What are Essential requirements in Planning for Future Cities using Open Data Infrastructures and 3D Data Models?

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Abstract

Major urban renewal programs including higher density and infill developments are being planned in brownfield and greyfield areas of the cities. These have increased the challenges in urban planning and management tasks. To address the challenges multi-dimensional and multi-spatial data is required to support city planners and policy-makers. There have been substantial improvements in developing and sharing the spatial data infrastructure. Moreover, the extended semantic capacity in 3D data models enables innovations in multi-dimensional urban planning and design. However, using these technologies to identify semantic relationships between objects, in diverse spaces and dimensions, enabling the stakeholders to evaluate future plans utilizing extra/open data sources is not yet possible. This study intends to develop a generic framework supporting a multi-spatial and multi-dimensional planning data model. The study examines the existing Australian Urban Research Infrastructure Network (AURIN) e-infrastructure to indicate the extent in which the formulated framework can improve spatial planning tasks.

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1. Introduction

A number of rapidly growing cities around the world are adopting compact city and urban consolidation strategies. The implication of this type of development strategy is already impacting suburban development in the form of smaller lot sizes and medium density subdivisions. There are also corresponding critical changes observable in the inner cities. Major urban renewal programs including higher density and infill developments are being planned in the brownfield and greyfield areas of the city (Newton, 2010). The new development approaches, however, have generated unprecedented challenges.

These trends have increased the challenges in urban planning and management tasks. For instance, the substantial proportion of new urban buildings in Australia will end up in the strata market. However, the strata system is challenged by lack of information on physical dimensions living or working environment. Other challenges are linked to increase in size and complexity of urban entities, being buildings or infrastructures. The challenges mostly address the need for developing an inclusive, vibrant, liveable, and healthy community (e.g., there is low social cohesion in neighborhoods with high rise buildings, considering physical barriers and spatial layout to ensure walkability). The challenges also highlight other issues like environmental concerns such as flood and earthquake risk increase, carbon emission, and urban heat island, as well as complexity in economic, political, and regulatory forces (e.g. affordable housing, in-fill development in brownfields and greyfields).

To address the new urban challenges, multi-spatial and multi-dimensional data are required to support city planners and policy-makers. This is because of the fact that challenges are associated to several spatial scales, such as building (e.g. height, shadow, building setbacks and separation), neighborhood (e.g. in-fill development, wind-drafts in built-up areas, crime prevention, healthy community), and broader city and regional scales (e.g. urban heat island, labor force pattern). Planning and decision making for these multi-spatial challenges require sophisticated tools incorporating comprehensive information from various sources and in three or more dimensions.

There have been substantial improvements in integrating building and urban data to foster the urban management domain. For instance, Singapore's CORENET e-PlanCheck system applies a single portal to support the building code compliance checking for over 12 regulatory agencies. In addition, the increasing array of datasets being made available through open data initiatives such as those created by various federal, state and local governments have been federated across Australia through an e-infrastructure known as the Australian Urban Research Infrastructure Network (AURIN) (Sinnott et al. 2015). AURIN comprise an online workbench of over 1,000 dataset and 100 spatial-statistical tools to support urban researchers, planners, and decision makers across Australia (Pettit et al. 2015). These can cover range of planning purposes from social and economic development to urban ecology and energy-efficiency analyses. Furthermore, the extended semantic capacity in 3D data models enables innovations in multi-dimensional urban planning and design. True multi-dimensional data structures move beyond the capability of analysis and decision making more than simply 3D graphic or virtual reality models. Some of the 3D enabled planning support systems such as ESRI's CityEngine (http://www.esri.com/software/cityengine), CommunityViz GIS (http://placeways.com/communityviz/index.html), and SynthiCity (http://www.synthicity.com/) have already adopted fundamentals of 3D data improvements.

However, using these technologies to identify semantic relationships between objects, in diverse spaces and dimensions that are included in development plans integrated to extra/open data sources is not yet possible. These systems and importantly the underlying data structures need to be improved and integrated in a way that the contents and meaning of plans are available, and can be evaluated using various information, such as health, demographic, environmental, economic, and legal data.

This study intends to develop a generic framework for supporting a multi-spatial and multi-dimensional planning data model. For this purpose, the study conducts a comprehensive review of the common and emerged planning tasks based on new urbanism paradigm using four spatial planning categories. We then evaluate the identified tasks and determine the interoperability of current state of the art in semantic 3D model and open data infrastructures.

2. Common and Emerging Spatial Planning Tasks

The contemporary urban planning and design paradigms and approaches are mainly focusing on the details of principles and objectives of *Smart growth, new urbanism,* and *ecological city* (or Eco-city), three development strategies. For instance, transit-oriented development (TOD) (Calthorpe 1993), compact city (Burton 2002; Cozens 2011; Elkin et al. 1991; Randolph 2006; Zhang et al. 2012), urban resilience and safe cities (Desouza and Flanery 2013; Jha et al. 2013), and healthy city (Harpham

2001; Rydin et al. 2012; Webster and Sanderson 2013) approaches are mostly defined based on new urbanism and smart growth principles to ensure the development of future sustainable cities.

These development approaches adopt land use control, design and architecture principles, and other regional and local policies to encourage more compact and mix land use development, urban revitalization and rediscovery, a diverse transportation and housing systems, walkable neighborhoods, distinctive, attractive communities with locally sensitive architecture and a strong sense of place, protection of open spaces, farmlands, and critical environmental areas, and collaborative decision making (Smart Growth Network 2015).

Emerging planning tasks are also stem from new urbanism and smart growth initiatives. Urban resilience for example, is a new paradigm focusing on the consequences of climate change, natural disasters, pollution, and crime prevention measures, particularly in high-density and rapid urbanizing areas (Adewole et al. 2014; Coaffee 2009; Eraydin and Taşan-Kok 2013). As a result, planning tasks such as land use planning for major accident hazards, crime prevention through environmental design (CPTED), planning for natural hazards risk reduction, designing healthy community, and enhancing the urban management through U-services are some of emerging planning tasks.

Most of these planning tasks are highly subjected to availability and analyzing location information through different timeframes. Pullar and McDonald (1999), pointed to the myriad of circumstances associated with location information and their analytic results, namely, land development information, site location analysis, policy evaluation, and scenario development. Understanding how 3D technology in both aspects of data set development and analysis can be used in common and emerging planning tasks effectively, we adopted the taxonomy of urban planning tasks implemented by Pullar and McDonald (1999). Their framework is presented based on whether or not the primary planning activity is known, and whether or not the location of activity is identified over the time period from the current situation to the future developments. Figure 1 indicates how the four planning tasks of urban management, site selection, impact assessment, and strategic planning are categorized.

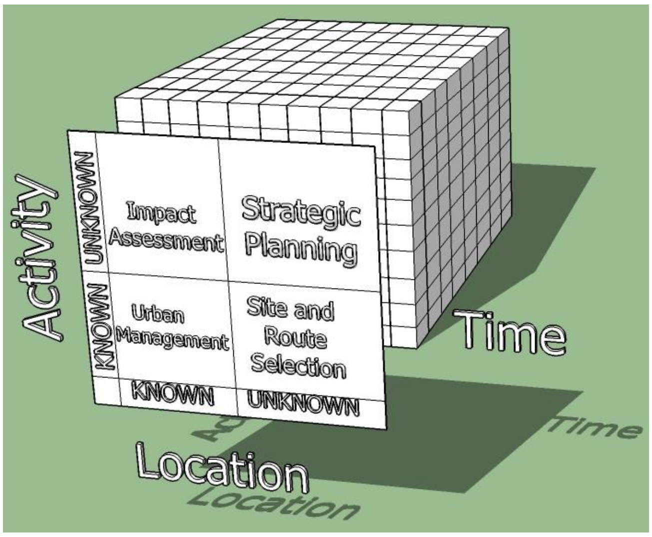

Figure 1 Taxonomy of spatial planning tasks according to knowledge of the land use activity and its location. Adopted from Pullar & McDonald, (1999)

The role of geographic information systems (GIS) in spatial planning has being appreciated in several studies (Al-kheder et al. 2009; Steiner and Butler 2012; Thompson et al. 2013). There are two major improvements on GIS and the application in urban planning. First, the current generation of spatial data infrastructure in most of developed (Herman and Rezník 2013) and some developing countries (Mukherjee and Ghose 2013; Sabri et al. 2014) allow the geographic information partnering across stakeholders and different jurisdictions, called open data infrastructure (Masser et al. 2008). Second, current state-of-the-art indicated the advantages of migrating from two-dimensional to third and fourth dimensional spatial data infrastructure in planning and decision making tasks (Lippold 2010; Yin and Shiode 2014). In next two sections these developments in relation with the taxonomy of spatial planning tasks will be explained.

3. Open Data Infrastructure and Spatial Planning

Several studies and spatial data infrastructure (SDI) advocates indicate the usefulness of standardized and harmonized SDIs in various types of spatial planning and urban management activities (Masser et al. 2008; Rajabifard et al. 2006). Several initiatives, therefore, implemented to ensure that different SDIs of sub-government states are compatible and useable in the urban research and planning community and trans-boundary context (Pettit et al. 2013; Pineschi and Procaccini 2013).

The European Union, for instance, initiated an infrastructure for spatial information in Europe "INSPIRE" directive as a legal framework and being implemented across 28 EU countries. INSPIRE allows the sharing of spatial information to support harmonized and sharing data for environmental policies, and policies affect the environment (Villa et al. 2011), as well as spatial planning data based on trans-national cooperation among EU public administrations (Pineschi and Procaccini 2013). INSPIRE directive contributed to spatial planning through Plan4all project, whereby the spatial planning data is harmonized based on existing best practices in EU and the result of current research projects (Pineschi and Procaccini 2013).

Australian federative initiated AURIN that offers seamless and secure access to data from several various sources. It provides an online capability to integrate and interrogate data using open source statistical and spatial analysis and modelling and visualization tools (Pettit et al., 2013). AURIN provides wide range of data types, various levels of spatial scales to empower urban settlement research and decision making by leading-edge, data-driven, and integrated e-infrastructure.

The aforementioned open data infrastructures are significant developments towards providing evidence-based urban planning. Nevertheless, more improvements such as harmonization and standard data sets across jurisdictions, identifying urban data ontology, and implementing 3D data structure for the future is required. CityGML, for instance, for representation and exchange of 3D city models (Gröger and Plümer 2012), 3D Cadastre (Aien et al. 2013), and building information model (BIM) (Wang and Sohn 2011), can be integrated to open data infrastructure to maximize the utilization of both in urban planning and policy making process. However, this integration is yet to be fully achieved. The next section will explore the current developments in 3D technology.

3. 3D Data Model and Spatial Planning

3D city models have started being developed in early 1990s to visualize future development and changes in urban infrastructure (Lippold 2010). Later, GIS data replaced 3D architecture models and 3D city models improved during last two decades from lower levels of detail (LOD) to higher levels and from non-semantic models to semantic models (Zhu et al. 2011). The development and improvements in standardization of 3D GIS such as City Geography Markup Language (CityGML) added more value to sustainable information sharing and semantic for representing volumetric urban objects, such as buildings, vegetation objects, waterbodies, and other urban infrastructures (Aien et al. 2013; Gröger and Plümer 2012; Zhu et al. 2011).

Recent developments in CityGML have many implications in urban planning tasks, particularly environmental sustainability measures and energy modeling. These improvements have transformed the analysis types from geometrical/visual aspects to more quantitative and accurate calculations such as urban heating energy demand prediction (Strzalka et al. 2011), and urban engineering (Borrmann et al. 2014).

Several studies indicated the advantage of integrating building information model (BIM) with GIS to add more value to 3D city model analysis outcomes (Borrmann et al. 2014; de Laat and van Berlo 2011; Mignard and Nicolle 2014; Wang and Sohn 2011). De Laat and van Berlo (2011), developed an extension for CityGML, called GeoBIM to integrate the strength of BIM and GIS for the purpose of enriching semantic 3D city models. Mignard and Nicolle (2014) developed a platform, ACTIVe3D dedicated to urban facility management. However, the legal aspects of urban features have not been considered in most of 3D city model improvements (Karki et al. 2010).

As Çağdaş (2013) suggests, there is possibility of integrating land and property legal attributes pertinent to cadastre mapping with 3D city models. He developed an application domain extension (ADE) with the intention of helping municipalities to conduct more efficient urban property taxation, particularly in strata properties. Similar to the issues highlighted by Çağdaş (2013), there is a large volume of published studies describing the different dimensions of 3D cadaster and highlighted its relevance and potentiality to visualize property information, such as ownership and property rights, restrictions, and responsibilities (RRRs) to be utilized in urban planning and management (Aien et al. 2013; Shojaei et al. 2014).

Nevertheless, there is a lack of conceptualization on integration of BIM, Cadastre, 3D city model to harness the current developments in 3D analysis and support the decision making in urban planning and policy process. This integration can be conceptualized based on spatial planning requirements to ensure developing models with higher opportunities to carry out the critical social, economic, environmental, and political investigation (Figure 2).

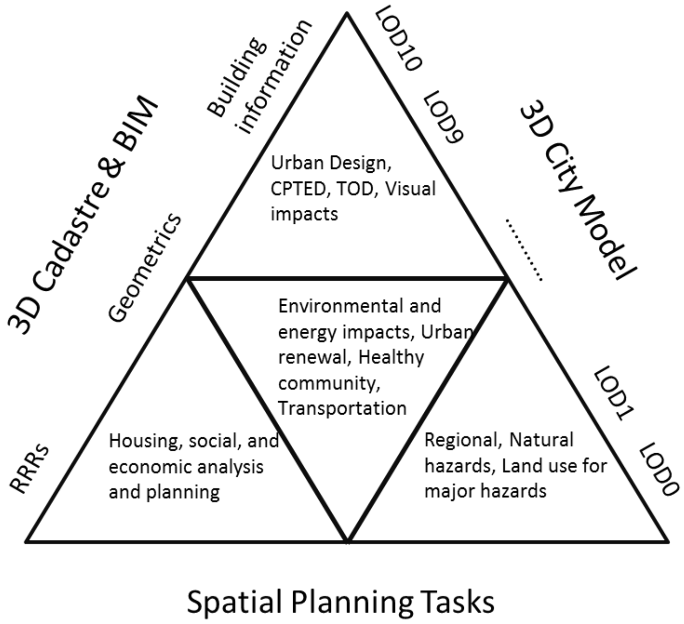

Figure 2 The conceptualization of integrating 3D Models in Spatial Planning Tasks

The conceptualization that is presented in Figure 2, includes new level of details (LOD) for representation of the 3D models, suggested by Biljecki et al. (2014). The new standardization of LODs are presented based on six metrics, namely, 1) presence of city objects and elements (the elements of the building and surrounding features that should be presented in each LOD); 2) feature complexity (the geometrical correspondence of the model to the reality); 3) dimensionality (the 3D buildings may contain windows modelled as polygons and chimney as points on the roof surface); 4) Appearance (elements that are not geometrically or semantically acquired are still important, like a window which is not geometrically presented in model, but it is important for visual inspection and rough measurements); 5) Spatio-semantic coherence (describes the granularity of the semantics in a model and its correspondence to the geometry, as an example, a tree may have its canopy and branches modelled, while in one case they may be assigned only a tree as the semantic, in other case they could have their specific names and functions as semantics). 6) Attribute data (depending on the application, a list of attribute can be assigned to each component of a 3D model, for instance the ownership of the building, the year of construction, or material of the wall).

The six metrics that constitute the basis for formulating ten LODs cover the requirements of spatial planning tasks. In addition, the exterior and interior city objects are decomposed and use the metrics for each separately. These will cover particularly the requirements of 3D cadastre and BIM in application to the spatial planning tasks. Besides, the new LOD standards cover the various acquisition and modelling techniques. In next section we examine a case study conducted by AURIN to evaluate how the application of conceptualized integrated 3D models can improve the functionality of this open data infrastructure.

4. Case Study

The AURIN e-infrastructure initiated by the Commonwealth Government of Australia to support the urban and built environment research community (Pettit et al., 2015). It has considered the national priority areas and set a number of strategic implementation streams, referred to as “lenses”. The lens-centric approach was conceived with principles such as focus on accessible, integrated, reliable, and authoritative data (Pettit, et al, 2013). The data generated is available for application and analysis through a suite of online spatial-statistical tools catering a significant diverse range of interests in Australia’s urban analytic community as follows:

1. Population and demographic futures and benchmarked social indicators,
2. Economic activity and urban labour markets;
3. Urban health, well-being and quality of life;
4. Urban housing;
5. Urban transport;
6. Energy and water supply and consumption;
7. City logistics;
8. Urban vulnerability and risks;
9. Urban governance, policy and management; and
10. Innovative urban design.

For the purpose of this study we focus on Lens 10, where 3D modeling tools have been developed and applied to support innovative urban design in precincts focusing on urban renewal. . For Lens 10, a 3D geospatial Web application was developed to import and interactively render a variety of datasets, from regional statistics down to individual elements of BIM models. The application integrated with a variety of external analysis tools to visualize their results in reports and 3D textures, allowing multiple studies to be brought together.

In Beenleigh, a town and suburb in Logan City, Queensland, Australia currently undergoing major urban renewal, the 3D technology is developed to visualize the building volumes, calculate gross floor areas with different uses and heights. Figure 3 shows the general view of urban morphology. Furthermore, height spectrum analysis; urban canyon analysis using sky view factor; and solar irradiance scenarios were developed using the integration of available data in AURIN and 3D modeling technology.

The height spectrum analysis indicates the distribution pattern of buildings with the different heights based on the Beenleigh master plan and visualizes the future cluster of high-rise buildings within close proximity to the railway station. This analysis used AURIN cadastral data with Logan City master plan height restrictions (White and Langenheim 2014a). Urban canyon assessment was conducted using rapid Sky View Factor (SVF) developed by White and Langenheim (2014a), a metric shown to have a strong correlation with Urban Heat Island. The SVF analysis provided rapid feedback for assessing street enclosure and highlighted areas where potential impact would be greatest when compared with the existing urban form. Due to the 3D nature of the analysis, the SVF assessment also gave an indication of building proximity and view quality – how much sky can be seen from each apartment (White and Langenheim 2014b).

Solar irradiance scenarios are developed for the purpose of evaluating urban renewal impacts regarding over shadowing in winter and solar heat gain during summer impacting pedestrian thermal comfort and also contributing to UHI. This analysis determines incident solar radiation on the building surfaces, which is particularly useful for high-density urban areas that are proposed as the geometrical shapes of buildings influence the microclimate in different seasonal daytimes (Chen et al. 2012; Hammerberg and Mahdavi 2015). Figure 4 indicates potential solar impact for future urban renewal in Beenleigh.

Figure 3 Overview of urban morphology indicating different precincts and zoning with indicative building volumes displayed in the Lens10, 3D urban design tool developed by MUTopia. Model built by White, Langenheim, & Kimm using AURIN data and 2D GHD and Logan Council master plan data.

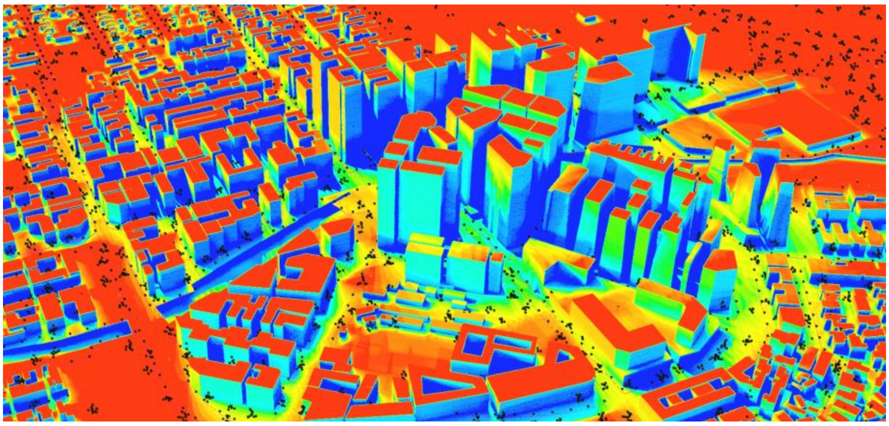

Figure 4 Solar evaluation in Beenleigh urban renewal. KMZ format mesh generated in 3ds Max™ with baked texture light map by White, Langenheim and Kimm.

The other tool that leverages the broad-spectrum data available in AURIN and serves as geo-spatial decision support tool incorporating 3D technology is Envision Scenario Planner (ESP) (Pettit et al. 2014). This tool provides facility for 3D visualization of potential development sites and also reports physical and environmental information on future development scenarios (e.g. land use, number of dwellings, Floor Area Ratio, and Energy demand, such as heating, water use, cooling, and lighting). ESP is proposed to deliver more effective stakeholder engagement through enabling better discussion about neighborhood changes (Newton & Glackin, 2013) and, like Lens 10, using modern Web technologies to make the data and analysis available on any platform.

As indicated in the two projects carried out using AURIN as a platform for providing various data sources, the 3D technology has being used in most of impact assessment and potentially urban management among four spatial planning tasks defined by Pullar & McDonald (1999). While, the environmental impact assessment presented in this study focused on the building envelope, the influence of other urban objects such as plants and green spaces have not been utilized. For instance, measurement of solar irradiation considering geometry of urban canopy will generate different result in terms of pedestrian thermal comfort (Chen et al. 2012). This can be resolved applying the principles of ten LOD standard suggested by Biljecki et al. (2014).

5. Discussion and Conclusion

This paper has argued that the current urban development approaches need more sophisticated conceptualization of spatial data and tools development providing facility for holistic spatial planning tasks. We adopted the framework that was presented by Pullar & MCdonald, (1999) for taxonomy of spatial planning tasks to indicate how the common and emerging planning tasks are associated to four tasks of urban management, impact assessment, site and road selection, and strategic planning. Then the study presented the state-of-the-art developments in open spatial data standardization for urban research and practice as well as multi-dimensional and multi-spatial urban analytics improvements. A new framework, therefore, was developed to appreciate the strength of current 3D technologies in urban modeling and analysis. Our framework leverages the new conceptualization of LOD developed by Biljecki et al. (2014) that covers most of 3D modelling requirements. AURIN as an e-infrastructure for urban and built environment research was used as the case study and capabilities of 3D analytics are evaluated using the suggested framework.

Complex three-dimensional urban scenarios enabled city designers to have a greater understanding of existing and proposed urban forms and identifying potential UHI problem areas. The study showed how 3D analysis plays a critical role in examining the impact of urban consolidation strategies and densification of inner-cities. Nevertheless, the 3D level of detail should be enhanced to support more accurate decision making. If the strata title is going to be visualized or the public and private ownership in future developments is in inquiry by the stakeholders, the present tools need to be improved to facilitate generating these types of information.

Moreover, the ability of measuring the capacity of the infrastructure underground and above ground that will serve the huge future developments can be added through combination of 3D cadastre and BIM that improves the process of scenario building and decision making particularly for infill developments. In addition, adopting 3D cadastre (Aien et al. 2013) will enable to evaluate more accurately the land and property value change in future, which is a great concern to many stakeholders involved in inner-city redevelopment (Shin 2009).

A greater focus on 3D data model for taxonomy of spatial planning tasks will improve this study. So if the debate is to be moved forward, a detailed conceptualization of spatial planning using open-semantic 3D urban data needs to be developed.

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