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Abstract. This paper reports on a 2-year research project undertaken in collaboration with a state planning authority, a major city municipal council and a government-owned development organisation. The project involved the design of an urban information model framework with the aim of supporting more informed urban planning by addressing the intersection where an individual building interfaces with its urban context. This adopted approach enables new techniques that better model the city and its processes in a transparent and accessible manner.

The project concentrated on two aspects of this issue. The first concerned the development of a framework for managing information at the precinct and building level through the adoption of an object-oriented database technology that provides a platform for information management. The second involved an exploration of ontology tools and how they can be adopted to facilitate semantic information queries across diverse data sources based on a common urban ontology. This paper reports on the first of those two agendas, examining the context of the work, the challenges addressed by the framework and the structure of our solution. A prototype implementation of the framework is illustrated through an urban precinct currently undergoing renewal and redevelopment, finishing with a discussion of future work that comes out of this project.

1. Introduction

At the centre of effective collaboration among the built environment professions is the need for ways to model both the things we design (from coffee-makers to cities) and the processes that define how those models are exchanged among the many professions involved in that collaboration. In that light, the primary driver for this project has been the challenge provided by the essential incompatibility
between legacy GIS (geographic information system) datasets and BIM (building information model) representations of the built form. When dealing with urban scale information, GIS technologies use an overlay mapping metaphor linked to traditional relational database technologies to identify features or regions in the urban landscape and attach attribute data to those in order to permit analysis and informed assessment of the urban form. On the other hand, BIM technologies adopt an object-oriented approach to model the full three-dimensional characteristics of built forms in a way that captures both the geometric and physical attributes of the parts that make up a building, as well as the relationships between those parts and the spaces defined by the building fabric. The latter provides a far richer semantic structure to the data, while the former provides robust tools for a wide range of urban analyses. Both approaches are widely recognised as serving well the needs of their respective domains, but there is a widespread belief that we need to reconcile the two disparate approaches to modelling the real world [1, 2]. This project addresses that disjunction between modelling approaches.

The core of our approach is to recognise the semantic strength of BIM technology, while acknowledging the analytical power of GIS tools, even at the building scale [2]. As such, the approach taken in this work is to adapt the open IFC standard developed by BuildingSMART for BIM, but extended to incorporate urban information. This introduces the notion of urban information modeling, reflected in the more specific objective of the project expressed at the time it was being conceived (quoted from the funding application) : "… to adapt an information modelling technology that is already gaining wide acceptance in the building industry for modelling at the individual building scale and apply that as an urban information model to facilitate coordinated decision-making based on scientific analyses to accomplish sustainable urban planning and management outcomes".

As the project unfolded, it became clear that there are three information modelling technologies that impact on this project : the extended IFC schema to represent urban information models [3]; the set of OGC-compliant standards for exchanging geographic data, implemented as Web Services to deliver information in defined XML formats [4, 5, 6]; and ontology language standards that provide a formal explicit specification of a shared conceptualization [7, 8]. These are all required in order to integrate the heterogeneous and autonomous data resources, and to manage the embedded meaning of much of the information required to facilitate decision-making, but the focus of this present paper is on the first.

Our approach to the implementation of the urban information model has been to propose extensions to ISO/PAS 16739, the international standard for modelling building information that is commonly known as IFC (Industry Foundation Classes). Our reason for adopting that approach is partly our deep commitment to the adoption of open standards to facilitate the exchange of information across the
built environment professions, but also because IFC is based on a robust object schema that can be used to construct a internet-accessible database able, theoretically, to handle the vast quantity of data needed to model urban-scale information [9]. The database solution comes with well-established protocols for handling data security, integrity, versioning and transaction processing or querying.

A central issue addressed through this work is concerned with level of detail. An urban information model permits a very precise and detailed representation of an urban precinct, while many planning analyses rely on simplified object representations [10]. Our approach is to simultaneously maintain multiple representations of buildings in a manner that is functionally equivalent to the LOD (level of detail) representations defined in the CityGML schema, adopted as a standard by the Open Geospatial Consortium (OGC).

2. The urbanIT information framework

The entire project became known as UrbanIT, with the key objective to develop the UrbanIT framework that is illustrated in Figure 1. In this section of the paper, we briefly outline the key components and underlying rationale of that framework, though for this current paper, our focus is on the urban information modeling components.

As illustrated in Figure 1, the UrbanIT framework is made up of the following key components:

- **User Application** - At the heart of this work is any kind of user application that requires access to the vast set of information sources related to urban planning, design and management processes. In our testing, we implemented a simple web interface that interrogates multiple databases and displays the results as KML representations overlaid on an aerial image constructed using the Google Earth API.

- **Urban Datasets** – These are illustrated across the bottom of the diagram and include any kinds of legacy urban data held in GIS databases, census data, customised datasets maintained by particular planning organisations, land title data, district boundaries and associated information, and so on. The Open Geospatial Consortium (OGC) has a core mission to facilitate the development of standards to allow interoperability and exchange of data between these types of data sources.
Fig. 1. The UrbanIT framework.

- **Semantic Layer** - A key aspect of the UrbanIT project work has been to explore the use of ontologies to facilitate the exchange of information between these diverse databases, while still maintaining the semantic integrity of the data. This complements the work reported in [1], but is not discussed further in this paper.

- **BIM Repositories** - Building information models are increasingly used to facilitate the design and construction of buildings (new and refurbished) and the potential exists for these to be stored in network-accessible database repositories in an open-standard format such as IFC [11]. Although not common practice now, it is envisaged that this could create a very rich source of detailed information about the built environment. Standard database management techniques can provide appropriate security of access to these repositories as well as support controlled transaction level querying of the data.

- **Urban Information Repositories** - The key contribution of the UrbanIT project reported in this paper has been the development of a proposed extension to the IFC schema for modelling buildings to encompass the concept of a cadastral lot. This is fully discussed in later sections of the paper.
• **Information Links** - Arrows used in Figure 1 indicate the possibility to move information from the urban datasets, via the semantic layer, in to the respective information repositories as well as the user application.

• **Project Specific Repository** - One opportunity offered by the urban information model concept is to set up database repositories that are specific to an urban precinct, draw their data as a once-off process from a diverse range of sources and are then used to support a specific design or planning purpose. The sourced data could be refreshed at any time, but the repository would serve as a single integrated database for that project.

The UrbanIT framework provides a visionary picture of how urban scale information can be effectively managed by the adoption of a standards-based object view of large-scale urban precincts. The following section discusses the urban information model in greater detail.

### 3. Urban information modelling

A core contribution of the UrbanIT project has been the development and implementation of the concept of an urban information model. This approach is quite different to much existing work that focus on the development of city models [10, 12, 13] where the emphasis is on visualisation of the urban landscape at a variety of levels of detail, with the addition of metadata to add some meaningful content to the entities represented. Those kinds of systems provide very powerful tools for navigating virtual models of cities, for accessing that metadata and even providing visualised links to more complete databases. In a later section of this paper, we illustrate the use of this kind of visualisation technique in a simple data retrieval scenario where a building shape outline (LOD1) is retrieved from an urban information model held in an object database.

The primary distinguishing feature of the urban information model is that it is based on a robust object-oriented database view in much the same way as the widely-used concept of a building information model (BIM). A critical feature of BIM is the semantic richness of its representation and that the objects have relationships to other objects. It is the ability of an object-based approach to capture very rich semantics that sets it apart from more traditional database structures.

The drivers for the adoption of urban information models are very similar to those that are driving the adoption of BIM in the construction industry generally. The first is the need for reliable, accurate and comprehensive information. In the construction sector, poor information leads to costly, inefficient errors and variations on the construction site. In the same way, poor urban information leads to bad policy decisions and mismanagement of public assets in areas such as
security, emergency response and transport (to name only a few). The other aspect of information modelling is the opportunity to measure performance across a whole range of metrics with greater accuracy and reliability. This becomes critical when faced with impending climate change and the imperative to develop more sustainable built environments.

The following two sub-sections explain our approach to the development of a robust urban information model, first by a succinct overview of our methodology, and then with an illustrated example of the implementation.

### 3.1. Proposed extensions to ISO/PAS 16739 (IFC)

Details of the proposed extensions to ISO/PAS 16739, the rationale and argued case for them, and precise technical details were provided in a working document submitted to the technical committee of buildingSMART International awaiting final endorsement and likely adoption in the next release of the standard (IFC 2x4). As such, it is subject to further refinement as this work proceeds beyond the formal end of the project.

The purpose of this section of the paper is to pick up key aspects of that proposed urban information model. We maintain that it should be related to the nature of the land form and ownership: ideally, this would be a 3D volume representing the terrain model, to which we attach a boundary, denoting the extent of ownership, and currently represented as a set of 2D points. That could also be a 3D volumetric representation in order to increase the utility of the resulting object by capturing any spatial region to which the owner has legal rights, such as airspace or subterranean holdings.

Therefore, the most appropriate spatial unit is a single cadastral lot or land parcel, being the definitive concept that describes the ownership of land defined by a boundary, typically a 2D bounded polygon mapped to the land surface. This is complemented with its modern counterpart, strata lots or condominiums. These provide shared ownership of a land parcel by several sub-entities, where each owns shared parts of a parcel at ground level with common access stairs and corridors, plus privately-owned apartments arranged over one or more storeys [14, 15, 16].

So, already there are a number of concepts:

- **Lot** - a boundary defining the extent of a land parcel, and sometimes accompanied by the location or footprint of one or more buildings on the land.

- **Strata Lot (or Condominium)** - a type of land title, being in addition to the land parcel, represented by a 3D description of the space volumes in the building defining the extent of common and private ownership.

- **Space** - a 3D volume where certain activities are carried out.
Cadastral data forms a core of the UrbanIT integration framework. At this stage we omit utilities, but note that an IFC implementation appears straightforward based on the extension of building services systems to the urban context. Any built structure can be represented in IFC, so it is fair to say that at a conceptual level, we can model any urban form, though this needs to be the topic of further research.

It is important to note that this work has been undertaken collaboratively with the Norwegian "Geo-referencing Project" under the auspices of Statsbygg and BE, Norway. In particular, we adopted their recommendations for capturing geospatial positioning information in the UrbanIT schema. In essence, we adopt the entity type known as ifcSite to represent a cadastral object and locate it within a Cartesian coordinate system relative to a project origin (ifcProject being the high-level container for an urban information model made up of a complex set of sites). Associated with each ifcSite entity, there are two defined Property Sets: ifcCoordinateReferenceSystem that captures the map reference data in a form consistent with the country that hosts the site; and ifcMapConversion that allows a local site origin to be accurately positioned relative to the map datum. In that way, a building is positioned relative to a site origin that is in turn positioned relative to a project origin (being the urban precinct represented by the urban information model), and all are positioned geospatially relative to a defined map datum according to a known mapping reference system.

A key concept in the urban information model is the notion of multiple geometric representations of entities. This is strongly supported in the IFC schema and allows us to handle appropriate visual and semantic representations of any entity to suit specific application needs. For example, an ifcSite can be represented by a surface terrain object, a 2D polygon that specifies the legal boundary of the land parcel in the traditional manner adopted by the Land Titles Office (or equivalent) or a 3D polyline entity that is mapped to the surface of the terrain and defines the position of the spatial site boundary on the ground, or an aggregation of spatial entities that defines a strata title holding.

Similarly, the ifcBuilding entity can be represented at various levels of detail to suit the planning context within which the object is being manipulated. This can range from a 2D building footprint, a simple extrusion of that footprint to denote a building volume, a more complex bounded shape that represents the building form including the roof shape, and an even more complex volume that includes the articulation of the façade and wall openings. These representations correspond roughly to the Levels of Detail (LODs) as defined in the CityGML schema for city models, providing potential integration with that OGC standard. Of course, within the object hierarchy, a building entity is broken down into all its component parts, so we are only talking here of its geometric representation as a single discreet entity.
The structure of the UrbanIT framework, therefore, matches the real-world analogy of the built environment’s natural spatial hierarchy: cities are composed of clusters of "sites". The sites may contain a building (that must have an owner) or many buildings. A building may have one floor or many, and a floor may have one or many tenancies, or discrete ‘units’. In turn, these units are aggregates of conceptual spaces and zones.

The need to accommodate a growing population in our cities is propagating denser, multi-unit developments, ideally clustered around existing infrastructure. The Strata Title system in Australia acts as documentation of location and ownership of properties at a sub-cadastral level (known as condominiums in other parts of the world). Although similar in concept and practice to the conventional 2D cadastral system, strata titles have a strong 3D component. Currently, when registering a strata scheme, the applicant must submit a set of 2D drawings defining the floor area, lot numbers and space boundaries. A repository exists of these drawings as scanned pdf files. Not only is this information a two-dimensional representation of a three dimensional system, but the ability for this format to be spatially queried and analysed is compromised. Furthermore, the terminology used in the strata title legislation is not consistent with cadastral terminology. For example, in our local context, a cadastral lot is the equivalent of a strata scheme’s site, and is referenced in the cadastre by a strata plan number (SP). In the context of strata title administration, a "lot" refers to an individual tenable unit. The existing Cadastral, Strata and Valuer General datasets have no explicit connection. This problem can be addressed by the UrbanIT framework by linking BIM and GIS not only with regard to the spatial mapping, but also semantic linking of like concepts.

3.2. Implementation of the Urban Information Model

The implementation of the urban information model is best explained through a series of screen shots that highlight different aspects of the model.

Figure 2 shows a plan view of the Green Square cadastre derived from Lands Department data and loaded into a project model on the EPM Model Server as an object database. For the purposes of clarity, only land parcels have been included in this model, so the road lots are simply left blank. The hierarchical list in the left pane of the application shows the underlying structure of the server database.
Here a single object database can have several repositories (or “workspaces”), which in turn, can have several project models. In this case, we are looking at a repository called GSProject that contains a single model called GreenSquarePrecinct (in IFC2x3 format). The model has a single ifcProject (second pane from the left) that consists in this simple model of a long list of ifcSite entities, each named using the Land and Property Data Authority (LPMA) CADid and the Plan Label (starting with DP for deposited plans and SP where the lot has a strata title). The view pane shows a plan view of the entire model. Note that the gaps are a caused by the graphic viewer where small tightly clustered lots (typically row housing) are not displayed at this view scale and actually only appear as you zoom in on the view.

Figure 3 shows the data attached to one of the cadastral entities, highlighted in red. Various tabs show different aspects of the IFC entity. The selected tab shows its property data, including the two geospatial property sets described previously, giving the map conversion coordinates relative to the map datum defined in the second property set called CRS (ifcCoordinateReferenceSystem). Note the tab that shows the ownership of the data that is held in the model. If we were to select that tab, we would see that the data came from the LPMA, was supplied by a specific person and produced using a small Java application developed by the UrbanIT team that converts DXF cadastral data in to IFC format.
That is, in this database context, the ownership data is as important as any other attribute data, permitting full operational management of the database.

Fig. 3. IfcSite attribute data display.

Also note the relations tab, where object relationships are explicitly stated: for any selected site, the property data shows the two-way relationship between the site and any buildings that it contains (using the IsDecomposedBy relation) and the backward relationship of the site belonging to its parent project (using the Decomposes relation). These are relationships that are implied, and appropriately captured, by the object hierarchy in the IFC model schema.

Figure 4 switches to another site within the Green Square precinct where we placed a strata title development that we named the Gadigal Apartments. The BIM was constructed from the strata title plans for that site, so does not accurately model the true building, but does serve this example. It illustrates the ability of the UrbanIT information model structure to represent strata information. The figure shows that on level 8, there are 5 space entities defined where the highlighted one (in red) is all or part of lot 62.
The IFC schema allows for the definition of a zone that consists of a set of disjoint space entities, meaning that we can represent the concept of a strata lot that is made of public and private spaces on different levels of the building (spaces assigned to zones in this way are not duplicated entities, but merely point to the defined space associated with the corresponding).

Fig. 4. Strata Lot 67 - aggregation of disjoint parts.

The next screen capture in this sequence (Figure 5) shows a view of the prototype model with a cluster of buildings near the town centre and Gadigal in the background. Some of the BIMs are quite complete with sun shading devices, handrail details, interior fittings and even door hardware.

This image (Figure 5) was captured from a live demonstration that showed how the data model can be extracted from the urban model server and loaded in to another IFC-compatible viewing and auditing tool (known as Solibri Model Checker). This allowed an inspection of the detailed components that make up the model, moving from the large urban scale to the precise details of individual building elements and fixtures.
The final set of images in Figure 6 visually illustrates the levels of detail contained within the single database, ranging from the general precinct level down to the fixed awnings on one of the buildings, the internal building elements (columns, walls, windows, etc.) and internal furniture entities. Each object is fully defined geometrically, with all properties and relationships (both implicit and explicit) and fully geospatially located.

The final implementation example, shown in Figure 7, illustrates how a database query transaction can retrieve an LOD1 representation of a building from the urban information model server (with its full geospatial location) and position it within an urban precinct model displayed in Google Earth. The existing urban fabric is shown as background, with the proposed building development envelopes (colour coded according to land use) extracted from a traditional GIS database. This illustrates the integration of information from diverse datasets, both GIS and an urban information model, brought together in a simple Web interface.
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**Fig. 6.** Set of images showing model details.

**Fig. 7.** Example of a transaction query: the full building model (shown in the upper right, as viewed within the urban information model database client) is displayed as LOD1 using a KML representation embedded in an image pulled from Google Earth (base image © 2010 Sinclair Knight Merz & Fugro). The coloured forms represent development envelopes derived from a separate GIS database.
4. Conclusion and future work

In this paper, we have shown that the object-based modelling approach used increasingly in the building design process and known as BIM can be extended to an urban scale by extending the concept of "site" to include a collection of individual cadastral lots, each one geospatially located and defined both geometrically (with different representations to suit different purposes) and with a full set of defined properties and relationships. This allows us to manage the urban information model as a database, integrate with traditional GIS analysis tools and better support collaborative built environment design processes.

Collaboration, by its nature, involves pulling together multidisciplinary knowledge and expertise to address a shared problem. Information model databases lie at the centre of that process, providing integrated data that can inform collaborative decision-making, support resolution of the conflicting needs and priorities of diverse stakeholders and provide an effective vehicle for evidence-based analysis.

Future work will extend the urban information model approach to manage the storage of other urban features such as infrastructure models (roads, bridges, tunnels, etc) as well an urban service networks (water, energy, transport, etc) analogous to building services, but at an urban scale.

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References

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