URBAN ANALYTICS DATA INFRASTRUCTURE: CRITICAL SDI FOR URBAN MANAGEMENT IN AUSTRALIA

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Abstract

Spatial data infrastructures (SDIs) are fundamental to enabling informed decision-making across a variety of industries and sectors but has primary relevance for managing land and land-related resources. Given the primacy of cities in meeting future sustainable development goals, SDIs are increasingly prominent in supporting the identification and management of urban-related issues such as water, energy, infrastructure and transportation, but also in the implementation and governance of urban policies aiming to deliver economic impact, social equity, housing, accessibility of public spaces and public safety.

This paper describes a new research initiative funded by the Australian Research Council that will see the development of an SDI to support urban analytics and urban research capabilities focused on Australian cities. This is a timely development for Australia, which is not only one of the most urbanised countries in the world, but is also witnessing high levels of growth rates in its urban areas uncommon in western developed countries. The Urban Analytics Data Infrastructure (UADI) intends to support multi-disciplinary, cross-jurisdiction, national-level analytics and through the design of its architecture, seeks to provide the urban research community with a digital infrastructure that responds to current challenges related to data access, sharing and application. Importantly, the UADI will build on significant existing urban research infrastructure, specifically the Australian Urban Research Information Network and its nationally federated Data Hubs. This is both critical and core SDI development for Australia, and will advance governments, industry and academia in undertaking more advanced data-driven modelling to support sustainable development in Australia’s cities.

Keywords: SDIs, cities, Australia, urban management, urban analytics

INTRODUCTION

Our cities are complex entities both in terms of the built environment and their social characteristics. Our ability to undertake sound planning, development and management not only ensures that cities continue to be engines of national economies, but also impact positively on global sustainability. Cities are therefore characterised by a plethora of information and in this digital age, the data deluge is both structured and unstructured. How can this data be leveraged, especially knowing that longstanding issues associated with data access, discovery, use and re-use, and governance, continues to be perpetuated by organisational silos variable scale, and a reliance on a range of indicators spanning both objective and subjective aspects, all of which are exacerbated by the sheer volume of available data?

We turn to the concept of spatial data infrastructures (SDIs) to propose a response. SDIs, comprising people (users, producers), data, policies, standards and technologies (Rajabifard and Williamson, 2001), are fundamental to enabling informed decision-making across a variety of industries and sectors through the use of spatial or location-based information but has primary relevance for managing land and land-related resources. Given the primacy of cities in meeting future sustainable development goals, SDIs will have prominent roles in supporting the identification and management of urban-related issues such as water, energy, infrastructure and transportation, but also in the implementation and governance of urban policies aiming to deliver economic impact, social equity, housing, accessibility of public spaces and public safety.

This paper describes a new research initiative funded by the Australian Research Council that will see the development of an SDI to support urban analytics and urban research capabilities focused on Australian cities. This is a timely development for Australia, which is not only one of the most urbanised countries in the world, but is also witnessing high levels of growth rates in its urban areas uncommon in western developed countries. The Urban Analytics Data Infrastructure (UADI) intends to support multi-disciplinary, cross-jurisdiction, national-level analytics and through the design of its architecture, seeks to provide the urban research community with a digital infrastructure that responds to current challenges related to data access, discovery, sharing and application. Importantly, the UADI will build on significant existing urban research infrastructure, specifically the Australian Urban Research Information Network (AURIN) and its federated Data Hubs. This is both critical and core SDI development for Australia, and will advance governments, industry and academia in undertaking more advanced data-driven modelling to support sustainable development in Australia’s cities.

THE CHALLENGE OF URBAN MANAGEMENT

With 70% of the world's population set to be housed in cities by 2050, the imperatives of evidence-based urban management cannot be overstated in future-proofing the sustainable development of cities. Cities may only account for around 2% of global land mass but they have a large economic footprint – generating more than 80% of global GDP (Dobbs et al., 2011), as well as a significant environmental one – contributing more than 70% of the world's greenhouse gas emissions (UN-HABITAT, 2011). Compounding these are a raft of other issues related to urbanisation including welfare, housing, accessibility, urban renewal, health, etc.

Yet urban management remains fraught as cities everywhere grapple with the challenges and opportunities that rapid urbanisation brings. In our digital society, data has become the main currency in urban management and decision-making. However, a longstanding challenge for urban data is its notorious heterogeneity (Psyllidis et al., 2015). This is further complicated by new streams of data such as big data, social media, etc. – a veritable deluge of data that traditional government decision-making organisations are often unable to accommodate within their regulated frameworks (Sabri et al., 2015). When faced with decisions pertaining to planning and developing complex urban infrastructure, e.g. underground train tunnels and associated stations, urban managers and urban researchers continue to struggle to understand the diversity of urban data available, to access this data, and leverage appropriate data sources for analysis and planning. Typically, analysis around urban developments also tend to involve cross-disciplinary data and analytics (e.g. land ownership, utilities, buildings and vegetation). These diverse data sources need to be interoperable, harmonised and integrated for analysis and modelling purposes.

One of the main ways that urban managers and urban researchers have long sought to overcome the data challenges is through the adoption of spatial data infrastructures (SDIs). That spatial data plays a fundamental role in cites is axiomatic. Cities are complex entities and spatial data, more than any other type of data enables decision-makers to understand what is happening within cities, and more importantly, understand where the phenomena is occurring. Indeed, geospatial data has emerged as one of the most important types of data in urban management and sustainable development (UN-GGIM, 2015).

Consequently, SDIs have become an intrinsic part of the urban decision-making infrastructure. Although nearly 20 years old now, Coleman & McLaughlin's (1998: 37) definition of SDIs (albeit originally in a global context) as those "policies, technologies, standards and human resources necessary for the effective collection, management, access, delivery and utilisation of geospatial data" remains relevant in today's digital society. Rajabifard & Williamson (2001) built on this definition, but emphasised the importance of interoperability – both among data and people components – as the key to delivering the integration that SDIs promise.

There are numerous examples of urban SDI initiatives around the world and they can exist at multiple levels. For example, Brazil has recently launched DataGEO as a state-level SDI initiative. This platform integrates spatial data across the state of São Paulo, providing several government and research institutes with access to and management of a repository of environmental spatial datasets to assist with monitoring, reporting and plannning activities. In the same vein, the Global Earth Observation System of Systems (GEOSS) Common Infrastructure is an example of a global SDI initiative as it allows users from all member countries and participating organisations of Earth Observations to access, search and use the data, information, tools and services available through GEOSS.

Such initiatives continue a trend of substantial SDI developments that have been initiated over the last three decades both in developing and developed countries. For instance, the INSPIRE (Infrastructure for Spatial Information for the European Community) directive has facilitated addressing interoperability and harmonisation issues among several European jurisdictions (Villa et al., 2011). Plan4all is an initiative that was developed on the basis of the INSPIRE directive to address spatial planning data for cross-jurisdictional cooperation (Pineschi and Procaccini, 2013). However, location-based and evidence-based city planning and policy-making reportedly still lacks access to robust data sharing and spatial platforms that can support practical analytics and data-driven decision making (Kyttä et al., 2013; Sabri et al., 2016).

There are several initiatives worldwide that address the issues of urban data accessibility. For instance, the Urban Big Data Centre (UBDC) is an initiative by the UK Economic and Social Research Counci, at the University of Glascow, in partnership with six other UK universities. The role of UBDC is to manage, link and analyse massive amounts of multi-sectoral urban open and authorised data in a portal allowing diverse users to conduct research and analysis (http://ubdc.ac.uk/). Similarly, the Urban Centre for Computation and Data (UrbanCCD) at the University of Chicago has developed a platform called Plenarion to facilitate urban data discovery, exploration, and application of open city data (Catlett et al., 2014). There are many other similar inititaives; however, these have also served to illustrate the challenges that a lack of a holistic infrastructure to address harmonisation within structured and unstructured data, as well as data semantics and ontology issues across different jurisdictions and disciplines associated with urban analytics and management (Thakuriah et al., 2016; Catlett et al., 2014; Villa et al., 2011).

In addition, urban planners need new predictive modelling tools that can help them understand the potential future impact of different scenarios, policies and decisions on the urban landscape and population (Bettencourt 2014). Increasing availability of open government data, social media data and real time sensor data streams are driving a demand for sophisticated data integration, analysis and visualization services (Caragliu et al., 2011). SocialGlass, for instance, is an attempt to incorporate various data streams from social media platforms, sensors, and periodical datasets from local governments to facilitate city-scale event monitoring and assessment (Psyllidis et al., 2015). Balduini et al. (2015), developed the 'CitySensing' system to integrate social media streams and anonymous Call Data Records (CDR) to visualise the emerging patterns and monitor their dynamics in city scale. CDR is also used to infer land use patterns in agains zoning regulations in urban areas (Toole et al., 2012). Additionally, integrating public participatory GIS (PPGIS), web-based visualisation and geotagged crowdsourced data in a platform called "SoftGIS" provided a valuable method to understand local perceptions in the implementation of urban consolidation projects in the inner-city of Helsinki, Finland (Kyttä et al., 2013).

Although there is a trend towards making such decision-making tools and planning support systems easily available through cloud services (Pettit et al., 2015; Catlett et al., 2014), there remains a lack of access to standardised and harmonised data, which in turn limits the applicability of such services. Furthermore, current geo-databases were also initially developed to be used in local- or domain-specific purposes, whereas city planning, management, and monitoring activities are likely to require more organised and complex SDIs that can respond to integrated spatial planning and programming activities.

Establishing SDI as a digital infrastructure is now increasingly important especially since the steep trajectory in data production has really occurred over the last decade (SINTEF, 2013). Even as cities continue to struggle with reaping the benefits of the urban data deluge, in parallel, they are also having to contend with the information demands associated with the global smart city movement. Smart cities are often referred to distinct factors of economy, mobility, people, environment, living, and governance, which leverage smart infrastructure with a strategic use of innovative technology and approaches to enhance the efficiencies and competitiveness of cities (Habitat III, 2015). Smart approaches often argue that the use of information and communication technologies (ICTs) will improve our understanding about community through analysis of urban efficiencies, address urban resilience challenges and enhance the quality and effective delivery of services . In his speech at the 2015 Geospatial World Forum, Carsten Rönsdorf, the Head of Advisory Services at Ordance Survey International, demonstrated that smart cities rely on multiple streams of digital data and networks for data reuse and innovation – amongst which spatial data, and hence SDIs, remains vitally important in future urban management.

URBAN MANAGEMENT IN AUSTRALIA

Australia is one of the most urbanised societies in the world. One of its greatest challenge over the next 50 years will be urban management, acknowledged in the Australian government's decision to appoint the first national minister for cities in late 2015. Urban planning research is increasingly important to devise strategies that will ensure the sustainability of our cities in the face of massive population growth, changing demographics and changing weather patterns (Shrestha et al., 2014). These factors are placing increasing pressure on the infrastructure in our cities, including public transport and roadways, power, water and waste systems, and population health within the urban environment. Urban renewal, redevelopment and high density living in inner cities are also driving an increase in strata titles and the demand for new 3D planning tools (Badland et al., 2014).

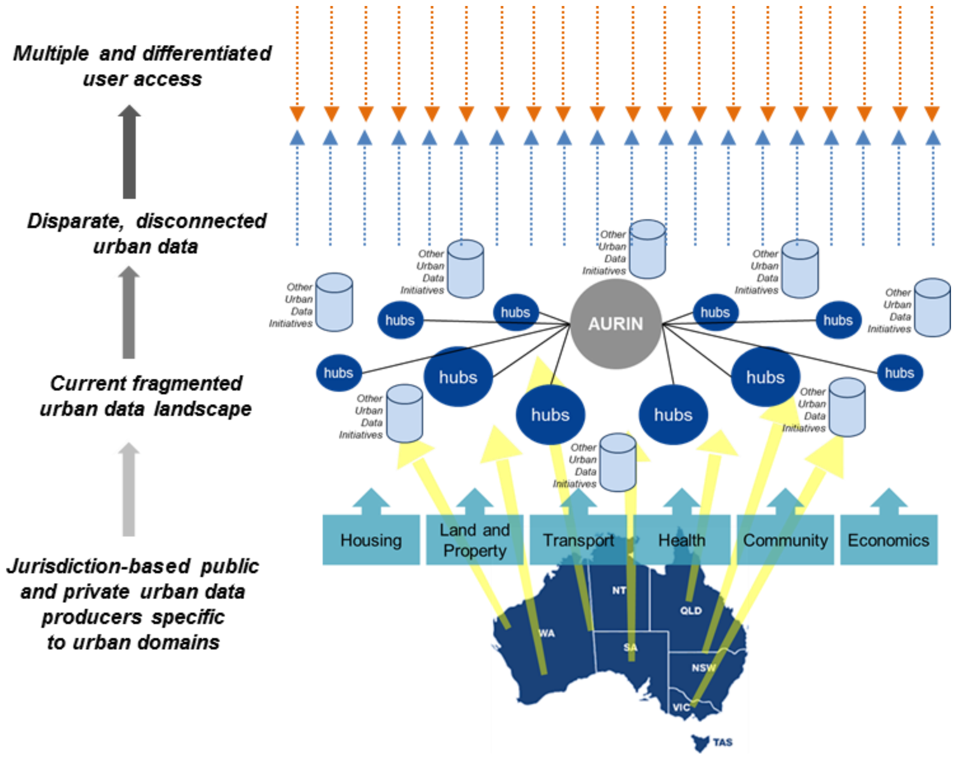
Evidence-based data-driven urban planning, will deliver specific, quantifiable, and measurable initiatives over various urban scales (Villanueva et al., 2015). It will highlight attributes that address residents' concerns and expectations (Hadavi et al., 2015), unlock complex planning challenges while directing local authorities and state governments to achieve evidence driven decision making. The research to practice in Australia, however, is yet to be widely appreciated and there is a limitation of practitioners being engaged with research outputs (Randolph, 2013; Troy, 2013). The reason seems to be the lack of infrastructure to mediate the research and practice information exchange (Taylor and Hurley, 2016).

Consequently, there has been substantial investment recently in urban data initiatives in Australia. Of significance is the $24 million investment by the federal government to establish the Australian Urban Research Infrastructure Network (AURIN) project. AURIN has succeeded in establishing urban data hubs across Australia to facilitate a range of research activities related to urban settlements (Sinnott et al., 2011). This has resulted in thousands of datasets being made available nationally representing the social, economic, environmental and physical characteristics of the urban built environment. A large proportion of this is held by the federated Data Hubs within the AURIN platform, which is accompanied by a range of analytic tools and services. However, in addition to AURIN, there are also numerous other important key datasets that contain vital information and data about the urban built environment and new emerging sources of relevant data. These are distributed across all levels of government across the country, and some are available through open government data initiatives such as the NICTA National Map and data.gov.au; others flow from a growing volume of social media content and real time sensor data streams.

While these initiatives constitute a major advancement towards enabling urban analytics for decision-making in Australia, the potential research capability offered by these initiatives for urban management is still yet to be fully maximised due to the fragmented and disparate operation of these initiatives. In addition, current urban data repositories are disparate and discrete, and an absence of consistent data structures prevents this data from potentially serving cross-jurisdictional and national-level analysis (Sinnott et al., 2015). There are some foundations for potentially enabling interconnected urban analytics in Australia e.g. “State of Australian Cities Research Network”, but these continue to operate separately. Such fragmented operation of urban analytic activities is contributing to a static, undifferentiated, and information-poor planning environment.

Consequently, we identify three distinct challenges in urban research in Australia today: a fragmented urban data landscape, which results in disparate and disconnected urban data repositories, which also implies differentiation among user access levels. These challenges are illustrated in Figure 1 below. Increasingly, there needs to be a dynamic, richly diverse, and interconnected operating system, which will reduce the cost of urban data acquisition and analysis to stakeholders and the community (Bettencourt 2014).

Figure 1. Current urban data landscape in Australia.



Over the last few years, AURIN, specifically, has succeeded in taking the preliminary steps in addressing these challenges and has established urban research infrastructure accessible to academic researchers across Australia. However, there is still more that needs to be done to more broadly support urban research for urban management in Australia..

THE URBAN ANALYTICS DATA INFRASTUCTURE PROJECT

Digital infrastructure and tools are one of the key ingredients in making a city smart (Komninos, 2002). While this includes the communications hardware to ensure ubiquitous connectivity, a more challenging component of digital infrastructure is the data and the tools that add value to the data and support the data-information-knowledge-wisdom pyramid (Rowley, 2007). In addition to physical infrastructure, the availability of knowledge communication and social infrastructure (human and social capital) increasingly determines urban performance (Caragliu et al., 2011). Importantly, the current state of urban analytics in Australia motivates the need to leverage current initiatives. This will not only improve fragmentation but also advance the capabilities and maturity of urban analytics in Australia. Therefore, any project in this area must build on the sizeable investment and those outcomes represented in AURIN.

The Urban Analytics Data Infrastructure (UADI) Project is a collaborative effort between a consortium of urban research centres across Australia and is funded by the Australian Research Council. The consortium comprises the Centre for SDIs and Land Administration at the University of Melbourne; City Futures Research Centre at the University of New South Wales; the eResearch Lab at the School of ITEE, and the Centre for Population Research, both at the University of Queensland; the Planning and Transport Research Centre at the University of Western Australia; the National Centre for Social and Economic Modelling at the University of Canberra; and the SMART Infrastructure Facility at the University of Wollongong. Collectively, these research centres represent expertise in the domains of land and property, housing, transport, health, community and economics.

By bringing together such diverse expertise, the project aims to develop the critical digital infrastructure required to underpin the next generation of data driven modelling and decision-support tools to enable smart, productive and resilient cities in Australia. The project will leverage the collaborative utility and latent knowledge that has been developed through AURIN to embark on a focused development of a data infrastructure that responds to the specific requirements of multi-source, cross-domain and cross-jurisdictional urban analytics. The principle aim of the proposal is to develop an SDI that will facilitate:

- The integration of the AURIN data hubs in each state, with other relevant data sets available via national, state and regional government agencies* who are adopting open data policies.
- The extraction of latent knowledge existing in these data sets through the development of a set of integration and analytical services that respond to the specific requirements of different urban analytic activities associated with: people (quality of life indicators, socio-economic indicators, population demographics); land (3D cadastre, housing affordability); urban infrastructure (energy, water, transport).

Figure 2 provides a conceptual overview of the proposed UADI and its intended response to current challenges in urban analytics identified in the previous section.

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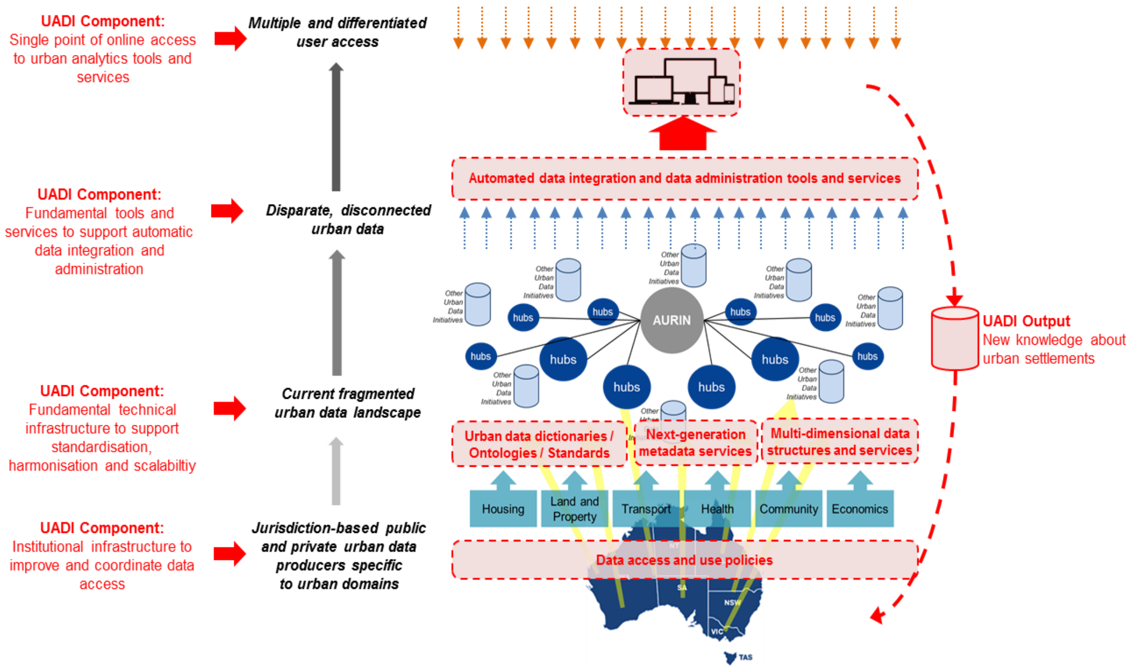
* Including the Australian Bureau of Statistics, Bureau of Meteorology, Departments of Transport, Public Works, Housing and Planning.

This requires not only a consistent and systemised ontology-based metadata/data harmonization and mapping framework across disparate domains and disciplines to support rapid integration and scaling-up, but also a focus on multi-dimensional (3D and 4D data) and dynamic (time-series and real-time) data analysis.

Figure 2. Proposed Urban Analytics Data Infrastructure concept.



4.1. Ontological Foundations

Advancing on the traditional notion of an SDI, data interoperabilty will be facilitated in the UADI through an ontology-based integration of datasets.

Specifically, an ontological framework that links policies, actions and urban quality of life indicators for smart sustainable cities will be developed to assist in the evidence-based policymaking and adaptive management cycles. In a bid to overcome many of the institutional and political challenges associated with data sharing, the UADI will focus on a data-driven approach based on urban data dictionaries and workflows to develop IS0 37120 indicators (The Smart City Standard). Fundamental datasets will be established and these can be scaled up to dynamically produce city indicators on Australia's urban settlements.

The priority will be on the standardization and harmonization of data sets in AURIN across Australian jurisdictions using already established international spatial infrastructures, which will provide capacity for more comparative and collaborative urban e-research as well as a robust platform for urban planning and decision making. This project will also seek to extend the Global City Indicator ontology to harmonise different indicators and link indicators to policies and programs. It will also aim to homogenise data standards.

Common urban data ontologies will also facilitate the development and use of semantic inferencing services. This will firstly serve to automate data integration within the UADI, which will enable changes in the system to cascade automatically throughout related integrated datasets. Secondly, it will faciliate the development of a range of semantic web services that will advance multi-source urban data integration and analysis.

4.2. Multi-dimensional (3/4D) Data Structures and Services

One of the distinctive features of the UADI will be its explicit focus on enabling dynamic and multi-dimensional data. This will mainly be focused on the development of 3D and 4D data structures and services to enable the query and visualisation of 3D content (e.g. 3D strata titles, 3D visualizations of sub-surface utilities). One aim is to provide 3D modelling and visualisation services using virtual globes. This requires the develoment of key data and metadata tools that will enable multi-dimensional data generation and automation, including spatial-statistical data cubes to permit 3D/time series and sub-surface visualization/exploration on virtual globes using Cesium. The 4D-focused component of this project aims to provide 4D modelling and visualisation services for improved dynamic and flows analysis.

4.3. Single Source Access

The project aims to establish a web portal that will enable users to have a single source of entry to AURIN and other urban data initiatives by developing open APIs. However, this may be limited by current licensing agreements.

4.4. Advanced Analytic Tools

In recognition that traditional spatial datasets tend to be limited in their level of granularity – where micro-level analysis may be necessary for specific planning tasks, the UADI intends to utilise micro-simulation capabilities developed by the National Centre for Social and Economic Modelling (part of the project consortium). This will enable the integration of unit record survey and census data to generate new synthetic data for small areas to provide measures on constructs (e.g. poverty, wealth, housing stress, etc.) not measured in traditional spatial datasets provided by agencies like the Australian Bureau of Statistics.

It is also the project's intention to develop openly available urban analytic tools and services to support spatio-statistical analysis of data sets related to their areas of practice, identify and quantify new relationships between parameters; develop new predictive modelling and visualization interfaces – specifically focusing on land management/housing, socio-economic analyses, people flows, transport/roads and utilities (water, power, waste management) in an urban environment.

DISCUSSION AND CONCLUSION

This project addresses the critical need for an SDI that can help deliver harmonized, interoperable data services, semantically enabled to support the modelling, designing, planning and management of the growth of Australian cities. The development of the UADI will support urban management, which requires consistent and complete urban datasets across a number of domains including housing, transport, utilities, demographic change and the economy.

The UADI intends to improve the state of urban analytics in Australia, and capitalises on significant urban data initiatives in this country, specifically AURIN, thereby adding more value to existing functions. It provides the capability to shift the current landscape towards one that is more consistent across jurisdictions, and build up the requisite intellectual capital to support evidence-based decision-making that transcends traditional disciplinary domains. This is vital for realising a sustainable urban future for Australia.

Current research in urban analytics is highly fragmented due to the lack of a relevant urban data infrastructure. The research activities among the project's partners provide ample evidence. For instance, while the City Futures Research Centre houses a comprehensive set of urban data regarding the Sydney metropolitan area, this is not accessible for other research centres. Moreover, the same centre has been involved in a study on affordable housing, urban renewal and emerging practices in planning in the states of New South Wales, South Australia and Queensland. However the lack of a data infrastructure presents a barrier in extending the same study to other jurisdictions. Some emerging data collection methods and supporting facilities such as automatic validation of crowd sourced data conducted by the Centre for SDIs and Land Administration on the North West Metropolitan Region of Melbourne could theoretically be replicated by other relevant research centers in Australia, but is currently not practically possible due to lack of a holistic infrastructure that facilitate the harmonisation and standardisation of data and integration of streamed and (semi-) static periodical data from different government departments such as state and local governments.

The proposed UADI could potentially overcome these limitations and enable more mature urban analytic activities to be derived from current data-driven initiatives. At a broad level, this supports greater return on investment from those initiatives; at an application level, it will enable planners and researchers to undertake urban analytic activities that are to date, simply not possible due to the ongoing limitations in linking, integrating, harmonizing and scaling multi-source data.

As one of the most urbanised countries in the world, the ability of the broader research community to undertake such activities is fundamental to planning for a more sustainable urban future. In addition, the development of the proposed UADI will provide an example and a practice case for other jurisdictions around the world seeking to overcome the challenges of extracting knowledge from federated datasets. Future work aims to develop the system architecture and implement it by using a set of use case scenarios.

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