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A multi-level perspective on a spatial data ecosystem: needs and challenges among urban planning stakeholders in New Zealand*

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Abstract

Spatial data ecosystems are often complex, and stakeholders express difficulties in finding, accessing, using and sharing spatial information. Doing so can be essential for making good evidence-based decisions on urban development. New Zealand's urban planning spatial data ecosystem is no exception. This paper identifies and maps key stakeholders, their data needs and respective barriers to an improved use of spatial information. We apply a multi-level perspective approach to analysing challenges of a transition towards an improved spatial data ecosystem for urban decision-making. Based on expert interviews and the international literature, we provide recommendations to improve the spatial data ecosystem and reduce barriers to making spatial data more available to support urban decisions. Our stakeholder-based analysis highlights the importance of intensive stakeholder engagement across the multiple levels of the spatial data ecosystem, fostering increased awareness and understanding of the value of fit-for-purpose spatial information for better planning outcomes. We argue for a coordinated, stakeholder-based mechanism addressing in particular cultural and governance local practices.

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1. INTRODUCTION

Cities are complex systems, driven by a series of urban processes; tackling them requires evidence-based decisions. In order to break down these complex spatial processes or simulate otherwise intangible spatial interactions, we see an increased use of decision-support tools in the urban planning community (e.g. Stevens et al., 2007; Coutinho-Rodrigues et al., 2011; Schetke et al., 2012; Chevalier et al., 2012; Glackin et al., 2016). These computer-based spatial tools help in estimating the impacts of decisions, making evidence-based trade-offs and providing potential to engage communities in decision-making processes through the visualization of planning scenarios.

Making evidence-based decisions, however, requires a comprehensive set of data describing the spatial relationships between studied phenomena and the context in which decisions are to be made. Great value is attributed to spatial data for urban decisions (e.g. Schetke et al., 2012) as it is a commodity, resource asset, infrastructure or relationship (e.g. Crompvoets et al., 2010); and the availability of pertinent spatial data is critical to making decisions on future development. The explanatory power and reliability of decision-support tools, however, is predetermined by the underlying spatial data. Therefore, spatial data quality issues have attracted increased attention in the literature (e.g. Wan et al., 2015; Delavar and Devillers, 2010). Uncertainty in the data arising from data gaps, scale mismatches or lack of knowledge translates into risks in decision-making (e.g. Brown et al., 2005; Hunter et al., 2009), which might manifest in additional costs or reduced social welfare due to unintended outcomes.

Spatial data itself is complex due to the variety of existing data models, formats and spatial relationships. The complexity of spatial data causes gaps between the needs of data users and the capabilities of data providers (Deng and Di, 2009). Filling in these gaps requires the development of interoperable, on-demand data access and services, while most current data systems still adopt the one-size-fits-all approach without recognizing different users' needs (Deng and Di, 2009). The emphasis must shift from data publishing which meets the needs of data producers to one that meets the needs of potential data users. High quality spatial data for one decision might not be suitable for other decisions (e.g. Frank et al., 2004). For instance, a site-based decision by a planner requires data of high precision, while rather indicative data can be sufficient for a strategic decision. The quality of spatial data is determined by the purpose of use (external quality) and its internal quality (e.g. error value) (e.g. Vasseur et al., 2003; Devillers et al., 2007; Triglav et al., 2011; Whitfield, 2012).

The availability of fit-for-purpose spatial data for evidence-based urban decisions is in many cases challenged by a fragmentation and heterogeneity of data sources that can hinder its integration, limit accessibility, lead to a mismatch of scale or lack of resources or result in the discipline-specific management of spatial data not suitable for interdisciplinary approaches to urban planning. Knowledge requirements (e.g. working with geographical data), suitable representation of spatial relationships in the urban context (e.g. standardized spatial identifiers) and the existence of a variety of data models and formats pose key challenges that are distinct from non-spatial data (e.g. Maguire and Longley, 2005). As Onsrud and Rushton (1995) state, "sharing of spatial information involves more than simple data exchange" and is a well-recognized challenge (e.g. Masser, 2006; Hunter et al., 2009; Montalvo, 2003). The true costs of spatial data are more than the data acquisition costs (Klinkenberg, 2003) until spatial data are ready for use in decision-making. For instance, publicly available data still need to be collated and processed to be integrated in decision-support tools.

Therefore, Crompvoets et al. (2010) argue for an actor-network focus on spatial data and view spatial data handling as a socio-technical practice. Spatial data are assembled between heterogeneous human and non-human actors within a social and political context, where value is added to spatial data through the translation between the different actors. Taking on this conception on spatial data, the term (spatial) *data ecosystem* (e.g. Medyckyj-Scott et al., 2016) describes a system of people, practices, values and technologies. This highlights the need to understand spatial data at a system level considering these components, including the complex stakeholder network and local practices.

We identify the challenges of fit-for-purpose spatial data for use in decision-support tools for residential and infrastructure planning. In our case we study the situation in New Zealand, which is interesting in three ways: First, it is a developed country with a non-federated system of small enough size for many political issues to be managed at the national level. Its population of roughly 4.8 million is distributed across the three major urban areas, Auckland (about 1.6 million), Wellington (about 400,000), and Christchurch (about 380,000), and a series of small cities with fewer than 200,000 inhabitants (StatsNZ, 2017). Second, following the 2010/2011 earthquakes in Christchurch, conversations about an improvement of spatial data availability have spread nation-wide, in particular across the three major urban areas. Finally, urban challenges such as a suggested housing crisis (e.g. Greenaway-McGrevy and Phillips, 2015) further underline the importance of fit-for-purpose spatial data for decision-making.

Based on expert interviews, we contribute an analysis i) of the complex relationships of stakeholders involved in the provision and use of spatial data and ii) of the barriers and needs of the identified stakeholders with regards to spatial data availability. Applying a multi-level perspective (MLP) approach (Geels, 2002), we provide recommendations for implementing a more sustainable socio-technical spatial data system for urban decision-making. Like many countries, New Zealand's spatial data ecosystem is based on complex configurations of stakeholders and technologies, and there have been numerous appeals to the virtues of moving to a more sustainable and effective system in the past decade. Identifying these individual initiatives and their role in the wider context of the multi-level socio-technical system contributes an explicit elaboration of which mechanisms can be beneficial to fostering change.

To our knowledge, few studies have assessed New Zealand's data ecosystem to date. Focussing on non-spatial data from public institutions, Glass and Schiff (2017) discuss the value of and barriers to sharing data. More generally, the NZDFF (2015) developed principles to advance New Zealand's ability to unlock the value of data and leverage its potential. Taking a technical perspective, Kmoch et al. (2016) analysed the availability of fit-for-purpose hydro(geo)logical data and spatial data infrastructures (SDI). In the context of resilience research, Stevenson et al. (2017) identified the types of needs with respect to data and data sharing and management practices to enhance researchers' work. They concluded that there is a great need for systems for knowing about ongoing research and for enhanced searchability of data across institutions. A report by ACIL Tasman (2009) quantified the productivity-related benefits to the New Zealand economy of the use and removal of barriers to increase the use of spatial information. From a data management perspective, Medyckyj-Scott et al. (2016) assessed the data ecosystem for land and water data, presenting a Data Management Maturity Model as a framework for handling identified data heterogeneity and complexity.

In contrast to existing literature on New Zealand's data ecosystem, we focus explicitly on spatial data, more precisely on data that is relevant to the urban planning community making decisions on urban residential and infrastructure developments. Table 1 provides an overview of the main types of spatial data we consider in this work, including public and non-public data. Furthermore, we take a stakeholder-based perspective to assess data needs, external data quality concerns and barriers at both the data and system level.

Table 1: Categories and types of spatial data considered in this article due to its high relevance to New Zealand's urban planning community.

Category	Information type
land use	zoning geometries and classification
properties	location, geometries, attributes
buildings	location, geometries and attributes
infrastructure (road and utilities network)	spatial layout, network attributes
territorial and administrative boundaries	geometries and classification
population demographics	spatial pattern, characteristics
localities	location, geometries, attributes
topography	elevation contours
natural hazard information	zoning geometries and classifications

The remainder of this paper is structured as follows. Section 2 presents the methodology; Section 3.1 maps New Zealand's fragmented stakeholder landscape along the life-cycle of spatial data, from which interview partners have been chosen to identify their spatial data needs (Section 3.2). Section 3.3 then analyses needs and barriers of the spatial data ecosystem using the multi-level perspective approach. Finally, Section 4 discusses our findings in the context of the international literature, provides recommendations for New Zealand's urban planning community and extracts lessons that can be learnt from the case study. Section 5 concludes.

2. METHODOLOGY

We adopted a case study approach to assessing needs, barriers and initiatives towards improved urban decisions using spatial data.

First, we mapped stakeholder groups among the urban planning community in New Zealand along the life-cycle of spatial data. This provides a structured perspective on the complex landscape of stakeholders.

Second, we conducted face-to-face expert interviews with 29 stakeholders among the identified groups in order to identify i) needs with respect to spatial data relevant for stakeholders' work within the planning community, ii) barriers to spatial data being fit-for-purpose, iii) barriers to an improved spatial data ecosystem with better availability of fit-for-purpose spatial data and iv) on-going initiatives towards a transition of the spatial data ecosystem to yield better outcomes for urban planning. Our interview partners are stakeholders within national governmental agencies (four) and territorial authorities (ten), developers (three), utility companies (four), consultancies (four) and researchers (four) in Christchurch and Auckland. We chose the two urban areas as case studies since we expected spatial data availability and transition trends to be led by New Zealand's major urban areas. Interviews with stakeholders within national government agencies in Wellington also provided a national perspective.

Third, based on the stakeholder interviews, we use the multi-level perspective (MLP) approach (Geels, 2002) to analyse needs and barriers towards a transition of the socio-technical spatial data system into an improved spatial data ecosystem for urban decision-making.

The MLP approach poses a conceptualization of overall dynamic patterns of socio-technical systems (Whitmarsh, 2012), such as the provision and use of spatial data in New Zealand's urban planning community. MLP is an actor-based approach which considers the interactions among different groups of stakeholders and focuses on complex dynamics and not only on linear processes with a simple driver for transition (Moradi and Vagnoni, 2017). This allows an in-depth and system-wide analysis of barriers to an improved spatial data ecosystem across multiple levels and key socio-technical aspects. The three levels are the i) landscape (external context), ii) socio-technical regime (dominant local practices of e.g. cultural, technological nature) and iii) niches (early-stage initiatives to challenge established local practices) (Geels, 2002).This approach is a vehicle for characterizing the current local practices of the socio-technical regime, identifying stakeholder roles across the multiple levels of the system and detecting potential mechanisms that are needed to foster a transition of the socio-technical system. We take a closer look at three stakeholder-driven niche-level initiatives towards transforming the spatial data ecosystem originating in the two urban areas, Christchurch and Auckland.

Policy frameworks, barriers and challenges vary widely across regions and cultures, leading to differently configured landscapes, regimes and niches. Adopting the well elaborated and widely applied MLP approach (e.g. Geels, 2005; Smith, 2007; Whitmarsh, 2012; Walrave et al., 2017; Moradi and Vagnoni, 2017) offers not only a conceptualisation of a specific case study like the New Zealand spatial data ecosystem but also makes it comparable and allows extraction of learning outcomes applicable beyond the specific case study.

3. NEW ZEALAND'S SPATIAL DATA ECOSYSTEM

Barriers to sharing spatial information can vary across countries. While, for instance, in Canada data quality, access and legal issues have been identified as main barriers, unavailability of digital datasets, absence of skilled human resources and lack of funding primarily hinder spatial data sharing in Ethiopia (Gelagay, 2017). A good understanding of the particular context is essential to developing mechanisms that foster a transition towards a more sustainable spatial data ecosystem.

We started our analysis of New Zealand's urban planning spatial data ecosystem by mapping the various stakeholders. Improved spatial data sharing based on stakeholder engagement requires thorough identification of the actors involved and a good understanding of their motivations and responsibilities.

3.1. Fragmentation along the spatial data life-cycle - Stakeholder mapping

A stakeholder is anyone who has an interest in a problem—in our case fit-for-purpose spatial data for urban planning—by 1) mainly affecting it, or 2) mainly being affected by it or 3) both affecting it and being affected by it (Banville et al., 1998). While the life-cycle of various spatial data traverses similar steps (such as data creation/collection, management, ownership, provision, value-adding, end-use) across disciplines and countries, which stakeholders are involved at which step in the life-cycle is context-dependent.

Analysing the stakeholder landscape in New Zealand's urban planning community reveals six different groups of stakeholders depending on their technical role in the spatial data ecosystem (Figure 1). These are spatial data collectors/creators, managers, owners, providers, value-adders and end-users. Spatial data can be collected directly through surveying or monitoring in the field or created indirectly through combining datasets or modelling. Spatial data managers are responsible for the governance of the data, while owners decide on user rights by providing data licensing. Data providers supply spatial data to others, which is either a data product they created themselves or is sourced from elsewhere. This classification generally follows Singh (2009) and Medyckyj-Scott et al. (2016) but is adapted to the New Zealand urban planning data context. We distinguish further among spatial data producers than Singh (2009), but less than Medyckyj-Scott et al. (2016), because data reviewers are not applicable in our case study.

Among stakeholders in each group, we further identified three categories of stakeholders, in line with Singh (2009): Key stakeholders who significantly influence the particular group within the spatial data ecosystem, primary stakeholders who are directly affected and can to some extent influence the spatial data ecosystem, and secondary stakeholders who play a role but do not directly influence the system.

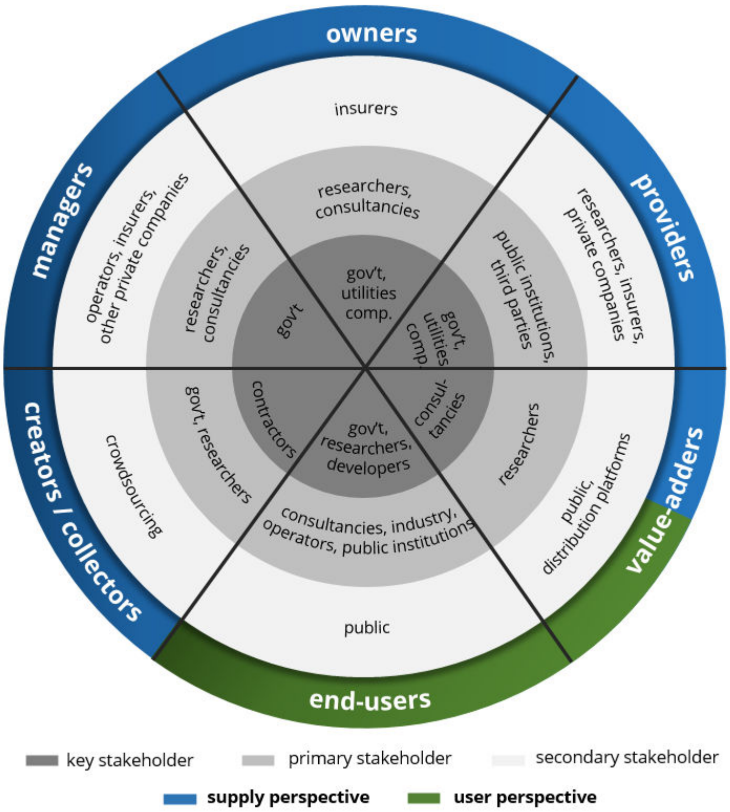
Many key stakeholders are found in more than one stakeholder group at different stages during the data life-cycle; that is, they are often both data providers and end-users. Budhathoki et al. (2008) refer to the two-way interaction of key stakeholders as producers and users with the concept of "produser," reconceptualising a user from a passive recipient of information to an active information actor.

New Zealand's spatial data ecosystem is exceedingly fragmented. Data providers are often not owners of the data, as data are created by a third party and other stakeholders function as intermediate value-adders. For instance, while councils own spatial data about lifelines, they may not necessarily manage it and some are created/collected by contractors; in many cases, the data distribution to users outside the council and the public occurs via a third-party platform; most end-users, however, inform decision-makers in public institutions by using these data. From Figure 1 it becomes evident that governmental institutions play a key role in most stages of the life-cycle of spatial data, while intermediate steps are performed by other key stakeholders.

Our interviewees identified one reason for the complex stakeholder configuration as the lack of resources: performance of the entire life-cycle of a spatial dataset by one single stakeholder requires skill, capacity and resources to which many do not have access; out-sourcing is then the more cost-effective solution, at least to the data provider. New Zealand's local government sector consists of 11 regional councils and 67 territorial councils[1]. The decentralized spatial data model in New Zealand requires all territorial authorities to have their own data model. Most stakeholders cannot exploit economies of scale with the spatial data they have. This leads to specialization of the data ecosystem in order to create economies of scale within each 'sector' of the cycle, and thus the establishment of value-adding services. Since the data is often not fit-for-purpose, consultancies (or often researchers) are involved in preparing and processing the raw data for further use; this induces a division between those stakeholders who are able to allocate resources to involve value-added providers and those who are not. This may create redundancy of work by value-added providers since it is often a proprietary solution. The value added spatial data product is a resource asset to the one who created it. Thus, it is often kept confidential as a product now owned by the value added provider in order to create revenue (commercial/consultancies) or protect intellectual property rights (researchers).

[1] New Zealand Government, Department of Internal Affairs: Local Government in New Zealand - Local Councils, http://www.localcouncils.govt.nz.

Figure 1: Mapping of stakeholders involved in New Zealand's spatial data ecosystem, inspired by Singh (2009).



Mapping stakeholders within the spatial data ecosystem as in Figure 1 highlights the socio-technical nature of the system: the spatial data life-cycle is based on a complex interplay between actors with different technical roles, values and motivations.

3.2. The nature of stakeholders' spatial data needs

It is important to gather information about user needs to assess the fitness for use of spatial information for decision-making (Vasseur et al., 2003). The importance of assessing the needs of local planning stakeholders has also been shown by Nedovic-Budic and Pinto (2001) in their study on the development of spatial data sharing mechanisms. The level of awareness and detail of available spatial data have been identified as main concerns about meeting the needs of local planning. Triglav et al. (2011) further argue that communication between users and producers is essential for aligning both perspectives.

Based on interviews among stakeholders groups as identified in Figure 1, we assessed stakeholders' main data needs. Based on the interview results and in reference to Table 1, their needs can be grouped into (1) advanced information on urban infrastructure, (2) address data of high internal and external quality, (3) spatially varying demographic attributes, (4) usable information on localized urban amenities, (5) bulk information on building and property attributes, (6) spatial relationships between the different types of land information and (7) natural hazards data. We summarize the seven groups of data needs in the following.

(1) Advanced attribute information on urban infrastructure. Making decisions on housing locations, attributes and densities requires reliable information about the capacity of existing infrastructure and costs of providing additional infrastructure to support new development. Yet, knowledge of infrastructure capacity is based on in-house models by infrastructure providers and thus commercially sensitive, not consistently measured across providers and often not readily available. Alternatively to (costly) on-demand information acquisition, capacity modelling could be performed by skilled users based on information about existing infrastructure. Yet, stakeholders stated a need for information about infrastructure attributes (e.g. pipeline diameter, traffic volumes), which is in most cases not available or not fit-for-purpose. A subset of stakeholders (i.e., select governmental agencies and researchers and utility companies) has access to re-usable spatial data on infrastructure networks, while many (i.e., developers, researchers in general, and the public) experience difficulties in obtaining and using the data due to the fragmentation of its life-cycle among different stakeholder groups.

(2) Address data of high internal and external quality. There are several sources of address data in New Zealand, which have their own system. Having consistent, accurate, complete and reliable address data was of major concern for most interviewees. Since these data are in some cases available but not ready to use due to their varying internal quality, consultancies provide value added services to create address data of high internal and external quality. A standardized approach towards defining addresses would reduce the costs associated with data use and improve outcomes. In particular, utility companies and national governmental agencies expressed this data need.

(*3) Spatially varying demographic attributes*. A major limitation expressed by housing and utilities planners is the lack of knowledge about the demographic composition of the built environment at a scale below the meshblock[2] level and projected population growth. Estimates based on census data are often seen as not fit for use due to scale restrictions, temporal resolution and validity concerns. While estimations are derived through public-private models, this information is often kept with data custodians. Spatial variations in demographic composition and other population related data, such as residential preferences or car ownership, are needed by developers and infrastructure planners to meet user demands.

(4) Usable and consistent information on localized amenities. In particular, developers express interest in knowing where local amenities are located. Inconsistencies in reporting of such amenities and their catchment areas and sharing information in a way difficult to re-use hinders the availability of a fit-for-purpose localities dataset. The same holds true for the definition of area boundaries in a consistent way across the country, such as suburb or urban/rural boundaries. Some information lies with data owners; yet, the main barriers to usable information on localities are a licence which vastly restricts its use and inconsistencies in definitions. Stakeholders of governmental agencies did not explicitly mention such data needs since most enjoy better access to these data.

(5) Information on building and property attributes in bulk. Information on single properties, such as its valuation, is available; yet, access in bulk for use in analyses is in most cases not possible. Although recently territorial authorities increasingly open up such data to experienced users, few provide Application Programming Interfaces (API) to support more complex data queries, and concerns about confidentiality and forgone revenue pose challenges. Interviewees further expressed a lack of (consistently reported) information on building characteristics to be used in decision-making. Such concerns have in particular been raised by researchers and strategic decision-makers for territorial authorities, while less so by utility companies or consultancies.

(6) Spatial relationships of land information. Most important of all for urban planning decision-support tools is the integrability of various spatial datasets. Land information is available on different scales, such as connector point level for infrastructure, property, building, parcel, precinct or network levels; yet, the spatial relationship between these scales is often missing or of insufficient quality. For stakeholders, however, it can be critical to know, for example, which property is located in which parcel or how an infrastructure connector point

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[2] A meshblock is the smallest geographic unit for which statistical data is reported by Stats NZ. It is a defined geographic area, varying in size from city blocks to large rural areas (Stats NZ, 2018).

spatially relates to a building. This is partly due to the fragmentation of data sources and stakeholders along the life-cycle of a spatial dataset, manifested also in little coordination between building and network infrastructure planners. This data need has been expressed consistently across our stakeholders.

(7) Natural hazard data. Interviewees see information on natural hazards as critical for local planning in New Zealand. In particular, small-scale data (parcel level and below) on hazard potentials is needed by developers, utilities planners and territorial authorities, but is rarely adequately available to most stakeholders at this scale. While large-scale data might be available, interviewees expressed concerns about inconsistent measures and classifications across planning areas and projects which hamper easy comparison. To this end, improved documentation and up-to-date information provide potential for better use of natural hazards data for urban decisions.

The identified data needs expressed by our interview partners show the potential of New Zealand's spatial data ecosystem for evidence-based planning outcomes if transitioned towards a more sustainable socio-technical system. Thus, we now turn to analysing the spatial data ecosystem and potential solutions to the identified data needs at the system level.

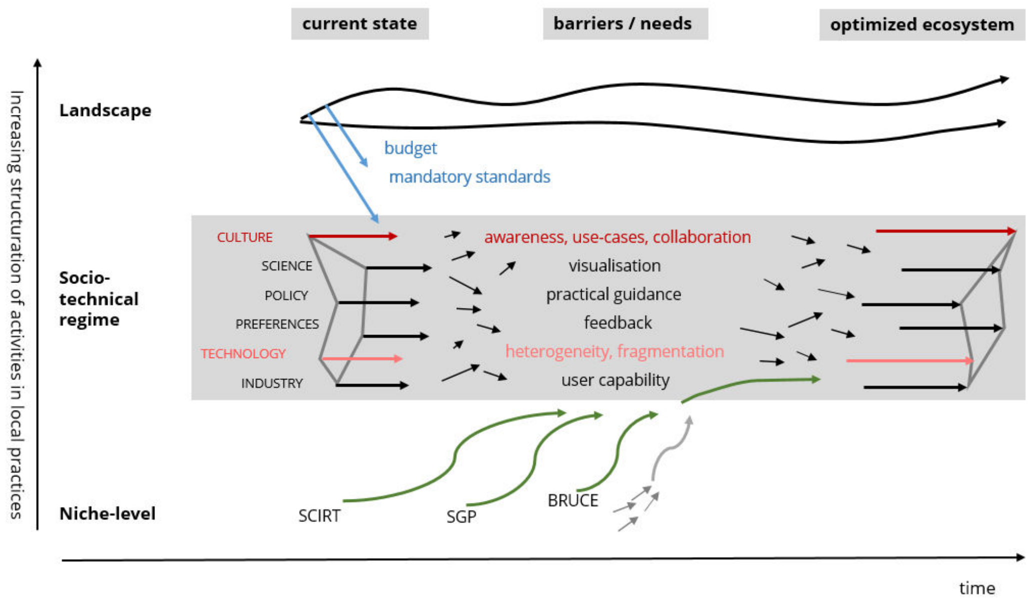
3.3. Multi-level perspective on the spatial data ecosystem

Applying the multi-level perspective (Geels, 2002) to the New Zealand stakeholder-based ecosystem (Figure 2) helps in systematically understanding the current state of the system, structuring barriers towards a transition to an optimized ecosystem and identifying developments and mechanisms to guide the transition.

As shown in Figure 1, the spatial data ecosystem is based on stakeholders and their technical role in the life-cycle of individual datasets. On a system level, the life-cycle of multiple datasets for urban planning decision-making is impacted by local practices at multiple levels, i.e., the socio-technical landscape, the socio-technical regime and the niche-level (Geels, 2002), as illustrated in Figure 2. Note that these levels are not equivalent to the spatial scales in New Zealand's urban planning community; rather, they reflect the increasing structures of activities in local practices from the niche to the landscape level.

The socio-technical regime refers to the current predominant practices within the system, the network of actors and social groups, technical elements and the set of rules (Geels, 2005). We analyse the regime along the six dimensions of culture, science, policy, preferences, technology and industry, following Geels (2002) (Section 3.3.2). The niche level is where novel practices and innovations emerge which do not yet have the economies of scale or wide support to be adopted by the socio-technical regime. We have a closer look at three niche-level developments in our analysis in Section 3.3.3. The socio-technical landscape forms an exogenous context and describes the environment in which the regime is embedded (Section 3.3.1). Changes at the landscape level can create pressure on the regime level and open up 'windows of opportunity' (Geels, 2002) for niche developments to be taken up in the regime. Changes at the landscape level are slowest, while niche-level experimentations tend to be relatively rapid.

Figure 2: The multi-level perspective on socio-technical systems by Geels (2002) adapted for the New Zealand stakeholder-based spatial data ecosystem. The figure depicts the current state of the spatial data ecosystem along the three levels i) landscape, ii) socio-technical regime and iii) niche-level with its identified barriers and needs along six dimensions of predominant local practices. Changes at the landscape level (slow) and niche-level developments (fast) can address the needs at the regime level and foster a transition towards an optimized ecosystem. We find that in particular changes in the governance framework can open up windows of opportunity to adopt niche-level developments as new cultural and technological local practices at the regime level. (SCIRT, SGP and BRUCE are niche-level developments further discussed in Section 3.3.3.; coloured arrows highlight key aspects at the three levels)



3.3.1. Landscape developments

Within the last decade, data sharing has been encouraged by the New Zealand Government through The Open Government Information and Data Programme (LINZ, 2017), including an open data licensing framework (NZGOAL) (New Zealand Government, 2014), the New Zealand government ICT strategy[3] and support on data standards and data release through Land Information New Zealand (LINZ)[4]. The government now requires data generated as part of its funded research to be made available consistent with Open Government Principles (ICT, 2017). Having adopted the International Open Data Charter[5], agencies are expected to proactively release high value open data and work towards an 'open by default' approach (ICT, 2017).

In order to improve availability of high quality data beyond governmental institutions, a recommendation was put forward in 2010 that LINZ lead the development of a national SDI (LINZ, 2015). An assessment by LINZ (2012) in 2012 found that in particular legal, funding, data and metadata issues are yet to be set in agreement with the European INSPIRE Directive[6]. There is no direct legal mandate or long-term funding supporting the creation of a national SDI (LINZ, 2012). To date, the drafting of non-binding (metadata) standards, also as part of ANZLIC's Foundational Spatial Data Framework (FSDF), has been supported by collaborations among stakeholders (including also some of our interviewees) from all levels.

3.3.2. Six dimensions of the socio-technical regime

The socio-technical regime is characterized by local practices on various dimensions as described in the following. We identified the main needs and barriers for an optimized ecosystem along the cultural and technological dimension of the spatial data ecosystem and linked with local practices along the other four dimensions, that is science, policy, preferences and industry.

Culture. As Rajabifard et al. (2002) state, the condition of a mechanism to facilitate data sharing as perceived by the members of a social system (or socio-technical system) determines its rate of adoption. This highlights the importance of the community or social context. Interviewees in our case study expressed

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[3] http://www.ict.govt.nz
[4] LINZ is the national public service department responsible for managing land titles, geodetic and cadastral survey systems, topographic information, hydrographic information and Crown land and property (http://www.linz.govt.nz).
[5] http://www.opendatacharter.net
[6] https://inspire.ec.europa.eu/

concerns about low awareness about the value of spatial data sharing, which is overall manifested in a silo mentality. In many cases, data sharing is not the responsibility of an employee's regular work within an agency; rather, it is the result of a personal initiative by individuals who perceive the value of shared data. High staff turnover, however, implicates short-term initiatives (at least within the same organisation). Little encouragement to publish results in many datasets being locked up with stakeholders. Furthermore, data releases are linked to quality assurance and elimination of liability concerns by data owners. Experts potentially request a process for communicating mistakes in the data and an environment of collaboration between data providers and users that allows continued adaptation of datasets. Interviewees demand a shift of liability from data providers to users who can evaluate the fitness of a dataset, which can open up many locked-up datasets. Insufficient documentation and diverse capability of users to evaluate spatial data quality are stated as barriers towards such a transition in New Zealand.

Science. In order to allow users to assess the fitness of a dataset for a particular use, the provision of metadata is encouraged. However, studies and experience show the limited benefit of metadata in their current form (e.g. Timpf et al., 1996); since data and metadata are often provided separately, many non-expert users are not aware of the existence and value of metadata (Devillers et al., 2007). Many call instead for a verbal description of the data quality and main issues of a dataset or visualisation of uncertainty for non-expert users (e.g. Devillers et al., 2007). This shift from a producer's view of data to a user's view was also demanded by our interviewees; however, there is, for instance, a lack of techniques for visualization of data quality information acknowledged in the international literature (Hunter et al., 2009). Raising awareness about uncertainty of spatial data among users is a main concern with local practices in our case study. The maturity level of spatial data users—also in the context of decision-support tools—varies widely in New Zealand. Therefore, the provision of data is best accompanied by help in the interpretation of data. A widely adopted practice among stakeholders, for instance by Environment Canterbury[7], is the preparation of (Esri) Story Maps[8] along with the publication of spatial data[9]. This provides a

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[7] Environment Canterbury (ECan) is the Regional Council of Canterbury, the largest region in the South Island of New Zealand. ECan is responsible for a variety of functions related to the management of resources, including river engineering, public passenger transport and environmental monitoring (http://www.ecan.govt.nz).

[8] https://storymaps.arcgis.com

[9] An exemplary Story Map by Environment Canterbury Regional Council can be found at https://apps.canterburymaps.govt.nz/FloodInvestigationAmberley.

broader perspective on the dataset than just metadata and helps in the evaluation of use cases, as required for instance by Whitfield (2012). The science dimension is requested to establish simple guidelines and develop good-practice guidelines that are flexible with regards to the use case in order to improve the use of spatial data among both experts and non-experts.

Policy. Each agency in New Zealand decides for itself how to share data and handle data issues. While this provides potential for individual solutions, Glass and Schiff (2017) see this as a crucial barrier for New Zealand's (non-) spatial data ecosystem. They stress a lack of guidance and therefore costs and risks that weaken sharing incentives. In addition, resources and capabilities for data supply are scarce for most stakeholders. This led to inconsistency in how and which data are shared. Glass and Schiff (2017) and many of our interviewees therefore call for practical guidance rather than conceptual models. This is reflected in results of a survey[10] conducted among government agencies in 2017, which identified, among others, data management processes (e.g., use of open technical standards), stakeholder support (e.g., documentation of datasets) and knowledge and skills (e.g., staff training) as areas showing a low level of maturity to date.

Preferences. In the current socio-technical regime, many stakeholders demand more information about user's preferences and spatial data needs. Stakeholders reported that they make their spatial datasets available with little knowledge about user requirements; that is for which purpose data are requested and which data formats and specificities or additional datasets might be suitable for users. Missing opportunities for feedback between data providers and users results in many datasets either not being fit-for-purpose or not being made available because providers have little knowledge about their potential value to others. Data provision is usually perceived as a one-way task; an interactive process, however, could increase the value of spatial data to users by considering user preferences and aligning needs through communication (e.g., Triglav et al., 2011).

Technology. Among advanced stakeholders we observe a trend towards a change in technology from individual responses to user requests towards automation of data sharing through web maps (WMS) or web feature services (WFS) such that up-to-date information is readily available to registered users.

[10] The survey questions were based on the Open Data Maturity Model developed by the Open Data Institute. It is a way to assess how well an organisation publishes and consumes open data, and identifies actions for improvement. https://data.govt.nz/blog/open-government-data-dashboard-prototype/.

For the majority, however, users may find datasets on each stakeholder's website or on one of many distributional platforms (e.g. Koordinates[11]) or receive datasets upon request via email. To date, users usually need to consult several sources to find data, cope with heterogeneous data formats and technologies and make considerable expenses to access and make the required data fit-for-purpose. Our interview partners described data searching as a tedious process due to a missing central searchable data catalogue and knowledge on who to contact for data requests or documentation. Though metadata catalogues have been created for data discovery, their content is created and maintained by few specialists (LINZ, 2012). Interview partners state that although government agencies are encouraged to publish metadata about all their datasets in these catalogues, a fraction of all datasets is published to date.

Industry. The stakeholder landscape is heterogeneous with respect to user capability to work with spatial data. From a data provider perspective, this poses the challenge to provide data in a way suitable for various maturity levels (i.e., sharing media, formats, complexity, documentation etc.); from a user perspective, lack of expertise on how to find, handle and interpret spatial information fit-for-purpose in many cases results in users refraining from exploiting the full value of spatial data in urban decision-making. Finally, as Glass and Schiff (2017) highlight, some governmental agencies in New Zealand have business models based around selling data (spatial or not) that severely restrict the sharing and use of their data.

In sum, stakeholder interviews revealed that main challenges towards the use of relevant spatial data are seen in i) from a supply side: a low awareness and understanding of the value of shared spatial data, commercially sensitive data/ assets perceived as revenue, inadequate data quality assurance (liability concerns) and a lack of (human) resources; and ii) from a user side: in spatial data often not being fit-for-purpose, data sources being fragmented and therefore missing information on where spatial data can be found and how various datasets relate spatially.

3.3.3. Stakeholder-driven niche-level developments

Partial awareness about the needs and barriers within the socio-technical regime has led to several niche developments. While most niche developments primarily address the technical needs and barriers identified in the regime (i.e., a searchable data catalogue, data integration, fragmentation of the data life-cycle), some also aim to overcome cultural barriers (i.e., raising awareness, fostering

[11] https://koordinates.com/

collaboration, demonstrating value). We identified three relevant niche initiatives from stakeholders within New Zealand's major urban areas, Christchurch and Auckland, which we discuss in the following.

SCIRT GIS Viewer (Christchurch). The Stronger Christchurch Infrastructure Rebuild Team (SCIRT) was a temporary alliance of public and private-sector entities formed to repair Christchurch's infrastructure that has been severely damaged by the earthquakes in 2010 and 2011 (SCIRT, 2016). The Christchurch City Council, the New Zealand Transport Agency (NZTA), the Canterbury Earthquake Recovery Authority (CERA)[12] and five construction companies were part of the temporary alliance (2011-2016). Access to reliable information about existing infrastructure (addressing data need (1) as defined in Section 3.2) was crucial to coordinating work performed by various involved parties, such as governmental authorities, construction companies, design teams, contractors and consultants. Since there was no existing spatial data infrastructure, SCIRT developed the GIS Viewer from scratch to provide quality assured spatial data to all alliance partners in a standardized coordinate system and database format, following metadata standards in a system that is flexible and easily scalable in a changing environment (SCIRT, 2016).

The SCIRT GIS system sourced different types of spatial and non-spatial information (Section 3.2, needs (1),(5),(7)) from varying organisations, including central and local governments and utility, maintenance and survey companies. An important feature of the SCIRT GIS Viewer was the different access levels assigned to the users; this provided a high level of trust in the system by data providers and users. It was created as a web-portal allowing secure and timely access to all information, usable also in the field via a mobile application (SCIRT, 2016).

After SCIRT completed their work in 2016, the GIS information was passed on to the city council, which is the asset owner. The transfer of knowledge was part of the political mandate agreed to in the alliance. The SCIRT GIS Viewer was a purpose-driven infrastructure to share information. Willingness to share

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[12] The Christchurch City Council (CCC) constitutes the local government making decisions about local issues and services (http://ccc.govt.nz); NZTA is the national body responsible for the management and funding of the national land transport system and related services (http://nzta.govt.nz); CERA was established under legislation as a governmental authority to lead and coordinate the Government's response and recovery efforts following the 2010/2011 Canterbury earthquakes, for a fixed mandate of 5 years (2011-2016). In April 2016, CERA has terminated its mandate and has been substituted by Regenerate Christchurch, Ōtākaro Ltd, and Development Christchurch Ldt (http://cera.govt.nz).

information was there since it was part of the alliance agreement and alliance partners understood the advantages of readily available data. The initiative created a sharing culture out of the need of the situation, which has been acknowledged across the country. The challenge is to transfer the knowledge, maintain the data and system and also perception of its value after the alliance ended. New agreements and access rights might need to be negotiated as the infrastructure is extended to new partners and datasets. SCIRT has published reports about lessons learnt[13], highlighting the importance of transparency and communication. Yet, spillover effects need to be ensured, training provided and knowledge transferred in order to keep the expertise even in case of staff turnover and embed it into the council's local practice.

Smart Growth Portal (Auckland). The Smart Growth Portal (SGP) is a people-driven initiative from within Auckland Council for a cloud solution for standardized harmonisation of their data, visualisation and analytics for evidence-based decision-making on infrastructure investments and development strategies (Read, 2017). It seeks integration of both infrastructure (need (1)) and parcel-level information (needs (3),(4),(5),(7)) in a flexible portal to support analysis for decision-making. SGP draws on cooperation between governmental organisations and utilities providers. It provides technologies to better integrate spatial data, model unavailable data (needs (1),(3),(4)) and engage communities through advanced visualisation of development strategies.

As an early-stage niche-development, it raises awareness about the value of harmonised spatial data for urban decisions and demonstrates the potential for improved urban decision-making. Yet, for an uptake as common local practice at the regime-level, it needs extensive communication, economies of scale through an extension beyond the Auckland community and motivation of other data providers to adapt the technology.

BRUCE (Auckland). Finally, we identified a niche development, named BRUCE, which is a digital asset register and communications dictionary for visual and non-visual data[14]. It is an initiative to integrate spatial metadata from various spatial data owners and providers in Auckland, including territorial authorities, utility providers and policy makers. It facilitates a technical solution to improve the work of participating stakeholders through providing spatial relationships (need (6)) and access via a single platform to various datasets otherwise locked-up uncoordinated with stakeholders. BRUCE is a digital infrastructure based on

[13] https://scirtlearninglegacy.org.nz

[14] Bruce is being developed by the private company Nextspace in collaboration with the Auckland Council, http://www.nextspace.co.nz .

metadata to manage access to datasets from participating stakeholders, focussing on infrastructure, amenities and property information (needs (1),(4)-(7)). Its objective is to facilitate data integration to support urban planning of the city of Auckland through 3D visualisation of utilities and urban assets.

BRUCE is a closed-community initiative in its early stages developed by a private company in collaboration with Auckland Council. While assuring that internal data quality is not a main objective of BRUCE and is left to the stakeholders, BRUCE aims at improving external quality through flexible data manipulation, a collaborative approach based on standardized metadata and trust. Our stakeholder interviews revealed noticeable interest in this niche development, also recognizing its potential beyond the initial spatial experiment space (Auckland). Nonetheless, its technological focus and commercial character are seen as major challenges towards system-wide adoption as local practice.

In sum, the three niche developments identified in Christchurch and Auckland exhibit potential to address identified needs of the spatial data ecosystem beyond the niche level and contribute to shaping changes in current local practices. Furthermore, their ongoing national discussion can inform future niche developments in other urban areas not discussed in this work. There are other niche developments which have not been reviewed in this article but contribute to New Zealand's spatial data ecosystem, but for the purpose of this research we focused on those with impact on urban planning on a local scale.

4. RECOMMENDATIONS FOR A SPATIAL DATA ECOSYSTEM TRANSITION

4.1. Towards an optimized spatial data ecosystem in New Zealand

An optimal spatial data ecosystem is built around a frictionless data life-cycle and is an adaptive, scalable and sustainable socio-technical system with potential for self-organisation (Medyckyj-Scott et al., 2016), flexibility (Stevenson et al., 2017), cooperation (Nedovic-Budic and Pinto, 2001), transparency (Masser et al., 2008), recognition of user needs (Deng and Di, 2009) and feedback mechanisms (Budhathoki et al., 2008); learning from international literature, it embodies fundamental principles following the European INSPIRE Directive: data are collected once and maintained at the most effective level; data integration and sharing is seamless; data are collected at one level and shared across all levels; data conditions are such that they are not restricting extensive use; data discovery, evaluation of fitness-for-purpose and conditions for use are easy (e.g. Masser et al., 2008). This then yields benefits to stakeholders through cost reductions, value creation, greater potential for innovation, evidence-based decision making and tailored outcomes (e.g. ACIL Tasman, 2009).

In order to achieve this, Kok and van Loenen (2005) state that technology is no longer the pressing problem; rather, the focus has shifted towards spatial data legal, economic and social issues. Also, Maguire and Longley (2005) identify too much technical focus while there is a lack of attention to issues of governance and policy. Furthermore, Masser et al. (2008) stressed that governance structures have to be understood and respected by all stakeholders. Our findings follow this literature and, in line with Maguire and Longley (2005), highlight the need for budgetary ties brought by a change in the governance framework.

Going further, we also follow Masser (2006), who states that future research should focus on the role of culture. He sees the challenge in finding ways of ensuring some measure of standardization, while recognizing diversity and heterogeneity of the different stakeholders. Challenges of spatial data handling and sharing are also seen in an environment of stakeholder diversity by other scholars, such as Elwood (2008). As termed by Nedovic-Budic and Pinto (2001), 'soft interoperability' or non-technical interoperability is more challenging than the technical issues of data sharing; they argue that stakeholder involvement, collaboration and trust are important conditions associated with this concept.

Moreover, Montalvo (2003) argues that the main components to understanding spatial data sharing behaviour are attitude, social pressure and perceived control. These three aspects can be assigned to 'culture' in the socio-technical regime in the MLP framework; adapting a mechanism that alters the cultural aspects of the current socio-technical regime, and thus, the three aspects outlined by Montalvo (2003) can increase the willingness to share. This is in line with Rajabifard et al. (2002), who argue that SDI development should be seen as a process within a social system: from awareness, to alignment of visions towards participation and utilisation, which is all linked via communication channels. We follow Akinyemi and Uwayezu (2011) in advising a multi-stakeholder approach and Kmoch et al. (2016) in stressing the importance of stakeholder involvement for New Zealand's hydro(geo)logy data community.

4.2. Recommendations to leverage New Zealand's potential

Interesting in the New Zealand case is that the niche-developments identified above originate partly from inside the socio-technical regime—that is, within local government and other key stakeholders—but are pushed forward by initiatives of individuals breaking away from local practices of the socio-technical regime. Their developments could be path-breaking and take ideas from outside the regime such as international findings, standards, technology and good practice examples. Based on our analysis, we put forward the following recommendations for New Zealand's urban planning spatial data ecosystem.

First, we argue for increasingly including spatial knowledge and capability building in New Zealand's educational programmes, to be eventually imparted to urban planning stakeholders. This is because spatial data need to be understood by the user in order to develop trust in their validity and therefore also trust in the decision-support tools based on the data. This emphasises the challenge to create an infrastructure for spatial data that serves the majority of users who are not spatially aware (Masser et al., 2008). The rising number of non-expert users of spatial data increases the risk of data misuse or misinterpretation (e.g. Devillers et al., 2007). Capability and public awareness about spatial data must be raised in order to foster a transition towards better data sharing, where data are seen as a strategic asset. This has also been stated by NZDFF (2015) (although not explicitly for spatial data). This requires long-term changes through increased exposure in tertiary education, import of skills from overseas, and training within stakeholder institutions encouraged through governmental priorities and motivated by the acknowledgement of the value of such spatial skills and their needs.

Second, a discoverable overview of existing spatial data relevant to planning stakeholders located centrally, together with improved communication between stakeholders, is beneficial. It could reduce the costs of data duplication and time spent on data acquisition and support the development of suitable decision-support tools. During our stakeholder interviews, it became clear that end-users and decision-makers are often unaware of already existing datasets either locked up in another stakeholder's system or available elsewhere. Similar findings have been reported by Stevenson et al. (2017) and Kmoch et al. (2016) for New Zealand's resilience and hydrological data community or by Schetke et al. (2012) in their German urban planning study. Yet, our interview partners believe that such a data catalogue needs to be centrally led, maintained and funded, and nudges provided to all stakeholders along the data life-cycle to incorporate it into their local practice. These are closely linked with an increased acknowledgement and awareness of the value of fit-or-purpose spatial data.

Third and above all, our findings suggest a focus on cultural and governance issues rather than on the sole provision of technological solutions. Based on our analysis, we stress the importance of continuous engagement and interaction among stakeholders in order to create learning processes between the actors at the niche and regime level. Niche-level initiatives can support the creation of a culture of sharing by raising awareness about the value of available fit-for-purpose spatial data, drawing attention to stakeholders' needs and providing the necessary technological support. This can create spill-over effects and lead to adoption as local practice at the regime level. We argue that a governance framework at the landscape level is necessary to support the niche-level initiatives and the creation of a culture of sharing. The importance of standards in achieving cross-organisational interoperability is recognized, and stakeholders from multiple levels are actively participating in establishing a wide range of standards. Practical use of these standards is, however, still limited to date. Costs associated with the adoption of standards by data providers still outweigh the perception of the values of commonly used standards. A nudge to stakeholders to get them to adopt standards is needed, for instance the development of use cases. This will likely require legislative changes and a shift from the decentralised approach currently adopted to a centralized one (Glass and Schiff, 2017) with increased transparency across stakeholders. For example a central actor like LINZ is seen by many interview partners as responsible for taking over the advancement of standardized address data. Providing mandatory standards linked to a budget for their implementation and adaptation of the education curriculum can open up windows of opportunity in which niche-level developments can find their way into local practices. This provides protection and legitimacy for niche developments and gradually increases their acceptance as local practice (e.g. Smith and Raven, 2012). Our analysis stresses the importance of stakeholder engagement to support early stages of a data ecosystem improvement and leverage New Zealand's potential as a well networked community.

We argue that such a joint and coordinated mechanism at the landscape and niche level can promote a transition towards an optimized spatial data ecosystem for New Zealand's urban planning community.

4.3. Lessons from the New Zealand case study

Despite the mentioned specifics of our case study, we can infer generic lessons useful beyond New Zealand. While we have discussed transferable findings throughout the previous sections, we highlight three key lessons.

First, while we have identified the need for the development of catalyst technologies for the transition of a spatial data ecosystem, access to and potential resources for relevant technology are not the main challenge for developed countries like New Zealand. Instead, a focus on cultural and governance issues is beneficial in that it can nudge stakeholders into adopting a culture of sharing and overcoming challenges of skill capacity, lack of practical guidance or limited awareness of the value of fit-for-purpose spatial data. Practical (and mandatory) landscape guidelines and improved regulations can be a potential way forward to encourage coordination among stakeholders instead of uncoordinated ad-hoc developments.

Second, incentives for public-private and multi-level stakeholder collaborations can leverage the potential of well-networked communities found in particular in small settings such as New Zealand. This could take the form of systems structured around shared benefits or cost structures that further encourage the exploitation of economies of scale.

Finally, our study emphasises the importance of taking a system-wide perspective that can align stakeholders' needs across the different groups and stages along the spatial data life-cycle and multiple levels of the ecosystem.

5. CONCLUSION

Based on stakeholder interviews within New Zealand's urban planning community, we have assessed stakeholders' understandings of barriers and needs with respect to spatial data quality for evidence-based urban decision-making. We applied the multi-level perspective conceptualized by Geels (2002) to analyse dynamics of the spatial data ecosystem and to derive recommendations for facilitating a transition of the socio-technical system.

The major barriers to spatial data being fit-for-purpose for urban decision-making in New Zealand, which we identified in our study, are inconsistent definitions and categorization, absent attribute information, bulk access and missing spatial relationships across datasets of various stakeholders within the planning community.

Furthermore, our case study emphasises the need for addressing the urban community's spatial data challenges with a system-wide perspective. Our analysis suggests that improving the availability of fit-for-purpose spatial data for urban decisions requires primarily a cultural transition towards increased openness to data sharing driven by innovative niche developments which identify and trigger the necessary changes in local practices, supported by a binding governance framework which provides practical guidance towards an improved spatial data ecosystem. Our study highlights the importance of intensive engagement between stakeholders along the spatial data life-cycle, including both the public and in particular the private sector, and across multiple levels fostering increased awareness and understanding of the value of fit-for-purpose spatial information for better planning outcomes.

In future work one could also consider other perspectives when applying the MLP to add further dimensions to the analysis. For example, an inclusion of the perspective of even individual actors in the system can hold interesting insights, since many (loosely structured) activities in New Zealand are driven by engaged individuals. Future research could explore ways to translate the identified needs and suggestions for a transition into practical guidelines for future niche and landscape developments. Through intensive engagement with the identified stakeholders, spatial data can be made available fit-for-purpose in line with the development of decision-support tools. Moreover, translating lessons from our case study on New Zealand's major urban areas to benefit smaller territorial areas is an avenue for future research.

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REFERENCES

ACIL Tasman (2009). *Spatial information in the New Zealand economy*. Realising productivity gains. Technical Report.

Akinyemi, F. and E. Uwayezu (2011). An Assessment of the Current State of Spatial Data Sharing in Rwanda, *International Journal of Spatial Data Infrastructures Research*, 6: 365–387.

Banville, C., M. Landry, J.-M. Martel and C. Boulaire (1998). A stakeholder approach to MCDA, *Systems Research and Behavioral Science*, 15(1): 15-32.

Brown, J.D., G.B.M. Heuvelink and J.C. Refsgaard (2005). An integrated framework for assessing and recording uncertainties about environmental data, *Water Sci. Technol*, 52(6): 153-160.

Budhathoki, N.R., B. Bruce and Z. Nedovic-Budic (2008). Reconceptualizing the role of the user of spatial data infrastructure, *GeoJournal*, 72: 149–160.

Chevalier, P., I. Thomas, D. Geraets, E. Goetghebeur, O. Janssens, D. Peeters and F. Plastria (2012). Locating fire stations: An integrated approach for Belgium, *Socio-Economic Planning Sciences*, 46(2): 173-182.

Coutinho-Rodrigues, J., A. Simão and C.H. Antunes (2011). A GIS-based multicriteria spatial decision support system for planning urban infrastructures, *Decision Support Systems*, 51(3): 720-726.

Crompvoets, J., E. de Man and C. Macharis (2010). Value of Spatial Data: Networked Performance beyond Economic Rhetoric, *International Journal of Spatial Data Infrastructures Research*, 5: 96–119.

Delavar, M. and R. Devillers (2010). Spatial Data Quality: From Process to Decisions, *Transactions in GIS*, 14(4): 379–386.

Deng, M. and L. Di (2009). Building an Online Learning and Research Environment to Enhance Use of Geospatial Data, *International Journal of Spatial Data Infrastructures Research*, 4: 77–95.

Devillers, R., Y. Bédard, R. Jeansoulin and B. Moulin (2007). Towards spatial data quality information analysis tools for experts assessing the fitness for use of spatial data, *International Journal of Geographical Information Science*, 21(3):261-282.

Elwood, S. (2008). Grassroots groups as stakeholders in spatial data infrastructures: Challenges and opportunities for local data development and sharing, *International Journal of Geographical Information Science*, 22(1): 71–90.

Frank, A.U., E. Grum and B. Vasseur (2004). Procedure to Select the Best Dataset for a Task. . In: Egenhofer M.J., Freksa C., Miller H.J. (eds) Geographic Information Science. GIScience 2004. Lecture Notes in Computer Science, vol 3234. Springer, Berlin, Heidelberg.

Geels, F.W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, *Research Policy*, 31(8–9):1257-1274.

Geels, F.W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective, *Technological Forecasting and Social Change*, 72(6 SPEC. ISS.): 681–696.

Gelagay, H.S. (2017). Geospatial Data Sharing Barriers across Organizations and a Possible Solution for Ethiopia, *International Journal of Spatial Data Infrastructures Research*, 12: 62–84.

Glackin, S., R. Trubka and M.R. Dionisio (2016). A software-aided workflow for precinct-scale residential redevelopment, *Environmental Impact Assessment Review*, 60: 1-5.

Glass, H. and A. Schiff (2017). *Getting more value from data sharing : Some potential solutions*. http://datafutures.co.nz/assets/Uploads/DF-Final-

Report-2.pdf.

Greenaway-McGrevy, R. and P.C.B. Phillips (2015). Hot Property in New Zealand: Empirical Evidence of Housing Bubbles in the Metropolitan Centres, *New Zealand Economic Papers*, 50(1): 88–113.

Hunter, G., A.K. Bregt, G.B.M. Heuvelink, S. De Bruin and K. Virrantaus (2009). Spatial Data Quality: Problems and Prospects, *Research Trends in Geographic Information Science*, : 101–121.

ICT (2017). *Open and Transparent Government*, at www.ict.govt.nz/programmes-and-initiatives/open-and-transparent-government/, [accessed 2 November 2017].

Klinkenberg, B. (2003). The True Cost of Geospatial Data in Canada, *The Canadian Geographer*, 47(1).

Kmoch, A., H. Klug, A.B.H. Ritchie, J. Schmidt and P.A. White (2016). A Spatial Data Infrastructure Approach for the Characterization of New Zealand???s Groundwater Systems, *Transactions in GIS*, 20(4): 626–641.

Kok, B. and B. van Loenen (2005). How to assess the success of National Spatial Data Infrastructures?, *Computers, Environment and Urban Systems*, 29(6 SPEC. ISS.): 699–717.

LINZ (2012). *New Zealand SDI State of Play*. Report 2012. 2012 NZSDI Benchmark Exercise New Zealand Geospatial Office.

LINZ (2015). *Geospatial strategy for a spatial data infrastructure*, at https://www.linz.govt.nz/about-linz/our-vision-strategy-and-values/our-location-strategy/geospatial-strategy-for-spatial-data-infrastructure.

LINZ (2017). *Open Government Information and Data Programme.*, at https://www.linz.govt.nz/about-linz/what-were-doing/projects/open-government-information-and-data-programme.

Maguire, D.J. and P.A. Longley (2005). The emergence of geoportals and their role in spatial data infrastructures, *Computers, Environment and Urban Systems*, 29(1 SPEC.ISS.): 3–14.

Masser, I. (2006). What's Special about SDI Related Research?, *International Journal of Spatial Data Infrastructures Research*, 1(1): 14-23.

Masser, I., A. Rajabifard and I. Williamson (2008). Spatially enabling governments through SDI implementation, *International Journal of Geographical Information Science*, 22(1): 5–20.

Medyckyj-Scott, D., K. Stock, R. Gibb, M. Gehagan, H. Dzierzon, J. Schmidt and A. Collins (2016). *Our Land and Water National Science Challenge: A Data Ecosystem for Land and Water Data to Achieve the Challenge Mission*.

Montalvo, U.W. De (2003). Mapping the determinants of spatial data sharing, *Policy*, 304: 1-31.

Moradi, A. and E. Vagnoni (2018). A multi-level perspective analysis of urban mobility system dynamics: What are the future transition pathways?, *Technological Forecasting and Social Change, 126: 231-243*.

Nedovic-Budic, Z. and J.K. Pinto (2001). Organizational (soft) GIS interoperability: lessons from the U.S., *International Journal of Applied Earth Observation and Geoinformation*, 3(3): 290-298.

New Zealand Government (2014). *New Zealand Government Open Access and Licensing Framework (NZGOAL)*. Technical Report.

NZDFF (2015). *Harnessing the economic and social power of data*. Technical Report 3.

Onsrud, H.J. and G. Rushton (1995). *Sharing Geographic Information*, Routledge.

Rajabifard, A., M.E.F. Feeney and I.P. Williamson (2002). Future directions for SDI development, *International Journal of Applied Earth Observation and Geoinformation*, 4(1): 11–22.

Read, H. (2017). *Metadata standards infrastructure. Auckland's response. Smart Growth Portal*.

Schetke, S., D. Haase and T. Kötter (2012). Towards sustainable settlement growth: A new multi-criteria assessment for implementing environmental targets into strategic urban planning, *Environmental Impact Assessment Review*, 32(1): 195–210.

SCIRT (2016). *SCIRT Geographic Information System (GIS) Viewer – a window to central data*, Technical Report, SCIRT Learning Legacy, Christchurch.

Singh, P.. (2009). Spatial Data Infrastructure in India : Status , Governance Challenges , and Strategies for Effective Functioning, *International*

Journal of Spatial Data Infrastructures Research, 4: 359–388.

Smith, A. (2007). Translating Sustainabilities between Green Niches and Socio-Technical Regimes, *Technology Analysis & Strategic Management*, 19(4): 427-450.

Smith, A. and R. Raven (2012). What is protective space? Reconsidering niches in transitions to sustainability, *Research Policy*, 41: 1025-1036.

Stevens, D., S. Dragicevic and K. Rothley (2007). iCity: A GIS-CA modelling tool for urban planning and decision making, *Environmental Modelling and Software*, 22(6): 761–773.

StatsNZ (2017). *Population statistics*. https://www.stats.govt.nz/ [Accessed December 2017]

Stevenson, J.R., D. Ph, J. Vargo, D. Ph, C. Thompson, D. Ph and L. Walsh (2017). *Resilience and data in New Zealand: The data integration and visualisation en masse (DIVE) platform 2016 Summary*.

Timpf, S., M. Raubal and W. Kuhn (1996). Experiences with metadata, *Proceedings of Symposium on Spatial Data Handling, SDH'96, Advances in GIS Research II*, 2: 12B31-12B43.

Triglav, J., D. Petrovic and B. Stopar (2011). Spatio-temporal evaluation matrices for geospatial data, *International Journal of Applied Earth Observation and Geoinformation*, 13(1): 100–109.

Vasseur, B., R. Devillers and R. Jeansoulin (2003). "Ontological approach of the fitness of use of geospatial datasets", *Proceedings of the 6th AGILE*.

Walrave, B., M. Talmar, K.S. Podoynitsyna, A.G.L. Romme and G.P.J. Verbong (2017). A multi-level perspective on innovation ecosystems for path-breaking innovation, *Technological Forecasting & Social Change*.

Wan, Y., W. Shi, L. Gao, P. Chen and Y. Hua (2015). A general framework for spatial data inspection and assessment, *Earth Science Informatics*, 8(4): 919–935.

Whitfield, P.H. (2012). Why the Provenance of Data Matters: Assessing 'Fitness for Purpose' for Environmental Data, *Canadian Water Resources Journal*, 37(1): 23-36.

Whitmarsh, L. (2012). How useful is the Multi-Level Perspective for transport and sustainability research?, *Journal of Transport Geography*, 24: 483–487.