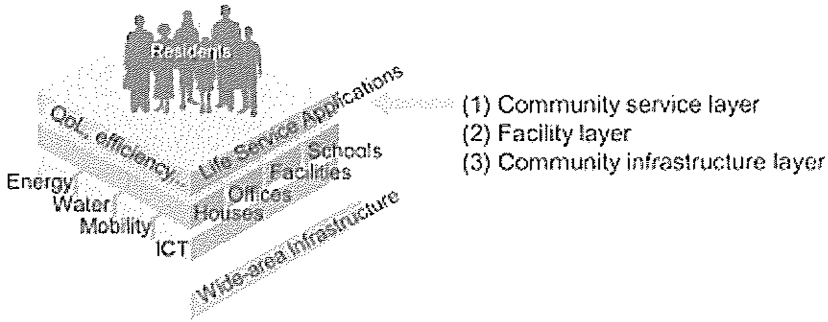

Figure 7.2 ISO model of multiple information layers required for precinct representation and performance assessment of smart sustainable built environment.

Source: Ichikawa (2013), used with permission.

The spatial scales for built environment modelling range from product scale objects to building objects to neighbourhood representations and upwards to cities and regions. As scales change so do opportunities for different types of information modelling application: BIM → PIM → GIS, with the need for data interoperability across these key analytical lenses (Figure 7.3). Geographic Information Systems (GIS) emerged in the 1970s, followed more recently by BIM to cater for the needs of planners and architects respectively. Urban design spans planning and architecture as well as the GIS-BIM information and modelling environments, operating primarily at neighbourhood/precinct scale. PIM as proposed here is central to this scale of urban innovation.

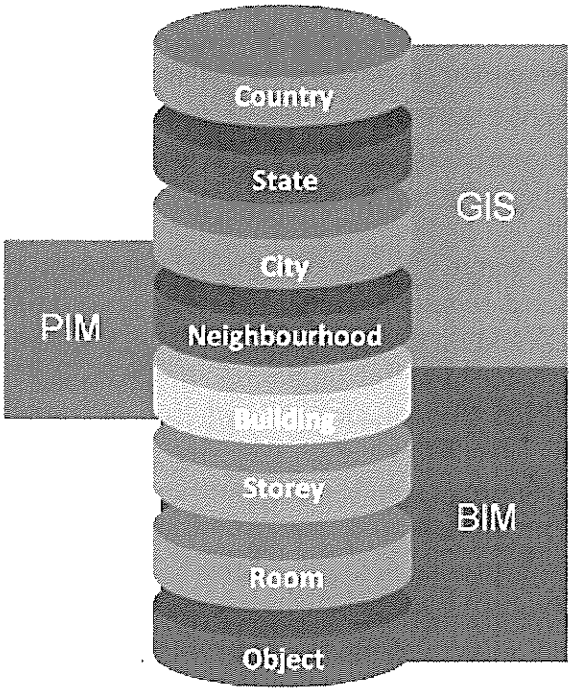
Country
State
City
Neighbourhood
Building
Storey
Room
Object
GIS
PIM
BIM

Figure 7.3

Spatial information platforms for the built environment.

Precincts constitute the critical operational scale at which a city is assembled (greenfields), re-built (brownfields, greyfields) and operated; and where residents spend large proportions of their day either in domestic or workplace settings (Figure 7.2). 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, that the unsustainable nature of today's cities is due in part to poor planning at the neighbourhood level (Codoban and Kennedy, 2008). 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, medium density, and walkability and public transit access having been designed into urban neighbourhoods in recent decades. Purely in CO_2 terms, variability in the housing and transport attributes of different suburbs means that neighbourhood-scale carbon emissions can vary by as much as 50 per cent across low-density, car-dependent 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 it is the scale at which an optimal combination of urban design innovation, urban technology innovation and behaviour change can jointly occur.

At precinct scale, the volume of data and information required to effectively model the built environment expands significantly beyond that required for an individual building: more than 7,000 individual objects for a city building, based on an examination by the authors of a range of typical commercial BIM models produced by architects, and not including detailed services information. It is at this scale where a convergence of digital technologies is required to support built environment planning and management. PIM is emerging as a critical platform for more effective planning, design and management of relevant spatial data at that scale. The operational structure of PIM is explained in a later section of this chapter. Since it is held in an accessible open standard format, any precinct can be modelled to accommodate the disparate needs of the range of analysis and operational activities that support more sustainable performance of precincts throughout their life-cycle (Figure 7.4). This is a fundamental, but still almost universally absent, component of urban development at either building or precinct scale.

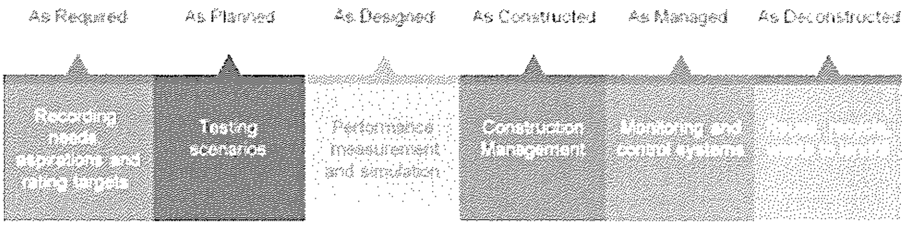

Figure 7.4 Temporal information platform for the built environment: precinct life-cycle.

A review of precinct scale assessment and rating systems, undertaken by the authors, reveals an increasing demand for tools that respond to the broad 'goals for built environment performance' established by national, state, metropolitan and local governments: sustainability, resilience, liveability, productivity and equity (Newton et al., 2013; Figure 7.5). These goals stimulate the development of performance indicators across core built environment systems such as energy, water, transport and waste, and more broadly into other areas such as human health and urban microclimate (Department of Infrastructure and Regional Development, 2011). 'Assessment tools', alternatively termed design decision support, model the performance of the precinct across core built environment systems such as energy, water, transport and waste, as well as the interactions and interdependencies that are in play, such as water–energy nexus and carbon mitigation–adaptation nexus. These tools rely on varying levels of computational sophistication as well as data and are continually evolving. 'Rating tools' (such as Green Star Communities, EnviroDevelopment, IS Rating, Building Research

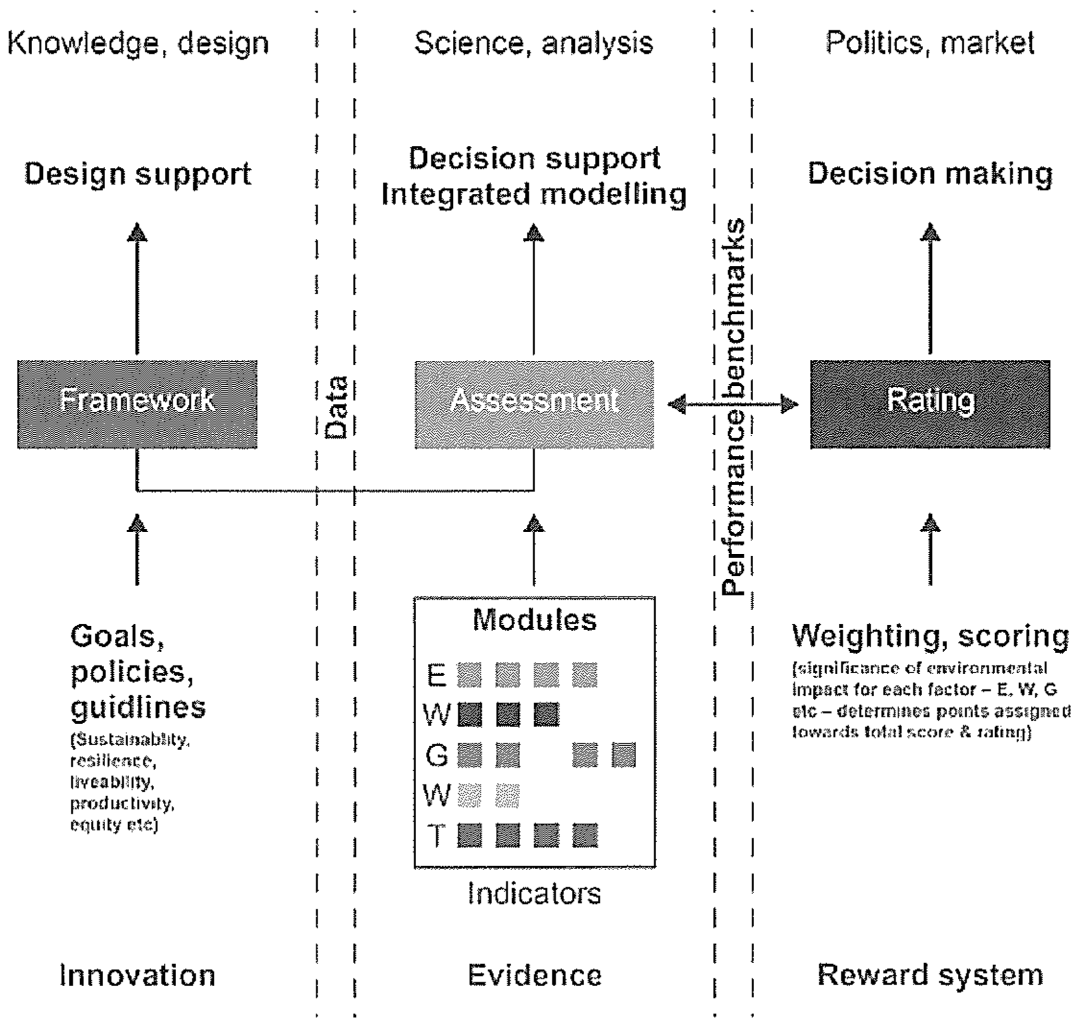

Figure 7.5 Precinct performance assessment framework.

Source: Adapted from Newton et al. 2013, used with permission.

Establishment Environmental Assessment Methodology (BREEAM) and Leadership in Energy and Environmental Design (LEED)) take the outputs from the assessment modelling as a basis for assigning weights ('importance') and ratings for use in industry 'labelling' or certification. Currently, most precinct assessments and ratings are evaluated against sets of benchmarks established by industry groups and/or governments. A PIM digital platform is designed to effectively support all the operations depicted in the precinct performance assessment framework (Figure 7.5). To date, only a small number of tools, such as MUtopia (Ngo et al., 2014) and ESP (Trubka et al., 2016) have been developed to undertake precinct assessment by taking advantage of PIM, object-oriented modelling and 3D visualisation. PIM-enabled data assembly and software application feature in the case studies reported at the end of this chapter. Before then, the following sections will address the geospatial context that has enabled PIM to emerge and the operational structure of PIM circa 2016.

Towards a digital built environment

It is important to recognise that PIM is only a part, albeit a very significant part, of a much bigger conception of the emerging role of digital technologies throughout the world. To appreciate that context, the idea of a digital built environment (DBE) encompasses all the digital technologies that are in widespread use today, and indeed still evolving, to help us understand and manage the physical built environment. As argued elsewhere:

> We envision an inevitable shift towards a world in which our interaction with the physical world is increasingly facilitated through digital technologies that rely on data and information, either to inform the decisions that we take, or, where appropriate, form the basis for the autonomous response of entities acting for our benefit in the physical world.
>
> (Plume, 2015)

This is a bold vision. It recognises that the vast amount of information we now create, collect and hold in diverse databases and models, using a plethora of technology, tools and innovations, can be linked to the physical world that we inhabit in order to activate our engagement and interaction with our environment. Imagine a scenario in which you are able to sense, through your own smartphone, not only all aspects of the current operational state of the physical world around you, but also its wider demographic, socioeconomic, environmental, regulatory and institutional context, and perhaps also the intent that lies behind the planning and design of that built environment. With all that information available, new apps will be developed that make use of that data to shape our experience and enjoyment of the world in ways that we cannot yet imagine. Similarly, the physical built environment will detect our presence and use whatever personal information we choose to reveal about ourselves to formulate responses to our needs and aspirations at that time and location.

This scenario, of course, paints a picture from our perspective as end-users and citizens, but there is an even more significant role for those who act as custodians of the built environment, particularly the diverse responsibilities of built environment professionals who range across a very broad spectrum from planners, architects and designers, engineers of many hues, constructors and trade specialists, through to asset, facility and operational managers. All these disciplines seek access to fully integrated information about the built environment to enable the planning, design, construction, management and operation of the constructed world. Although much of that information already exists, the vision of a fully integrated digital built environment would facilitate its access.

The challenge is to develop robust ways of integrating all that information across the entire life-cycle of built facilities and infrastructure, ranging across all scales of development from urban land, buildings, service utilities (e.g. water, energy), transport network infrastructure, civil and landscape engineering projects, all the way up to an urban or regional scale.

At the heart of this vision are two traditional modelling or digital prototyping technologies, falling broadly into either the spatial domain or the design/construction domain (Plume et al., 2015). The modelling technologies for the spatial domain are often characterised as GIS. This generalisation, however, underrates the scope of technologies now associated with spatial modelling. These include satellite imaging, photogrammetry, laser scanning and Light Detection and Ranging (LiDAR), city modelling, smart city technologies (the Internet of Things), global navigation satellite systems (GNSS) and emerging initiatives like the Digital Earth. The modelling technologies associated with the design and construction domain are similarly characterised as BIM. This again fails to recognise the ever-widening scope of its application to all forms of civil, transport, mining and utility infrastructure and the expansion of its scope to encompass software technologies that accommodate both policy and processes associated with managing the built environment.

Most of these tools and approaches are developed as proprietary technologies and are often unable to share information across those software platforms in a reliable fashion. Although open information exchange formats exist in both domains, their development relies on limited funding and struggles to keep pace with the rapid innovation that is possible in the commercial sphere. At a project level, where industry is under constant pressure to innovate and deliver, there is a tendency to rely on a proprietary suite of software tools supplied by a single vendor. Robust open standards can break this reliance on exclusive proprietary software systems and serve to encourage wider commercial software innovation based on vendor-neutral data formats.

buildingSMART is a worldwide not-for-profit industry organisation that has developed open standards for exchanging BIM data, as well as standardised processes and technologies needed to support collaborative design (buildingSMART, 2016). There has been a shift, since around 2013, to apply these standards to transport infrastructure projects (roads and railways) and civil structures such as bridges and tunnels. The Open Geospatial Consortium (OGC) is the complementary global standards organisation that serves the spatial sector by developing standards for the delivery and management of spatial data across the internet (OGC, 2016). It is well known for its CityGML and Indoor GML standards.[1] Currently, OGC is actively working towards a new standard known as InfraGML, designed specifically to address the modelling of infrastructure elements of the built environment.

These modelling approaches have been traditionally seen as complementary, each addressing exclusively their own disciplinary needs, but there is a growing recognition that in order to address the pressing needs of global urbanisation, climate change, carbon accounting and management and urban resilience, it is critical to find ways of integrating information across these two domains. There are a number of initiatives in different parts of the world to bring these two domains together (JBIM, 2010; Galbraith, 2015; Gomez Zamora and Swarts, 2014; Hobson, 2013; Mommers, 2014).

In order to realise the full vision for an effective, digitally enabled built environment, there needs to be a way of accessing that information when required. That leads to the set of facilitating technologies that are generally associated with the spatial industry: the internet for transporting the information; the semantic web to enable smart ways to find and retrieve unstructured contextual information; geolocation technologies to enable searching based on geographic context; and radio-frequency identification (RFID) with sensors to facilitate the Internet of Things to create a 'sensate environment'.

An operational structure for a PIM platform is proposed in the next section, followed by two case studies that illustrate its implementation.

Operational structure for a PIM platform

Precincts typically are composed of multiple cadastral entities (legal ownerships), containing built facilities and infrastructure (roads, railways, bridges, service utilities) and/or natural features. They are also occupied and used by people, and governed by organisations. At present, an interested party may be able to collect data about particular aspects of a precinct. The elements of that dataset are, however, often disaggregated within various databases, modelled using differing data definitions, held under different ownerships and, consequently, have potential access impediments. A shared PIM, based on an open standard, can be created and maintained to address these issues.

Figure 7.6 illustrates the precinct modelling strategy that is being developed as part of a collaborative research project (detailed in two use-case projects). The following sub-sections explain each part of this figure.

Data schema

All data models require a formal definition of the structure that will be used to store the data. This is referred to as the 'data schema'. The proposed PIM schema extends the current version of the international standard for building information (IFC4, 2013) to include new infrastructure and cadastral entities. In order to do this, the PIM research team proposes a new 'facility' concept that serves to collect together all built 'things': linear entities such as roads, railways and waterways, bridges and tunnels, as well as individual buildings or complexes of buildings. A further generalisation is proposed for subdivisions of these entities. While storeys are vertical subdivisions of a building, many linear infrastructure entities such as roads and railways can be defined in terms of horizontal spatial segments. For example, a road is composed of segments (length of road between intersections) and the intersections themselves. It is perhaps useful to go one level deeper in the spatial hierarchy and consider traffic lanes within road segments in the same way we think of spaces within a building storey. Similarly, an important bridging concept between the urban and building-level scales is the idea of a planning zone. The Industry Foundation Classes (IFC) standard already has a spatial zone entity, which can be used for schematic precinct planning. The PIM team proposes the need for a new specialisation of this spatial zone entity to hold the legal and spatial definition of property. In this way, cadastral entities at the building scale are the lots on which built facilities exist, and at the urban scale they are the fundamental spatial units of local environment and regional plans.

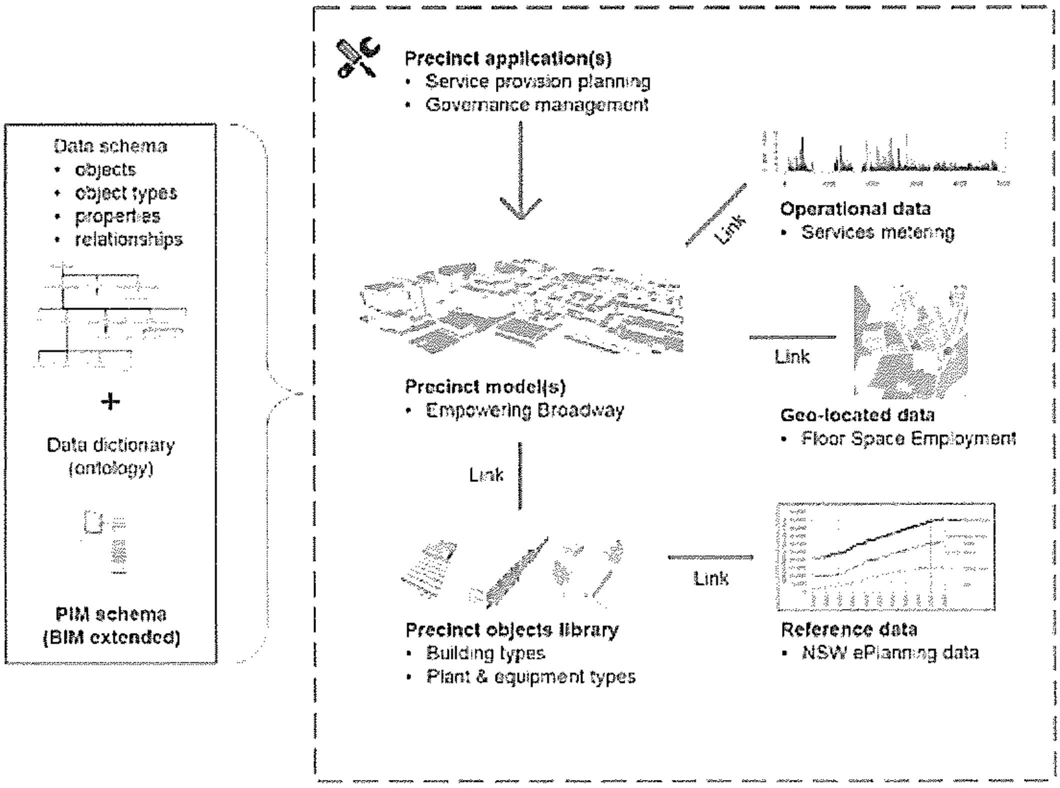
Data schema
• objects
• object types
• properties
• relationships
+
Data dictionary (ontology)
PIM schema (BIM extended)
Precinct application(s)
• Service provision planning
• Governance management
Link
Operational data
• Services metering
Link
Precinct model(s)
• Empowering Broadway
Geo-located data
• Floor Space Employment
Link
Link
Precinct objects library
• Building types
• Plant & equipment types
Reference data
• NSW ePlanning data

Figure 7.6

Precinct Information Model for an urban retrofit project.

Data dictionary

The challenge when extending a data schema to include new concepts, such as those described for infrastructure and cadastral entities, is to limit the complexity of the schema as a whole so that it remains sufficiently expressive, without becoming too cumbersome to implement in software. The second component of the PIM schema, shown in the box at the left of Figure 7.6, is a data dictionary (ontology) that provides a solution to this issue. Within a PIM data model, instances of a generically defined PIM entity such as the spatial zone can be categorised by means of a reference to the relevant concept in the data dictionary. An example of such a dictionary is that developed by buildingSMART (bsDD, 2015). This is a repository of concepts, their definitions in multiple languages and the relationships between concepts. Each concept in the data dictionary is uniquely identified with its own globally unique identifier, so when used against an entity instance in the PIM model, the definition of that entity is unambiguous. For PIM purposes, all the land use and development types as published by the New South Wales state government (NSW Government, 2015) have been added to the dictionary as a preliminary trial of this methodology. Figure 7.7 shows the use of these concepts to depict local environment planning zones for a precinct in the central Sydney metropolitan area.

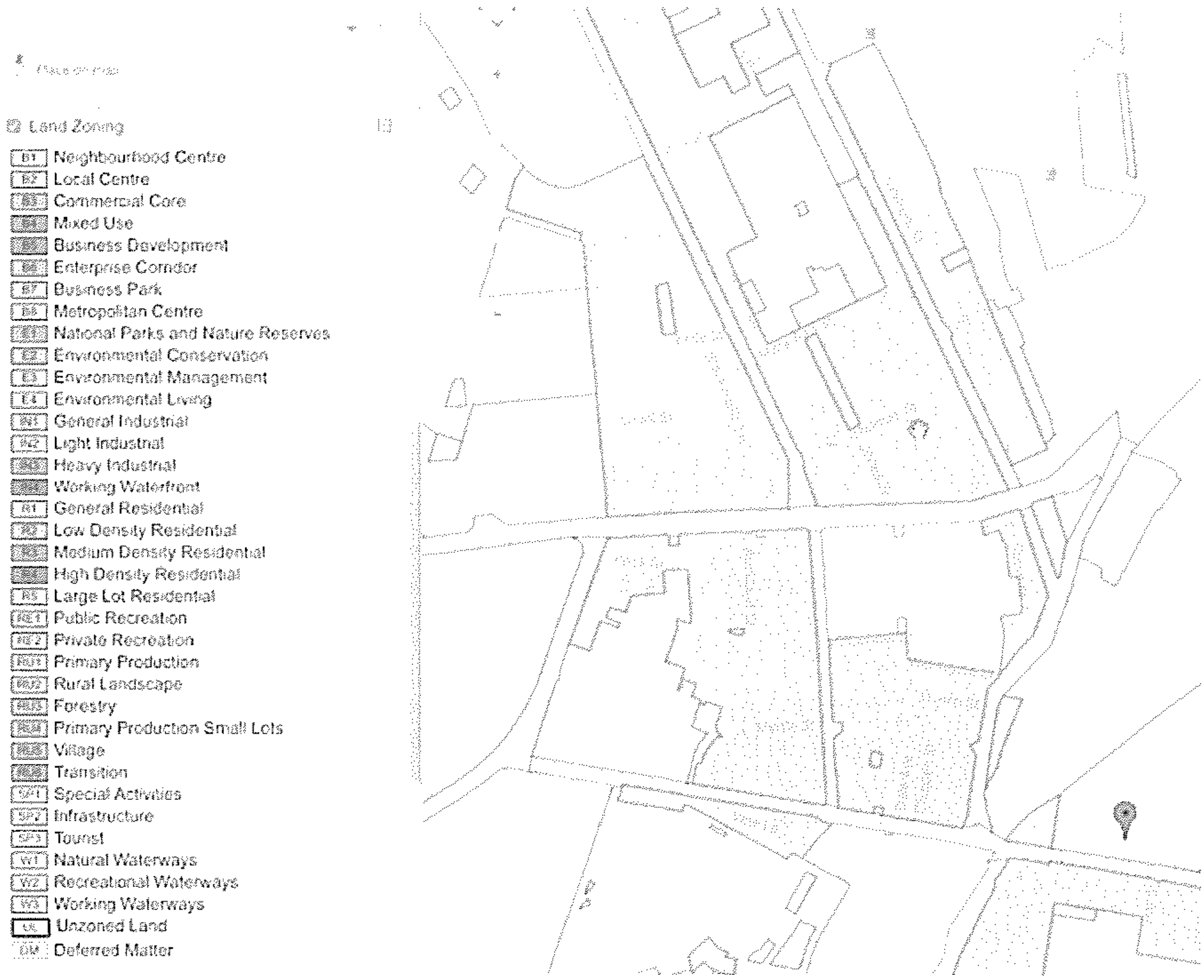

Figure 7.7

Land use map of the 'Empowering Broadway' precinct.

Source: NSW Department of Planning, public web site.

The authors envisage that as governments adopt open data formats, each authority will maintain their own database and make this data publicly accessible in a standardised, useable form. The definitions of land use and development types are then expected to be uniform across all authorities referenced from an open data dictionary, bsDD or otherwise, and only the choices of development types that are permitted for a given land use will vary between authorities.

Levels of development

Precinct information models may be broadly characterised at three levels of development (Figure 7.8).

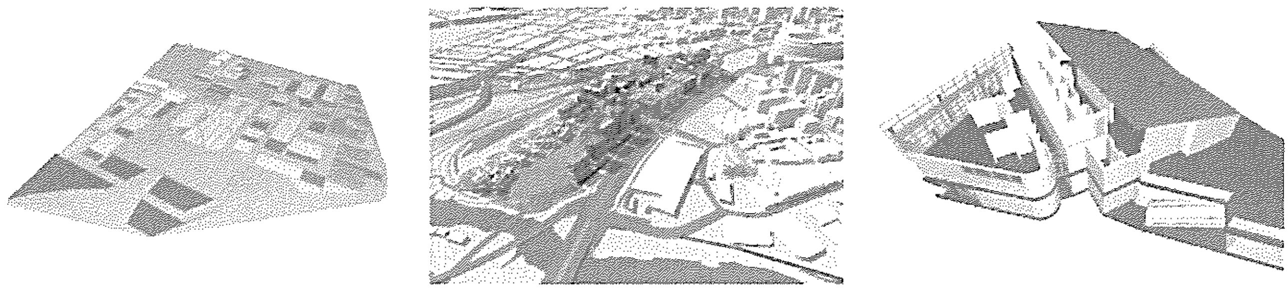

Figure 7.8

(a) Zonal functional typology – schematic master plan; (b) Built facility type – development proposal; (c) Elemental object typology – detailed asset model.

Zonal functional typology

A precinct model at initial concept stage will designate geographic zones or simple volumes and spaces to represent the broad-level activities in the precinct. These zones have intrinsic geometric properties such as dimensions, volume and area; specified functional usage such as residential or commercial; possible performance properties including energy, carbon, water and waste; or cost properties such as construction and operational costs.

Built facility typology

At a more detailed level, the functional uses of space are modelled in 3D form based on approximations of the scale of development required and with more attention to the relationships between the spaces. Traditionally, building types are classified in this way for costing purposes. In Australia for example, the National Construction Code (NCC) Building Class Table (ABCB, 2016) and the Rawlinsons (2011) extended *Building* Types Classification both provide this type of classification. PIM however requires more comprehensive built asset type definitions, in particular for infrastructure entities or civic spaces.

Elemental object typology

At the most detailed level, all infrastructure and buildings are increasingly authored in BIM tools; with all spatial and physical elements described precisely including detailed properties of the specified products.

Interaction with the precinct information model data

The precinct model itself is stored in an object-oriented database that can be accessed remotely via secure login. Users can be assigned to groups with access rights to all or part of the database. The data can also be accessed via web requests; this functionality allows software developers to create either web-based or standalone applications that interact with relevant data entities in the model for particular purposes. This is done for example to allow precinct stakeholders to review and add their requirements and performance objectives against the existing precinct entities in the model. Figure 7.9 shows the PIMViewer software that has been written as an example of such an application. It can open a model across an internet connection to the server, edit that model and save the amended model either to a model file on the user's computer or merge it back into the source model on the server.

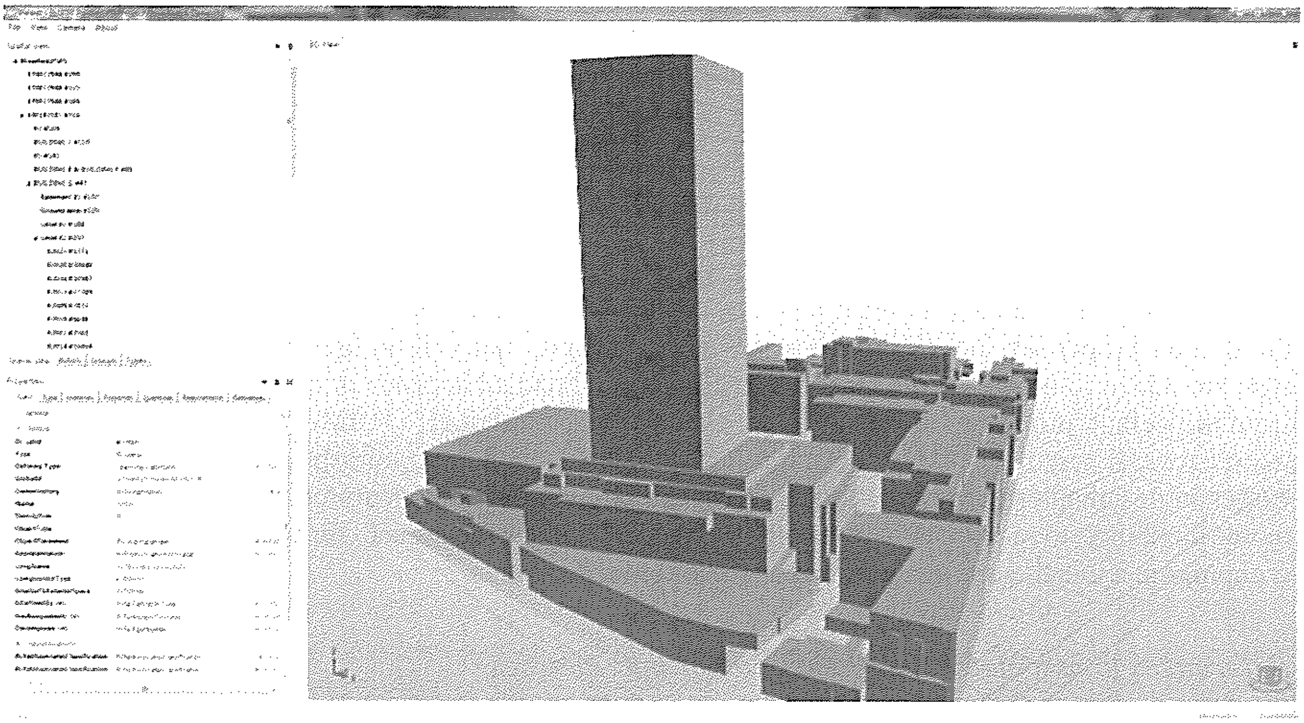

Figure 7.9

PIMViewer application.

Precinct object library

In BIM, a type is a standard object that can be accessed from a library of objects. The type defines the default properties, including geometry where relevant, that will be used when instances of that type are added to the project model. Properties of an individual instance of a type may be set to vary from the default properties as required. For the PIM research, the IFC BIM data schema is extended to add several new types to correspond to the additional spatial and infrastructure entities discussed earlier in this chapter. The use of types in association with data dictionary concepts should allow for more flexibility to accommodate many use cases across geographic jurisdictions and language groupings in a much more flexible, consistent and robust manner.

References to associated data held in other data sources

Three sources of reference data are shown on the right-hand side of Figure 7.6. Operational and reference data is linked to associated entity instances in the PIM project model using references. There are a number of optional properties of a reference: a description of the referenced data source, a uniform resource locator (URL) that defines where to look on the web, and what parameters are required to access a particular set of data from the target site. A contemporary example of this approach is given in van Nederveen et al. (2015). The URL mechanism will be subject to review for PIM if and when an alternative standardised construct becomes widely adopted by open data providers, especially government authorities. Geo-located data is data that includes longitude and latitude coordinates, and standard orientation. The site and cadastral entities in the PIM data schema both include these properties. On the basis of this commonality between the PIM project model instances and the referenced data, selections from the reference source can be viewed in association with, or merged into the model and correctly located in space.

Required functionality of a precinct information model

In summary, to be effective and useful for the many stakeholders who may interact with precinct information, the data model should include the following features:

- standardised identification, definition and management of precinct entities including units of measurement;
- stakeholder concepts; ownership, operational responsibility and user status;
- a standardised method to enable a given precinct model to be easily co-located within a common spatial context to other precincts or larger scale models;
- support for multiple performance objectives related to the precinct entities;
- method(s) to link entity instances that are within the current precinct information set to appropriate reference data that exists elsewhere;
- a filtering capability to enable ad hoc and/or defined queries (model view definitions) to provide relevant data to industry software tools;
- support for analytics at various levels of granularity (by land use zone, built facility type or component product element);
- metadata associated with data entities to indicate data provenance and reliability / level of accuracy.

Application of PIM to built environment precinct design projects

One of the grand challenges for sustainable urban development this century is the regeneration of the established and poor-performing built environments in the inner and middle suburbs of large, fast-growing cities. Precincts represent the scale at which this renewal needs to occur. The key arenas where such precincts exist are:

> - central business districts (CBDs); CBDs and major activity centres of cities;
> - brownfields; abandoned industrial and commercial property, usually in central and increasingly sought after locations;
> - greyfields; the extensive, ageing but occupied residential areas of the inner and middle ring suburbs where the land is the asset, and the properties are prime for more intensified forms of redevelopment.
>
> (Newton, 2016)

The case studies briefly outlined below involve PIM-based data definition, assembly and modelling of precinct-scale regeneration being explored for the Broadway precinct in Sydney's CBD and Fishermans Bend, a 240-hectar brownfield redevelopment adjacent to Melbourne's CBD.

Case Study 1: precinct infrastructure retrofit

The Broadway precinct, located on the edge of the Sydney CBD, is a unique opportunity to implement a precinct model as the project is retrofitting a dense urban area undergoing significant change. It is the focus of the Empowering Broadway Project (CRC LCL, 2015) that is examining ways to develop the governance protocols associated with multiple owners intending to share common energy and water services (distributed energy generation and integrated water technologies utilising stormwater harvesting, wastewater treatment and re-use) involving long-term commercial contracts.

The precinct spans several existing development types:

- the redevelopment of the old Carlton United Brewery site, which created Central Park, a brownfield redevelopment providing a 'clean sheet' for new facilities, but requiring significant site remediation and utilities investment. Buildings include premium residential, shopping and retail, and commercial offices with significant green infrastructure and excess capacity associated with a state-of-the-art water treatment and trigen energy plant;[2]
- an education campus offering trade-based courses, dating to the mid 1800s, with a large proportion of heritage and/or old buildings, poor environmental performance of the building stock in general and increasing energy consumption;
- an ambitious and expanding university, proactively upgrading its facilities to support the new learning needs of the digital age with a large existing and dense building stock, having to identify complex renewal/growth options through replacement of existing structures, and having increasing energy needs.

The stakeholders are initially focusing on issues related to developing a governance framework with respect to the mechanics of sharing local energy and water resources. The presumption is that the operating profiles of the three participants will lead to aggregate lower levels of energy consumption, and significantly reduced operational costs and embodied carbon profiles. Thus, the complementary goals of the project are to investigate the *commercial* feasibility of shared precinct infrastructure water + energy, and to develop *a precinct model that hosts the data* for those assessments and scenario modelling.

In order to support this work, the precinct model must consist of four categories of information, serving to define the required scope of the PIM:

- a representation of the physical entities that make up the precinct containing appropriate general property data;
- information relating to the planned performance characteristics of those precinct entities;
- the ability to hold actual performance data, often collected in real time and perhaps aggregated in an appropriate manner;
- information about the people associated with the precinct, their roles, ownership and responsibility with respect to those entities.

This information is required across all built asset types for any PIM. In all of these categories, acquiring definitive, up-to-date and consistent data is a major challenge, not only with the direct participants of the organisations/owners engaged in the project, but external government authorities and service providers.

The Broadway project has benefited from a City of Sydney dataset developed to track changes in development patterns over its jurisdiction. The floor space employment survey that is undertaken every five years records a site by its cadastre, all buildings on the site, all storeys in the building and then all spaces (rooms) on the storey. Importantly it uses two classifications to identify precisely the '*type of business enterprise*' and the specific '*activities*' hosted in the rooms.

The dataset for the Broadway precinct comprises some 379 sites, 440 buildings, 1,404 storeys, 830 businesses and 16,000 rooms. The value of this dataset is its comprehensive coverage, the consistency of representation and the classification of the business types and the activities undertaken in their facilities. For PIM purposes, this has served as a valuable base dataset, but lacks the basic building fabric and services data that is needed for carbon and other calculations. The conversion of this data from its GIS implementation into open BIM format (IFC) results in models as those visualised in Figure 7.10.

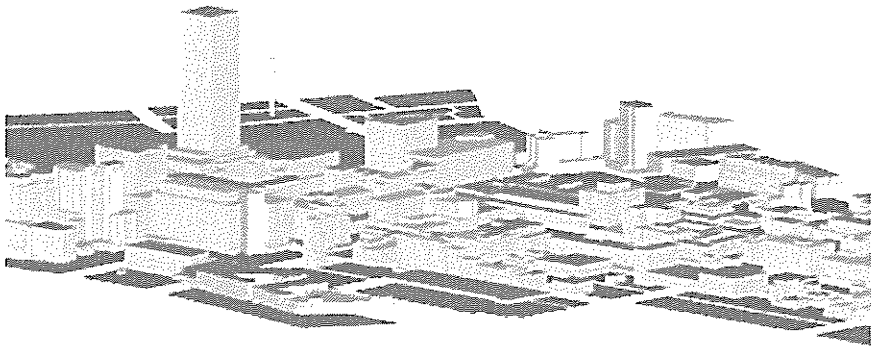

Figure 7.10 BIM model derived from City of Sydney 2012 FES data (view looking south-east from Darling Harbour across to Central Railway).

To date, a major part of work undertaken has been in the physical modelling and the primary classification systems used by state and local governments. Scenario modelling of current and future demand based on facility populations and consumption rates, as well as utility supply data, for existing and new services is scheduled to occur once governance details have been finalised and precinct partners provide their proprietary data. Once a PIM has been established, it becomes the framework for the next stages of retrofit design and construction and then operations. The integrated data model provides a 'life-time model' repository to enable the transition to a more sustainable operation. PIM becomes the foundation for more sophisticated eco-efficiency-oriented asset management system.

Case Study 2: brownfields precinct modelling

The precinct modelling illustrated in the following case study employs the latest generation of object-oriented, web-enabled, open-source software designed for application to a sustainability assessment of alternative precinct redevelopment scenarios within a rapidly evolving PIM environment. The software application (Figure 7.6) involved is MUtopia (Ngo et al., 2014). Here, integrated domain models (for energy, water, waste, transport, green space and demographics, among other data) inform a 3D spatial platform supporting urban infrastructure modelling for 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 such as liveability, carbon emissions, water consumption, travel time, waste generation and life-cycle cost. The MUtopia tool is informed by the Australian Green Building Council'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. Its key features are: open, scalable and adaptable, cloud-based architecture; integrated GIS + BIM using PIM; advanced visualisation capabilities for rendering and reporting; predictive modelling capabilities, what-if scenario simulation; multi-user architecture, collaborative design and simulation platform; and public engagement capabilities via a web portal for community consultation. The tool can be used in multiple phases of a development project such as preliminary planning, stakeholder communication, master planning, community consultation, design and monitoring.

The value of a PIM-enabled precinct assessment and visualisation tool at preliminary planning stage was demonstrated by the application of MUtopia to a rapid one-month envisioning exercise focusing on a low carbon future for Fishermans Bend. Fishermans Bend is a 250-hectare brownfield precinct adjacent to the CBD in Melbourne required to accommodate around 120,000 residents and 60,000 commercial jobs over the next 40 years. It sought an urban design response for its buildings that aspired to be:

- low carbon: ultra-energy efficient buildings with maximum use of renewable energy;
- biophillic: optimising the exposure of buildings and their occupants to natural elements through, for example, green walls;
- water sensitive: minimising the import of potable water into and export of wastewater from the precinct by maximising the use of rainwater harvesting by buildings and greywater recycling within buildings.

For MUtopia modelling of the future Fishermans Bend precinct, a spectrum of building star ratings ranging from current practice to international best practice were employed. This was done to provide an estimate of the total amount of energy, water and CO_2 emissions associated with the required stock of residential and commercial buildings. This enabled a comparative performance assessment to be made as to the scale of environmental benefits to be achieved from adopting current versus best-practice performance targets in design briefs for developers. The latter represents what should be prescribed as a target for those developers wanting to be involved in the creation of Melbourne's largest inner city precinct. A full report on ‘Ideas for Fishermans Bend’ is to be found in CRC for Water Sensitive Cities and CRC for Low Carbon Living (2015); these documents report only on the MUtopia modelling undertaken for the residential apartments.

Using world leadership performance, a 10-star NatHERS[3] residence is expected to reduce operational energy by 27 per cent when compared to the currently mandated six-star dwelling. This is principally the result of the reduction of space heating and cooling requirements. Further reductions in energy demand of approximately 21 per cent can be gained from the installation of more efficient appliances and lighting. Energy efficiency gains beyond the building envelope, lighting and appliances can be derived from a decrease in hot water usage. Hot water usage reductions are obtainable with the installation of water-efficient appliances such as taps, shower heads, dishwashers and washing machines; delivering a 33 per cent reduction in hot water usage when compared to business-as-usual (BAU) practice (Australian Government, 2016). Further decreases in hot water usage could be obtained through behavioural adjustments such as reduction of shower length (Athuraliya et al., 2012) and, when combined with water-efficient appliances, can further reduce residential energy demand by 20 per cent.

Finally, local distributed energy systems were explored in order to determine the possibility of delivering carbon neutral or carbon negative precincts. Solar photovoltaics and storage appear most prospective at present. Given the likely development of approximately 180 new apartment buildings at Fishermans Bend, it is anticipated that approximately 143,000m^2 of roof area will exist. Accounting for services, walkways and a packing factor of 70 per cent for minimal shading it is therefore anticipated that a maximum of 14.4megawatts (MW) of solar photovoltaics could be installed. This solar photovoltaic (PV) installation will produce in the order of 60,800GJ of energy per year. For the BAU residential 6-star apartments this accounts for approximately 3 per cent of annual residential energy requirements. However, with the 10-Star building, water and energy efficient fixtures and behaviour adaptation scenario, a more sizeable 10 per cent of the residential energy demand can be accommodated by renewables. Combining all energy reduction measures (10-star NatHERS, energy efficient built in and plug in appliances, conservation behaviours by households and rooftop PV) a potential reduction in residential energy demand of 70 per cent could be achieved (Figure 7.11).

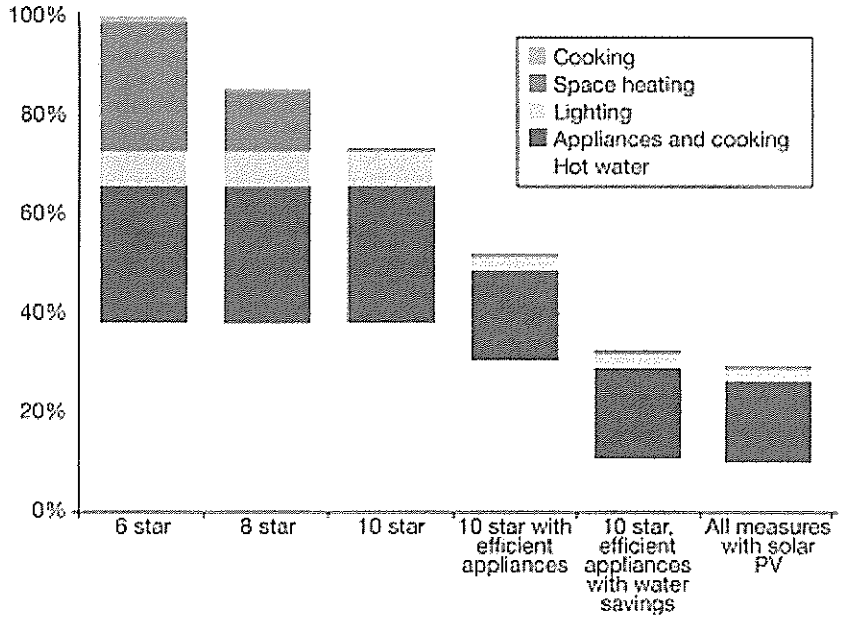

Figure 7.11

Alternatives to BAU energy scenario for new residential building at Fishermans Bend.

Conclusions

PIM is in its infancy, perhaps equivalent to where BIM was 20 years ago, but the frameworks and initiatives outlined in this chapter suggest significant promise for accelerated activity once its full potential has been recognised. Reflecting on the drivers that have led to the present international endorsement of BIM in the building and construction sector, we can identify several factors that will be needed to drive the widespread adoption of PIM. Academic research will provide the underpinning rationale for schemas and object libraries, among others. Prototype implementations and applications as discussed in this chapter will raise its profile by demonstrating the value that can be added to an urban design project with PIM-enabled databases and software.

The development of information exchange standards, especially those that cross the current divide between the urban planning and building/construction domains, will provide the platform for innovation using PIM. At the same time, PIM must be seen and applied as a collaborative tool that engages multiple disciplines, addressing different views of the information throughout the entire life-cycle development of streetscapes, city blocks, neighbourhoods and larger urban districts. This will include multiple stakeholders, such as property owners and managers, the design professions (architects, planners, landscape architects and engineers), local and state government agencies and end-users of the built environment. Positive support needs to emerge for the move to PIM, endorsed and even mandated by major public and private stakeholders.

All this needs to be encouraged by software developers who see the opportunity to innovate and build new tools that employ precinct scale models that link into the emerging sources of open data to inform all aspects of our interaction with the built environment. Finally, there must be a willingness across all stakeholders to make a break with the past and adopt a new way of working. Indeed, the shift from current ways of representing, modelling and managing the built environment is as radical as the shift from 2D drawing to 3D modelling during the late twentieth century. Precinct Information Modelling offers a new and radical way of conceptualising how we manage our world. The opportunities are enormous if we can accelerate and scale up this transition.

Notes

1 GML stands for Geography Markup Language and is an XML grammar developed by OGC to describe geographical features.

2 A trigeneration (trigen) plant is a facility that uses the one energy source, typically natural gas or biomass, to simultaneously generate electrical energy, while using the waste heat for both direct heating and cooling.

3 NatHERS (Nationwide House Energy Rating Scheme) is Australia's energy rating system for residential buildings.

References

Athuraliya, A., Roberts, P. and Brown, A., 2012. *Yarra Valley Future Water: Residential Water Use Study Volume 2-Summer 2012*, Victoria: Yarra Valley Water.

Australian Building Codes Board (ABCB), 2016. *National Construction Code*, Australian Building Codes Board. Available at: https://services.abcb.gov.au/NCCOnline/ [Accessed 9 February 2016].

Australian Government, 2016. *Water Efficiency Labelling and Standards Scheme*, Canberra: Australian Government.

bsDD, 2015. *buildingSMART Data Dictionary*. Available at: http://bsdd.buildingsmart.org/ [Accessed 7 February 2016].

buildingSMART, 2016. *buildingSMART: International Home of OpenBIM*. Available at: www.buildingsmart.-org/ [Accessed 15 February 2016].

Codoban, N. and Kennedy, C. A., 2008. The metabolism of neighbourhoods. *Journal of Urban Planning and Development*, 134(1), 21–31.

Crawford, R. and Fuller, R., 2011. *Energy and Greenhouse Gas Emissions Implications of Alternative Housing Types for Australia*, paper presented at State of Australian Cities National Conference, Melbourne, Australia, 29 November–2 December.

Cooperative Research Centre for Low Carbon Living (CRC LCL), 2015. *Retrofitting Urban Precincts to Create Low Carbon Communities*, project RP2018, Low Carbon Living CRC. Available at: http://lowcarbo-nlivingcrc.com.au/research/program-2-low-carbon-precincts/rp2018-retrofitting-urban-precincts-create-low--carbon [Accessed 15 February 2016].

Department of Infrastructure and Regional Development, 2011. *Creating Places for People: An Urban Design Protocol for Australian Cities*, INFRA 1219. Available at: www.gbca.org.au/uploads/244/36084/Creating-%20Places%20for%20People%20-%20An%20Urban%20Design%20Protocol%20for%20Australian%20Ci-ties.pdf [Accessed 2 March 2016].

Galbraith, I., 2015. *Digital Infrastructure – The Future of Engineering*. Online. Available at: www.infrastructure-intelligence.com/article/may-2015/digital-infrastructure-%E2%80%93-future-engineering?utm_medium=email&utm_source=transactional&utm_campaign=weekly-email [Accessed 15 June 2015].

Gomez Zamora, P. and Swarts, M., 2014. Campus landscape information modeling: Intermediate scale model that embeds information and multidisciplinary knowledge for landscape planning, *Proceedings of the XVII Conference of the Iberoamerican Society of Digital Graphics: Knowledge-based Design*, Sao Paulo, Blucher Design Proceedings, 1(7), 61–65.

Hobson, A., 2013. *Technology, Innovation, and Collaboration in Project Delivery*. Network: Pathways to Innovation, A technical journal by Parsons Brinckerhoff employees and colleagues, 76, 21–23, Available at: www.pbworld.com/news/publications.aspx [Accessed 11 July 2015].

IFC4, 2013. *Industry Foundation Classes IFC4 Official Release*. Available at: www.buildingsmart-tech.org/ifc/IFC4/final/html/index.htm [Accessed 7 February 2016].

Ichikawa, Y., 2013. *ISO/TC268/SC1 – Smart Community Infrastructures*, PowerPoint Presentation, 05 February 2013, International Telecomunication Union. Available at: www.itu.int/en/ITU-T/jca/ictcc/Documents/docs-2013/YoshiakiIchikawa_JCA_Feb2013.pdf [Accessed 6 March 2017].

JBIM, 2010. *Journal of Building Information Modelling, Fall 2010*, Washington: National Institute of Building Sciences, buildingSMART Alliance. Available at: www.scribd.com/document/43227845/Journal-of-Building-Information-Modeling-Fall-2010 [Accessed 6 March 2017].

Mommers, B., 2014. The crossover revolution, *Geospatial World*, March,62–63. Available at: www.bimtaskgroup.org/wp-content/uploads/2014/04/crossover.pdf [Accessed 10 November 2016].

New South Wales (NSW) Government, 2015. *NSW Planning Legislation*. Available at: www.legislation.nsw.gov.au [Accessed 07 February 2016].

Newton, P., 1995. Virtual project teams. In: M. A. Fisher, K. H. Law and B. Luiten (eds) *Modeling of Buildings Through their Life Cycle*, CIB Publication 180, California: Stanford University.

Newton, P., 2008. *Transitions: Pathways Towards Sustainable Urban Development in Australia*, Dordrecht, The Netherlands: Springer.

Newton, P., 2012. Liveable and sustainable? Socio-technical challenges for 21st century cities, *Journal of Urban Technology*, 19(1), 81–102.

Newton, P., 2016. Framing new retrofit models for regenerating Australia's fast growing cities. In: T. Dixon and M. Eames (eds) *Retrofitting Cities for Tomorrow's World*, London: Wiley-Blackwell.

Newton, P., Hampson, K. and Drogemuller, R., 2009. *Technology, Design and Process Innovation in the Built Environment*, Spon Research Series, London: Taylor & Francis.

Newton, P., Marchant, D., Mitchell, J., Plume, J., Seo, S. and Roggema, R., 2013. *Performance Assessment of Urban Precinct Design: A Scoping Study*, Low Carbon Living CRC, August 2013. Available at: www.lowcarbonlivingcrc.com.au/resources/crc-publications/reports/performance-assessment-urban-precinct-design-scoping-study [Accessed 15 February 2016].

Newton, P., Pears, A., Whiteman, J. and Astle, R., 2012. The energy and carbon footprints of housing and transport in Australian urban development: Current trends and future prospects. In: R. Tomlinson (ed.) *Australia's Unintended Cities*, Melbourne: CSIRO Publishing.

Newton, P., Wilson, B. G., Crawford, J. R. and Tucker, S. N., 1993. Networking construction: Electronic integration of distributed information. In: K. Mathur, M. Betts and K. Tham (eds) *Management of Information Technology for Construction*, Singapore: World Scientific Publishing Co.

Ngo, T., Aye, L., Arora, M., Mendis, P. and Malano, H., 2014. *MUtopia: Platform for Envisioning Future and Transition Scenarios of Sustainable Urban Development*, paper presented at Practical Responses to Climate Change Conference, Melbourne, Australia, 23 May.

Open Geospatial Consortium (OGC), 2016. *OGC: Making Location Count*. Available at: www.opengeospatial.org/ [Accessed 15 February 2016].

Plume, J., 2015. Integrated digitally-enabled environment: The internet of places. In: A. Kemp (ed.) *AGI Foresight Report 2020*, London: The Association for Geographic Information, pp. 207–209.

Plume, J., Simpson, R., Owen, R. and Hobson, A., 2015. *Integration of Geospatial and Built Environment – National Data Policy*, Joint buildingSMART – SIBA Position Paper, Version 2, Canberra: SIBA.

Rawlinsons, 2011. *Australian Construction Handbook*, 29th edn, Perth: Rawlinsons Publishing.

Sharifi, A. and Murayama, A., 2013. A critical review of seven selected neighbourhood sustainability assessment tools. *Environmental Impact Assessment Review*, 38, 73–87

Trubka, R., Glackin, S., Lade, O. and Pettit, C., 2016. A web based 3D visualisation and assessment system for urban precinct scenario modelling. *ISPRS Journal of Photogrammetry and Remote Sensing*, 117, 175–186.

van Nederveen, S., Luiten, B. and Böhms, M., 2015. *Linked Data for Road Authorities*, paper presented at 32nd CIB W78 Conference 2015, Eindhoven, The Netherlands, 27–29 October.

8

INTEGRATING INFORMATION IN BUILT ENVIRONMENTS

FROM CONCEPT TO PRACTICE

EDITED BY
ADRIANA X. SANCHEZ, KEITH D. HAMPSON
AND GEOFFREY LONDON

cib

Sustainable
Built Environment
National Research Centre

ROUTLEDGE

Integrating Information in Built Environments

From Concept to Practice

Edited by Adriana X. Sanchez, Keith D. Hampson and Geoffrey London

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

Sustainable Built Environment National Research Centre

First published 2018
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
Names: Sanchez, Adriana, editor. | Hampson, Keith (Keith Douglas), editor. | London, Geoffrey, editor.
Title: Integrating information in the built environments : from concept to practice / edited by Adriana X. Sanchez, Keith D. Hampson and Geoffrey London.
Description: Abingdon, Oxon ; New York, NY : Routledge, 2018. |
Series: CIB series | Includes bibliographical references and index.
Identifiers: LCCN 2017004102| ISBN 9781138706323 (hardback : alk. paper) | ISBN 9781315201863 (ebook)
Subjects: LCSH: Construction industry–Information services. | Building–Data processing. | Building information modeling.
Classification: LCC TH216 .I59 2018 | DDC 690.028/5–dc23
LC record available at https://lccn.loc.gov/2017004102

ISBN: 9781138706323 (hbk)
ISBN: 9781315201863 (ebk)

Typeset in Goudy
by Saxon Graphics Ltd, Derby

Contents

Contributors

Fonbeyin Henry Abanda
Senior Lecturer, Oxford Brookes University
Oxford, UK
Fonbeyin has a BSc (Hons) from the University of Buea-Cameroon and an Engineering Diploma in Mathematics/Physics and Civil Engineering from the Ecole Nationale Supérieure Polytechnique de Yaoundé-Cameroon respectively. He obtained his PhD from Oxford Brookes University in the UK in 2011. His PhD investigated the extent to which Semantic Web technologies can be used in managing sustainable building technology knowledge for use in different building projects. Currently, Fonbeyin is a senior lecturer in the School of the Built Environment at Oxford Brookes University. He teaches Construction Project Management/Building Information Modelling at undergraduate and postgraduate levels. He supervises PhD students in the area of Construction Information Technologies. Fonbeyin is a Chartered Engineer, an assessor at the UK Institution of Engineering and Technology and a fellow of the UK Higher Education Academy.

Knut Boge
Associate Professor, Oslo and Akershus University College of Applied Sciences
Oslo, Norway
Knut is an associate professor and coordinator of Oslo Business School's Bachelor's programme in Facility Management. Knut has also been employed at Oslo and Akershus University College of Applied Sciences since 2006, and his research interests mainly focus on facility management, real estate, and innovation and entrepreneurship. He is particularly interested in service innovations. Prior to his current role, Knut was an assistant professor at BI Norwegian School of Management doing research and teaching about the intercept areas of political science, economic history, and innovation and entrepreneurship.

Frédéric Bougrain

Researcher, Economics and Human Sciences Direction, Centre Scientifique et Technique du Bâtiment (CSTB)

Champs-sur-Marne, France

Frédéric works as a researcher for the Economics and Human Sciences Department at Technical Centre for Building (CSTB, Centre Scientifique et Technique du Bâtiment), a state-owned industrial and commercial research centre under the wing of the Ministry of Housing in France. His research concentrates on societal issues with a particular focus on innovations in the building and construction industry and energy saving performance contracts. Frédéric previously lectured at the University of Orléans, France, where he defended a thesis on innovation, small and medium-sized enterprises and the consequences for regional technology policy. Frédéric has published works on public–private partnerships, energy-saving performance contracts, innovation in small and medium-sized enterprises and the social housing sector.

Jan Bröchner

Professor and Chair of Organization of Construction, Division of Service Management, Chalmers University of Technology

Gothenburg, Sweden

Jan holds the Chair of Organization of Construction at Chalmers University of Technology in Gothenburg, Sweden. He is an adjunct member, representing the Swedish universities of technology, of the Research Committee of the Development Fund of the Swedish Construction Industry (SBUF). Currently, he leads the productivity and innovation effect analysis project within the 'Bygginnovationen' Programme, supported by Swedish Governmental Agency for Innovation Systems (VINNOVA) and an industry consortium.

Jessica Brooks

Research Assistant at Sustainable Built Environment National Research Centre (SBEnrc)

Sydney, Australia

Jessica has a Bachelor's in Psychology from University of Wollongong, Wollongong, and has been working at the Australian Sustainable Built Environment National Research Centre (SBEnrc) headquartered at Curtin University, Perth since August 2015. In this role, she has been involved in the development of Australia's first BIM decision-support tool, BIM Value, and is currently developing Australia's first BIM benefits benchmarking system: BIM Value Benchmark. This system aims to overcome barriers traditionally found in industry benchmark development by applying crowdsourcing principles and building on a collaborative effort between industry, government and research.

Albert PC Chan

Head of Department and Associate Director of the Research Institute for Sustainable Urban Development, The Hong Kong Polytechnic University

Hong Kong, China

Albert is Head of Department of Building and Real Estate and Chair Professor of Construction Engineering and Management as well as a chartered construction manager, engineer, project manager and surveyor by profession. He has worked in a number of tertiary institutions both in Hong Kong and internationally. Albert's research and teaching interests include project management and project success, construction procurement and relational contracting, construction management and economics, construction health and safety, and construction industry development. Albert holds an MSc in Construction Management and Economics from the University of Aston in Birmingham and a PhD in Project Management from the University of South Australia.

Antonio Aguiar Costa

Assistant Professor, University of Lisbon

Lisbon, Portugal

António is an assistant professor at the Department of Civil Engineering and Architecture of the Superior Technical Institute (IST, Instituto Superior Técnico), University of Lisbon. His research interests are information management and integration, interoperability, Building Information Modelling (BIM) implementation and standardisation and BIM-based e-procurement. His other areas of research include intelligent buildings, and Internet of Things for buildings and smart cities. At the national level, Antonio is Chairman of CT197-BIM, the Portuguese Technical Committee for BIM standardisation, and Coordinator of the Information and Design Support Systems Research Group of Civil Engineering Research and Innovation for Sustainability (CEris). Internationally, he is the representative of Portugal at CEN/TC442 (BIM European Standards) and member of the European Union BIM Task Group supported by European Commission. Antonio is also a member of CIB TG90: Information Integration in Construction and CIB W98: Intelligent and Responsive Buildings and works as an independent expert for the European Commission; participating in evaluation of Horizon 2020 projects.

Marianne Forman

Senior Researcher, Danish Building Research Institute, Aalborg University

Copenhagen, Denmark

Marianne is a senior researcher at the Danish Building Research Institute, Aalborg University. Her research area encompasses innovation, user-driven innovation, sustainable transition, environmental management in companies and product chains, project management and change processes. Since 2006, her research has been related to challenges within the construction industry. She has an MSc in Civil Engineering from the Danish Technical University, where she also defended her PhD thesis on 'Processes of Change and Participation Forms in Preventive Environmental Work'.

Margrethe Foss
Senior Advisor, Multiconsult / Lecturer, Norwegian University of Science and Technology (NTNU)
Trondheim, Norway
Margrethe is currently holding three positions in Norway: Senior Advisor Multiconsult (since 2009), Benchmarking Officer for NfN (Norwegian Facilities Management Network), Course Coordinator and Lecturer in Facility Management (FM) at the Master's programme for practitioners at NTNU (Norwegian Institute of Technology). Margrethe's main areas of competence are developing FM strategies and organisation, early phase building projects, workplace strategies, business development, benchmarking (FM and RE), procurement processes, localisation studies, life-cycle evaluations, organisation and competence development. She has often had roles as advisor, lecturer or in project/process management. She has always strived towards optimising the cost–benefit factor for the customers so real estate and FM activities bring more value to the core business. Margrethe strongly believes that a good process is often the key factor in a good product/result. Margrethe's previous experience includes Managing Director for Analyse & Strategi AS (2005–2009), Concept Developer for Veidekke Bostad AB (Stockholm 2005–2007), and Project Manager for Ericsson Real Estate and Ericsson Telecom (Stockholm, 1995–2005).

Keith D. Hampson
CEO, Sustainable Built Environment National Research Centre, Curtin University
Perth, Australia
Keith has over thirty years of industry, government and research leadership. He has a Bachelor of Engineering with Honours and an MBA from Queensland University of Technology (QUT), and a PhD from Stanford University focusing on innovation and business performance. He is a Fellow, Institution of Engineers Australia; Fellow, Australian Institute of Company Directors and Fellow, Australian Institute of Management. Keith currently co-coordinates the CIB TG90: Information Integration in Construction. Keith serves as CEO of the Sustainable Built Environment National Research Centre, successor to the Australian CRC for Construction Innovation, for which he led the bid team in 2000 and was CEO for its nine years of operation. As Professor of Construction Innovation at Curtin University, he continues to work collaboratively with colleagues across Australia and globally to transform industry performance in sustainability, safety and productivity for a stronger and more competitive industry.

Geir K. Hansen

Professor, Norwegian University of Science and Technology (NTNU)
Oslo, Norway
Geir is a professor in Architectural and Facilities Management at the Department of Architectural Design and Management, Faculty of Architecture and Fine Art, NTNU. He is Head of the Centre for Real Estate and Facilities Management and leads two Master's programs in Real Estate and Facilities Management at NTNU. Geir graduated as an architect from the Faculty of Architecture at the Norwegian Technical University. His main fields of research are programming, evaluation of processes and buildings, and usability of buildings related to the user and organisational perspective. Geir has previously worked with topics such as adaptability and flexibility, new use and transformation of existing buildings, and run several architectural design courses on this. Geir has been an active member of International Council for Building (CIB) working commissions: W96: Architectural Management; W70: Facilities Management; and is the coordinator of W111: Usability of Buildings.

Kim Haugbølle
Senior Researcher, Danish Building Research Institute (SBi), Aalborg University
Copenhagen, Denmark
Kim conducts advisory services to the Danish Government, undertakes teaching, provides training of professionals and develops research-based knowledge to improve the built environment. He has authored or co-authored more than 200 publications on innovation and socio-technical change in the construction industry with a special focus on the role of the construction client, life-cycle economics and sustainability. Kim has been coordinating and managing several national and international R&D projects. Previously, he headed the secretariat of the think tank Danish Building Development Council and, later, a research department at the national building research institute. Kim is the international co-coordinator of the CIB Working Commission W118: Clients and Users in Construction as well as a board member of the Nordic researchers' network on construction economics and organisation, CREON.

Jeroen van der Heijden
Associate Professor, Australian National University (ANU)
Canberra, Australia
Jeroen is an associate professor at the ANU's Regulatory Institutions Network (RegNet) and at the University of Amsterdam's Law School. He received his PhD in Public Administration (highest honours) in 2009 and his MSc in Architecture (high distinction) in 2002, both from Delft University of Technology, the Netherlands. Jeroen works at the intersections of regulation and governance, policy change, and urban development and transformation. His research aims to improve local, national and international outcomes of urban governance on some of the most pressing challenges of our time: climate change, energy and water use, and a growing and increasingly urbanising world population.

Through his work, Jeroen seeks to inform ongoing academic debates on these challenges as well as provide hands-on lessons to policy-makers and practitioners on how to govern urban sustainability and resilience on a day-to-day basis.

Eilif Hjelset
Associate Professor, Oslo and Akershus University College of Applied Sciences
Oslo, Norway
Eilif is an associate professor at Oslo and Akershus University College of Applied Sciences, where he focuses on integrating Building Information Modelling (BIM) into the existing curriculum. His research interest is in BIM-based model checking, specifications for information flow in the life-cycle of buildings, in addition to processes for implementing BIM in the industry. He is Norwegian representative for European Conferences of Product and Process Modeling (ECCPM) and member of the Scientific Committee of IT in Construction (CIB W78). Eilif also serves as Educational Coordinator at buildingSMART Norway, connecting students with industry. He is active as ISO expert in development of BIM-related standards. Prior to these roles, he worked for the Norwegian Building Authority (DIBK), Standards Norway and the Norwegian University of Life Sciences.

Ali Hosseini
PhD Candidate, Norwegian University of Science and Technology (NTNU)
Oslo, Norway
Ali works as a researcher in the Coastal Highway Route E39 Project, funded by Norwegian Public Road Administration (NPRA). He is also carrying out his PhD candidacy at the Department of Civil and Transport Engineering, NTNU, while supervising Master's students working on implementation strategies and types of contract. His research currently focuses on innovative and relational delivery methods for infrastructure projects. Prior to this role, Ali worked as a project planner (detailed planning in engineering fabrication and procurement) in the Norwegian oil sector while he was involved in educating and training new employees for ÅF Reinertsen AS. He started his career as an industrial engineer working in the construction industry and later completed a Master of Engineering in manufacturing system engineering.

Leif D. Houck
Head of Department of Building and Environmental Technology, University of Life Sciences (NMBU) and Partner at SPINN architects AS
Oslo, Norway
Leif has been teaching architectural design and project management at NMBU since 2009. As a researcher, he has specialised in school buildings, daylight and universal design. He is internationally recognised for his research on school architecture and has published several papers on school design, especially linked to daylight, sustainability and universal design. As an architect, Leif has worked with several school buildings in Snøhetta, Kristin Jarmund Architects (former

partner), and currently SPINN Architects (founding partner). SPINN Architects is specialised in the programming and designing of school buildings. Leif has also participated in several school competition juries and has worked as an advisor in procurement and evaluation methods.

Ole Jonny Klakegg
Professor, Norwegian University of Science and Technology (NTNU)
Trondheim, Norway
Through his twenty-six years of work experience, Ole Jonny has alternated between teaching and research at the university and working as a consultant in project management, building substantial experience as well as theoretical and practical insight. Ole Jonny shares his time between his current position as Professor of Project Management and his role as R&D Director of WSP Norway. He has been involved in a large number of major projects in Norway in both public and private sectors, including building, civil engineering, transport, health, defence and organisational development. He is currently involved in research on project governance, project risk management, target value delivery and digitalisation of the building process. He also serves as leader for the construction programme in Project Norway.

Vegard Knotten
PhD Candidate, Norwegian University of Science and Technology (NTNU)
Oslo, Norway
Vegard's research focuses on a new integrated methodology for design management. This project is the result of a collaborative effort between NTNU, University of Agder and several industrial partners. The project compares the architectural, engineering and construction industry with offshore and shipping industries, while focusing on the early design phases of building design management. Vegard has extensive industry experience accrued through his work as Project Manager for Veidekke Entreprenør AS, Project and Construction Manager for Helsebygg Midt-Norge and Senior Engineer at Interconsult ASA.

Judy A. Kraatz
Senior Research Fellow, Griffith University
Brisbane, Australia
Judy is a senior research fellow with the Cities Research Centre at Griffith University. Judy has over twenty-five years of professional activity in the built environment as a design architect; leading a team of professionals delivering city-wide solutions for public buildings and parklands; and integrating sustainability into curriculum, design practice and business solutions. Judy's research addresses issues of corporate and social responsibility in the delivery of urban and social infrastructure. Judy brings a focus on meta-research and evaluation frameworks to better leverage research and achieve practical outcomes for both the urban environment as well as its residents. Current research focuses on the need for an efficient, effective and equitable social housing sector in Australia.

Ola Lædre

Associate Professor, Norwegian University of Science and Technology (NTNU)
Oslo, Norway
Ola is an associate professor at NTNU's Department of Civil and Transport Engineering. His most recent research publications deal with contracts and contract strategies, viability of large investment projects, internal rent schemes and building design management. Ola completed his PhD with the thesis 'Selection of contract strategy in construction projects' in 2006 and has working experience in research, private industry and local government.

Jardar Lohne
Research Scientist, Norwegian University of Science and Technology (NTNU)
Oslo, Norway
Jardar presently works as a research scientist/post-doctoral fellow at the Department of Civil and Transport engineering and at Klima 2050, a centre for research-based innovation. Over the years, he has published on a wide range of areas of research, including facilities management, project management, contract strategies, process innovation, sustainability analysis and formal frameworks for the construction sector. He is currently working on several publications within the field of climate change adaptation in the built environment.

Geoffrey London
Professor, The University of Western Australia
Perth, Australia
Geoffrey is a Professor of Architecture at The University of Western Australia where he is a past Dean and Head of School. He is a Professorial Fellow at The University of Melbourne, a Life Fellow of the Australian Institute of Architects (AIA) and an Honorary Fellow of the New Zealand Institute of Architects. He previously held the positions of Victorian Government Architect (2008–2014) and Western Australian Government Architect (2004–2008). He has been involved in advising those state governments on a wide range of projects, from the scale of individual houses to the complexity of major new tertiary hospitals. He has advised on issues that include design quality, project procurement, heritage, master planning, sustainability and development strategies, and been responsible for setting up design workshops on key, large-scale projects. He maintains a role as a consultant on urban design, architecture, design review and architectural competitions. He is an active researcher and program director in the Cooperative Research Centre for Water Sensitive Cities and has a long-term professional and research interest in medium density housing and forms of delivery that provide more affordable and better design.

David Marchant

Senior Research Fellow, University of New South Wales
Sydney, Australia
David is a senior research fellow at University of New South Wales in Sydney, Australia. He is currently a member of the team working on the Precinct Information Modelling (PIM) research project within the Cooperative Research Centre (CRC) for Low Carbon Living. His doctorate research addressed integration of design briefing within building information models. This research is also applicable to record design intent for data models addressing larger scales of planning such as precincts. David is a registered architect in NSW. He has also been an adjunct associate professor in the Key Centre for Design Computing and Cognition, Faculty of Architecture, University of Sydney. Prior to the current CRC, he participated as an active industry member of the CRC for Construction Innovation, particularly focused on research projects addressing use cases around Building Information Modelling and team collaboration.

Annie Matan
Adjunct Senior Research Fellow, Curtin University
Perth, Australia
Annie is Adjunct Senior Research Fellow at Curtin University Sustainability Policy (CUSP) Institute in Perth, Western Australia. She is interested in creating sustainable, vibrant and people-focused urban places. Her research focus is on social housing and active transport, particularly walking and cycling, pedestrian planning and urban design, focusing on how people interact with the built environment and human health outcomes of planning decisions. She worked for state and local government before joining Curtin University in 2011.

Torill Meistad
Senior Advisor, Nordic Energy Research
Oslo, Norway
Torill's work currently focuses on renewable energy systems in Nordic countries. She coordinates collaborative studies among Nordic universities and institutes about sustainable and reliable energy for transport, heating and industry production. Her work has especially focused on energy-efficient buildings, leading to publications on the issues of early involvement and integration in planning and construction projects. She completed her PhD at the Norwegian University of Science and Technology (NTNU). She has also worked at the Department of Civil and Transport Engineering, the Research Centre for Zero Emission Buildings (ZEB) and the Department of Architectural Design and Management. Torill has previously been involved with applied research projects related to industrial transformation and local community development at Centre for Rural Research, Trøndelag R&D Institute and NORUT Finnmark AS.

Øystein Mejlænder-Larsen

Technology Manager, Multiconsult/ PhD Candidatee, Norwegian University of Science and Technology (NTNU)

Oslo, Norway

Øystein is an industrial PhD candidate, employed at Multiconsult and associated with NTNU. The PhD is part of the research project 'Collaboration in the building process – with Building Information Modelling (BIM) as a catalyst' ('SamBIM'), with Statsbygg, Skanska, Link Arkitektur and Multiconsult as industry partners, and NTNU, SINTEF and FAFO as research partners. The focus of his PhD is to explore how the use of project execution models and BIM can increase the efficiency of the building process, based on experiences from the execution of major oil and gas projects. Øystein currently has a leave of absence as a technology manager in Multiconsult, one of the leading firms of consulting engineers and designers in Norway, to pursue his industrial PhD. He holds a Master of Science in Civil and Environmental Engineering (NTNU) and Master of Technology Management (NTNU, NHH, MIT Sloan). Prior to joining Multiconsult in 2009, Øystein worked as a technology manager at Selvaag Bluethink (2000–2009).

John Mitchell

Senior Research Fellow, University of New South Wales

Sydney, Australia

John is Chairman of the buildingSMART Australasia Chapter and committed to the adoption of digital technologies for the design and construction professions. He takes an active role in research that provides new ways of working, increased productivity and extending building performance. One of his key interests is the Industry Foundation Classes (IFC) openBIM standard and the use of IFC model-servers that manipulate large datasets to support precinct-scale integrated built asset models being developed by the Precinct Information Model project at the Australian Cooperative Research Centre for Low Carbon Living. This development and the extension of the standard into all infrastructure types provides an innovative toolkit for the management of urban development by local government.

Peter Newman

Professor, Curtin University

Perth, Australia

Peter is a Professor of Sustainability at Curtin University. He has authored sixteen books and over 300 papers. His books include *The End of Automobile Dependence* (2015), *Green Urbanism in Asia* (2013) and *Sustainability and Cities: Overcoming Automobile Dependence* which was launched in the White House in 1999. Peter was a Fulbright Senior Scholar at the University of Virginia Charlottesville and was on the Inter-governmental Panel on Climate Change (IPCC) for their Fifth Assessment Report. In 2014, he was awarded an Order of Australia for his contributions to urban design and sustainable transport. He is a Fellow of the

Academy of Technological and Engineering Sciences Australia. Peter has worked in local government as an elected councillor, in state government as an advisor to three Premiers and in the Australian Government on the Board of Infrastructure Australia.

Peter Newton
Research Professor, Swinburne University of Technology/Research Program Leader, Cooperative Research Centre for Low Carbon Living
Melbourne, Australia
Peter is a Research Professor in Sustainable Urbanism at Swinburne University of Technology in Melbourne, Australia. His research is focused on pathways capable of achieving a sustainability transition for cities and their residents. They include technological innovation in urban infrastructure, innovation in urban planning and design, and in understanding household consumption behaviour. Before joining Swinburne in 2007 Peter was Chief Research Scientist at the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). He is a member of Australia's major urban research networks: CRC for Low Carbon Living, CRC for Spatial Information, CRC for Water Sensitive Cities, AHURI, AURIN and SBEnrc. His research on low carbon living includes studies on zero carbon housing, quantifying the significance of alternative urban forms for energy use in cities, a study identifying the determinants of household energy use and an Australian Research Council (ARC) Discovery project on the green economy.

Tuan Ngo
Associate Professor, the University of Melbourne/Research Director, Australian Research Council (ARC) Centre for Advanced Manufacturing of Prefabricated Housing
Melbourne, Australia
Tuan is the leader of the MUtopia Platform, a simulation and visualisation system for designing and assessing sustainable precincts as well as sustainable cities. The MUtopia platform has been used in a range of urban development projects in Australia.

Paul Osmond
Director of the Sustainable Built Environment Program, University of New South Wales
Sydney, Australia
Paul has been engaged with sustainable development since the 1980s in practice and more recently through teaching and research. Prior to taking on an academic position with the University of New South Wales Built Environment Faculty, he managed the former UNSW Environment Unit. Paul has also worked in consultancy and local government roles, where he was responsible for the delivery of a variety of pioneering environmental management, landscape and urban design programs and projects. His previous professional background includes experience in forestry, freelance technical journalism and

the metal industry. Paul has qualifications in applied science, environmental management and landscape design. His PhD research focused on methods for evaluation and design of sustainable urban form. He is a Certified Environmental Practitioner, Associate of the Institute of Environmental Management and Assessment, Registered Environmental Auditor and Green Star Accredited Professional.

Jim Plume
Senior Research Fellow, University of New South Wales
Sydney, Australia
Following an academic career that spanned over thirty years, Jim now holds a half-time position as a senior research fellow at the University of New South Wales in Sydney, leading a research project on Precinct Information Modelling. His current research focus is concerned with extending the concept of BIM to the scale of urban precincts, specifically to facilitate the measurement, assessment and management of carbon impact to achieve sustainable built environments. Jim is on the Board of buildingSMART Australasia and is a member of the Infrastructure Committee for buildingSMART International, contributing to the development of international standards for information modelling of the built environment. Recently, he was lead author on a position paper for the Australian Commonwealth Government, written in collaboration with Spatial Industry Business Association (SIBA) and examining the relationship between construction and spatial modelling. He also co-chairs an international buildingSMART Working Group, working closely with Open Geospatial Consortium (OGC) to examine the role of standards across the building and spatial domains.

Adriana X. Sanchez
Research Associate, Sustainable Built Environment National Research Centre, Curtin University and PhD Candidate, University of New South Wales
Sydney, Australia
Adriana has ten years of research experience accrued across four continents and resulting in a growing list of academic and industry publications. These include the edited Routledge books *R&D Investment and Impact in the Global Construction Industry* and *Delivering Value with BIM: A Whole-of-life Approach*. Adriana also teaches at UNSW and University of Technology Sydney (UTS) on topics related to sustainable, resilient and smart cities. She is one of the coordinators of the International Council for Research and Innovation in Building and Construction (CIB) Task Group 90: Information Integration in Construction. Adriana's current interests centre on increasing urban resilience and leveraging information across organisational and system boundaries. Her research activities focus on how to translate policies into tangible outcomes and research into practice. Her most recent experience has been in sustainable infrastructure, urban resilience, developing national strategies for the adoption of new technologies and how to maximise and monitor benefits from the implementation of these technologies.

Ruben Santos

PhD Candidate, University of Lisbon
Lisbon, Portugal
Ruben is a PhD Candidate in Civil Engineering at Superior Technical Institute (IST, Instituto Superior Técnico) at the University of Lisbon. He specialises in Building Information Modelling (BIM) and has experience in the fields of sustainable construction, energy efficiency, life-cycle assessment (LCA). Ruben has been doing research at the Civil Engineering Research and Innovation for Sustainability (CEris) (IST, University of Lisbon) on BIM, multi-objective optimisation models for energy efficiency based on BIM models and IFC as well as about the integration of smart technology with BIM-based objects. Ruben is also engaged in the promotion of BIM in Portugal, particularly in the field of normalisation, through his work as secretary of the Portuguese Technical Committee for BIM Standardisation (CT197-BIM). He also has experience in the field of structural design, having practised in Portugal and the United Kingdom.

Ahmet Anıl Sezer
PhD Candidate, Chalmers University of Technology
Gothenburg, Sweden
Ahmet is a PhD candidate at the Division of Service Management and Logistics of Chalmers University of Technology. His research focuses on performance measurement and resource-use management at refurbishment sites, including information and communication technologies (ICT) support for these activities. He is interested in the links between productivity and sustainability in housing and office refurbishment projects. Ahmet has a Master's in Design and Construction Project Management from Chalmers University of Technology and a Bachelor's in Civil Engineering from Karadeniz Technical University.

Sonia Lupica Spagnolo
Adjunct Professor and Research Fellow, Polytechnic of Milan (Politecnico di Milano)
Milan, Italy
Sonia is Adjunct Professor and Research Fellow at the Department of Architecture, Built environment and Construction Engineering (ABC), Politecnico di Milano. She holds a PhD in Building Systems and Processes, and a Master of Science in Building Engineering. Her research interests and expertise lie in the areas of durability, maintenance management, information integration in construction, performance decay over time and energy efficiency. She was coordinator of three experimental programmes at Politecnico di Milano, two on photocatalytic materials and one on External Thermal Insulation Composite Systems (ETICS). She also collaborated with the Italian Institute for Building Technologies – National Council for Research (ITC-CNR) and with the French Scientific and Technical Centre for Building (CSTB, Centre Scientifique et Technique du Bâtiment) developing new methods and tools for service-life prediction. Sonia is

a member of the CIB Working Commission 80 (W080): Prediction of Service Life of Building Materials and Components, and of CIB Task Group 90 (TG90): Information integration in Construction. She has authored over sixty academic publications, including books, peer-reviewed journal papers, conference papers and book chapters.

Marit Støre-Valen
Associate Professor, Norwegian University of Science and Technology (NTNU)
Trondheim, Norway
Marit leads the research on Property Management at NTNU and teaches Master's courses within the Civil Engineering and Environment Master's programme at the Department of Civil and Transport Engineering, Faculty of Engineering and Technology Science, NTNU. She also participates in the Master's programme in Real Estate and Property Development and Management at the Faculty of Architecture and Fine Art. Her field of research is real estate and property management of public and private building portfolios, refurbishment and development of buildings, strategic facilities management and maintenance planning, assessment tools for whole-of-life sustainable buildings and building processes, and use of smart technology. Marit was Head of Department at NTNU (2009-2013) and has since served as a Senior Consultant/Project Manager for the Norwegian Building Authority (DIBK), where she led 'Bygg21' (2013–2014), an initiative to develop a policy instrument and strategies for the Norwegian construction industry. Marit is an active member of the CIB, participating in task groups, contributing to the development of roadmaps for research, and publishing articles and book chapters. She is an active networker among Norwegian researchers with a special interest in improvements within the construction industry.

Fredrik Svalestuen
PhD Candidate, Norwegian University of Science and Technology (NTNU)
Oslo, Norway
Fredrik is doing his PhD on the communication between engineering and production in construction projects at NTNU's Department of Civil and Transport Engineering. Prior to this, Fredrik worked as Site Manager for a subsidiary of Veidekke Group involved in asphalt/aggregate operations and public road maintenance in Norway. Fredrik has a growing list of publications ranging in topic from performance measurements, improving design management, using mobile devices to improve communication in construction projects, to Virtual Design and Construction.

Joseph Handibry Mbatu Tah
Head of School and Professor in Project Management, Oxford Brookes University
Oxford, UK
Joseph is Professor in Project Management and Head of School of the Built Environment at Oxford Brookes University in the UK. He has extensive

experience in the application of artificial intelligence, distributed computing and Building Information Modelling techniques to systems for managing large-scale projects and extended enterprises in the construction and related industries. He has published widely in these areas and provided consultancy and advisory services to national and international companies and governments. He is a Fellow of the Royal Institution of Chartered Surveyors (FRICS) and a member of the Chartered Institute of Building (MCIOB).

Xiangyu Wang
Professor and Director, Australasian Joint Research Centre for Building Information Modelling (BIM), Curtin University
Perth, Australia
Xiangyu is the Director of the Australasian Joint Research Centre for Building Information Modelling at Curtin University. He is also a project leader at the Sustainable Built Environment National Research Centre. Xiangyu serves as Curtin-Woodside Chair Professor for Oil, Gas & LNG Construction and Project Management and Chair of Curtin Advanced Technology Research and Innovation Alliance (CATRINA). His research interests include Building Information Modelling, information technology in construction, virtual, augmented and mixed reality, computer-supported cooperative design/work, mobile, pervasive and ubiquitous computing in design and construction, computer-aided design and e-learning. He holds a PhD from Purdue University and has published over a hundred academic papers, chapters and books.

Peng Wu
Senior Lecturer, Curtin University
Perth, Australia
Peng is a senior lecturer at Department of Construction Management, Curtin University. He did his PhD in Project Management at the National University of Singapore. He also holds a Master of Science in Construction Management from Loughborough University, UK and a Bachelor of Science in Project Management from Tsinghua University, China. His research areas include sustainable construction, lean production and construction, production and operations management and life-cycle assessment. He has provided consultancy services to many clients in the construction sector, including the Housing and Development Board, Singapore.

Wen Yi
Research Fellow, Australasian Joint Research Centre for Building Information Modelling, Curtin University
Perth, Australia
Wen is a research fellow at the Australasian Joint Research Centre for Building Information Modelling at Curtin University and a Post-Doctoral Fellow at the Department of Building and Real Estate at the Hong Kong Polytechnic University in Hong Kong, China. Wen's research interests include occupational

health and safety, information technology in construction management, construction labour productivity and ergonomics. Wen holds an MSc in Construction Management and Economics from the Chongqing University China and a PhD in Construction Management from the Hong Kong Polytechnic University.